Extended Prospect Theory

Findings on Choice Behaviour from Economics and the Behavioural Sciences and their Relevance for Travel Behaviour

Evert Jan van de Kaa

To be, or not to be; that is the question.

William Shakespeare (1603), *Hamlet*, Act 3 Scene 1

Context: Hamlet suspects that his father is murdered. Struggling with the choice of whether to avenge him or not the indecisive Hamlet, Prince of Denmark, frames his survival as the determinant attribute of alternative courses of action. In the successive monologue he judges the expected values of this attribute affectively and chooses to stick to his passive behaviour.

Cover illustration: Delhi's city streets offer plenty of alternatives for each individual to choose a travel mode and a path through the crowd.

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Proefschrift

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Evert Jan VAN DE KAA

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Prof. dr. G.P. van Wee

Samenstelling promotiecommissie:

Rector Magnificus	Voorzitter
Prof. dr. G.P. van Wee	Technische Universiteit Delft, promotor
Prof. dr. ir. P.H.L. Bovy	Technische Universiteit Delft
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Prof. dr. H.J. van Zuylen	Technische Universiteit Delft

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TRAIL Research School
P.O. Box 5017
2600 GA Delft
The Netherlands
T +31 15 278 6046
F + 31 15 278 43 33
E info@rstrail.nl
I www.rstrail.nl

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In remembrance of Evert Jan van de Kaa (1901-1956)
who made me experience the power of feelings,
the excitement of discovering and the joy of understanding

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Preface

My professional career started in the early 1970s with a long-term research into the behaviour of currents and waves generated by the interplay of a ship sailing in constrained waters, which obviously constitutes a complex system. I was taught at Delft Technological University and therefore used a logic-analytical, rule-governed, conscious application of the basic laws of hydrodynamics, followed by experiments and measurements in physical scale models. From that time on, my work interfered with complex systems, such as controlling algae blooms in large freshwater lakes using active biological control, and the management of an organization with over a hundred professionals engaged in the development of tools for traffic management. Over the years the opportunity to understand and predict the behaviour of such systems in a conscious, analytical way decreased. It appeared increasingly easy, however, to estimate the outcomes of processes even when their calculation was out of the question. Presumably I had developed implicit, holistic models of judgment and choice over time that unconsciously fed my intuition, as Mintzberg so aptly described from his observations of the behaviour of managers.

After holding several management positions I got the feeling that in due course this would become routine. My involvement in the preparations for the introduction of road pricing in the Netherlands aroused my interest in the way travellers influence the transport system by their response to policy measures. In order to study human choice behaviour and its manifestations in travel behaviour in a scientific way I gave up my position and became senior researcher at the TRAIL Research School.

I started with a fascinating foray through the social sciences, in search for generic first principles of human choice. I became acquainted with the thoughts of many giants of science, including, of course, the 17th century philosopher Descartes, well known in mathematics from the Cartesian coordinate system. His dualist view on mind and body, which seemed to be pervasive in all social sciences, appeared to be similar to an open loop system of human behaviour controlled by the subject's mind. A century later Daniel Bernoulli, famous among civil engineers for his energy conservation law of hydrodynamics, appeared to be the founder of the state-dependent utility maximization concept that, in a somewhat adapted form, is still the backbone of mainstream microeconomics today and fits well with the concept of the open loop system. But the 19th century founder of psychology, Wundt, established that mental feelings precede conscious thought. He and the present-day neuroscientist Antonio Damasio referred to Spinoza and his monist views on mind and body. Spinoza's *Ethica* revealed an

implicit generic descriptive model of context-dependent, adaptive human choice, with the urge for fitness to survive as the driving force, the actual feelings as the input for actual choice processes and as output the will to perform an actual behaviour that contributes to the pursuit of happiness. A virtually identical model can be inferred from the work of Maslow. I feel privileged that I got the opportunity to consult these and many more original thinkers.

Once I had developed a generic systems-theoretical framework for human choice behaviour the basic assumptions of mainstream and behavioural microeconomics could be positioned. This allowed me to compare their agreement with observations reported in a few hundred publications from psychology and other social sciences. The stunning kaleidoscope of research techniques and contexts employed for the study of human choice and behaviour I encountered offered a clear demonstration of human ingenuity. Even more amazing were the abilities of the participants in these studies to imagine themselves in the research environment and demonstrate trustworthy judgments and choice behaviour. During this search across the social sciences it was very stimulating to get a more than superficial picture of the work of great scientists like Kahneman, McFadden, Mintzberg, Svenson, Tversky and Zajonc, to mention just a few. From this comparison of theoretical assumptions and actual choice behaviour emerged Extended Prospect Theory.

The examination of the travel behaviour literature for observations that supported or rejected the descriptive ability of the different assumptions of Extended Prospect Theory revealed a variety of research and real-life contexts similar to that encountered in the social sciences. Among the many travel behaviour researchers whose work inspired me I would like to mention here Gärling, Gunn, Hensher, Mahmassani, Ortúzar and Polak. Their and others' publications showed convincingly that travellers behave according to the same assumptions as people in other domains. This encouraged me to round off the scientific method approach by integrating the different behavioural assumptions in a predictive model and by testing its applicability in a particular travel choice context. The well-documented start of road pricing in Singapore appeared very suitable for this purpose. The predicted choice behaviour approached the observed behaviour very closely, much better than a similar implementation of the prevailing Utility Theory. Though this conclusion of my research was not particularly surprising to me it definitely gave me great satisfaction.

My research was realised within the framework of a long-term project by TRAIL Research School that was commissioned by the Centre for Transport and Navigation of RWS. Without wronging the Centre's many former and current staff members who supported me with comments, reviews and ideas I want to thank Joris Al, its CEO, for his interest shown during our regular meetings and Jacques Sistermans, who was always ready to solve matters concerning the contract. At TRAIL headquarters I appreciated the profound support of Arjan van Binsbergen for our brainstorming sessions in which, right from the beginning of my work there, he encouraged me to consider overlooked topics and to improve my concepts. Esther van Baarle and Conchita van der Stelt were always there, prepared to help me in practical matters and in the preparation of the publication of this book, for which I am grateful. I should also credit Rachel Heap for her invaluable improvements in the far from perfect English in the draft of this book.

Being a relative novice in travel behaviour research I owe a debt of gratitude to Piet Bovy, Karel Brookhuis, Caspar Chorus, Hugh Gunn, Carl Koopmans, Luis Rizzi, Jacques Sistermans, Arjan van Binsbergen and Henk van Zuylen who were kind enough to review preliminary versions of important chapters of this book. Among them I would like to mention

in particular Piet Bovy, who challenged me to transform the predominantly explanatory character of Prospect Theory into an operationally applicable version and checked all sections of the draft book thoroughly. Most of all I want to acknowledge here the large influence that Bert van Wee had on my work. He continuously encouraged me, from 2004 on, when we agreed on the topic of my PhD work, particularly by showing his confidence in what I was doing even though I definitely did not follow the customary method of working. He never failed to find time for reading and commenting on my extensive writings in preparation for our progress meetings. During these meetings our stimulating discussions provided me with many ideas. And without his to-the-point comments throughout the realization of this book I fear that many readers would get lost in the first chapters. I also appreciate it that Piet Bovy, Karel Brookhuis, Carl Koopmans, Peter Kroes and Henk van Zuylen were willing to participate in my promotion committee. With their educational backgrounds in geography, civil engineering, psychology, economics, philosophy and physics they may constitute the best multi-disciplinary committee that is feasible for the judgment of an interdisciplinary research on human travel choice behaviour.

The years in which I indulged anew in scientific research definitely meant hard and time consuming work but I enjoyed it very much. I am grateful to my family for preventing it from becoming an addiction. My sons and daughters in law, Evert Jan Jr., Bram and Gisèle, and Geerten and Aafke kept me happy by reciprocating the love I feel for them and, of course, often distracting me from my research by marrying, applying for jobs, buying cars, sharing holidays, moving from residence to residence and so on. Unintentionally they have thus also provided me with invaluable insights into actual human choice behaviour, by sharing with me their considerations about these strategic real-life choices. Maybe most helpful in this respect was my grandson Julian, born in Spring 2006, who, during the many delightful hours I have spent on my knees playing with him, has unconsciously shown me how human choice behaviour develops. The birth, last month, of his brother Thijmen gives me the prospect of many more pleasant moments. Last but not least I want to thank you, Willie, for your love, continuous support and understanding. Choosing you as my wife and love of a lifetime was definitely my most strategic decision. In the context of this book it is telling that while my choice was based on intuition and dominated by feelings, I have always felt that it was the best and most rewarding decision I made in my life.

Evert Jan van de Kaa, June 2008

Summary

Problem definition

Implementations of Utility Theory (UT) are commonly considered as the most useful concept for the description and modelling of human choice behaviour and the prediction of its outcomes. However, its descriptive-behavioural validity has been under discussion since the 1950s. Many experiments and surveys in several behavioural sciences have demonstrated violations of its principles. Drawing on these findings, Prospect Theory (PT) was proposed some decades ago as an alternative behavioural-economic model of choice behaviour. Though researchers in mainstream economics and transport sciences are well aware that many individuals and organizations violate UT's principles, PT and alternative behavioural concepts are only incidentally considered. Improvements to the structure and mathematical formulations, particularly of stochastic elements of discrete choice models, followed by calibration to empirical findings, are the dominant approach to coping with 'inconsistent' subjects.

The purpose of the current research is to examine whether the assumptions of PT, superadded with insights from other social sciences, might be synthesized into a theory that offers a better explanation of observed outcomes of human choice behaviour than UT. If such a theory can be found, a further ambition is to investigate whether, after parameter estimation, it can be put into operation for travellers' choice prediction. As demonstrated hereafter both questions can be answered positively. The present research that ended in this result evolved into a broad, supra-disciplinary examination of human choice behaviour in general, including a large in-depth investigation of the real-life travel behaviour. It led to several methodological challenges which are addressed in the introductory sections of Chapter 3, 4, 6 and 7. This summary continues with an overview of the research activities as a frame of reference for the findings that are listed in the following sections. It ends with the most prominent conclusions and recommendations.

Overview of the research activities

In the first stage of this research (Chapter 2) the basic principles of human choice behaviour are considered. Theories and empirical findings about human choice behaviour from philosophy, behavioural economics, cognitive psychology and several other behavioural disciplines are traced through the scientific literature. The analysis comprises a systems-theoretical examination of the development of the scientific paradigm of choice-and-

behaviour from about 1500 to date (Annex A). It results in the proposal of a generic Meta Theory of Choice Behaviour. This offers a coordinating framework to facilitate comparison and synthesis of concrete assumptions about choice behaviour.

The second stage of this research (Chapter 3…5) evaluates the assumptions of choice behaviour in concrete contexts. First, the assumptions about human choice behaviour as employed in microeconomics are fitted into the framework of the Meta Theory (Chapter 3). These assumptions are compared with findings about choice behaviour reported from the behavioural sciences (Chapter 4). Many findings are re-analysed, in some places quite extensively (e.g. Annex B). An extension of PT with assumptions about the valuation of attributes and the use of different decision rules yields a functional-descriptive concept of choice behaviour that is able to describe most of the reviewed empirical findings to a larger extent than the UT paradigm. These premises are further extended with a few assumptions that draw on the cognitive consistency principle of Social Psychology and offer a weak substitute for UT's context-independent preference order. This enables predictions to be made that apply to different contexts. The resulting 'Extended Prospect Theory' (EPT) has the character of a generic choice paradigm rather than of a domain-specific or context-specific model (Chapter 5).

The third stage of this research (Chapter 6) aims to assess the descriptive ability for travel-related choice behaviour of the five assumptions in EPT that distinguish it most from the corresponding assumptions of UT. Application of discrete choice models that cover assumptions that are at odds with UT appear uncommon in travel behaviour research. Most widespread are several detached try-outs of PT. To examine the descriptive ability of the five assumptions the travel behaviour literature is reviewed for information about observed actual choices (Section 6.1). From 85 studies enough information on the choice context, research design and observed choices is retrieved. These studies cover the whole range of domains and contexts of travel behaviour, from strategic decision making to operational choice behaviour, in experimental and real-life contexts, including choices from alternatives with certain, probabilistic and uncertain outcomes (Section 6.2…6.4). After re-examination all but three studies show a better descriptive performance for one or several assumptions in EPT compared to the corresponding assumptions in UT (Section 6.5).

The fourth phase of this research (Chapter 7) investigates whether further improvement of the descriptive and particularly the predictive performance of choice models can be attained when the relevant assumptions of EPT are considered in connection with each other. The development of car use by commuters in Singapore who, over a number of years have been confronted with changes in road-pricing fares, offers sufficient information for such an evaluation (Section 7.3, Annexes C, D and G). A discrete choice model is developed that is suited to predicting the responses of car owners to the road-pricing measures according to the UT and EPT paradigms (Section 7.4). The individuals' value-of-travel-time-savings for both implementations of the model are calibrated to the mode choices observed before road pricing was introduced (Section 7.5). Next, the frequencies of different responses to the 1975 introduction of road pricing are predicted (Section 7.6, Annex F). Other predictions follow for the responses to the sudden 1976 fare increase (Section 7.7) and to the long-term developments in the travel context and socio-economic circumstances (Section 7.8). All predictions are compared with the observed frequencies. Both for short-term and long-term tactical travel choices the model that agreed with the EPT paradigm shows a better predictive ability than the one that adhered to UT (Section 7.9).

Basic principles of choice behaviour

Until the 20th Century most scientists adhered to the 'rationalist's paradigm' of human choice and behaviour. This is strongly influenced by Descartes' mind-body dichotomy, where choice behaviour is an element of conscious reasoning. In systems-theoretical terms it may be characterized by considering the human body as a 'machine' that is controlled by an autonomous, conscious, literally 'reasonable' mind that does so to attain happiness. Most prominent in this paradigm is the absence of feedback loops, thus in control-theoretical terms this paradigm is an open-loop controller. Several elements of this paradigm still linger in present-day choice theories.

In the first half of the 20th Century the 'Behaviorist's paradigm' ruled. Humans, like animals, were considered to be 'black boxes' in which choice behaviour is a covert process that provides an 'automatic' response by individuals to the opportunities available in the environment. In systems-theoretical terms it is an open-loop controller, containing a reactive process of behaviour with a measurable output in terms of material assets. The context-independent preference order to which the contemporary mainstream microeconomics adheres is one of the relics of this paradigm.

Spinoza's monist view of mind and body as two manifestations of one integrated whole gave rise to an alternative tradition that strongly influenced the 19th Century founders of psychophysics and psychology, amongst others. Interpreted from a modern systems-theoretical perspective and taking into account the state of 17th Century scientific knowledge, he offers an impressive functional model for the understanding of purposeful choice and behaviour.

The most persuasive new insights that arose from the surge of new theories in the second half of the 20th Century might well be assembled in a current Cognitivist's paradigm. It considers choice behaviour as a set of mental functions, executed by a mind that works predominantly unconsciously, which together account for the interaction between the organism and its environment. Its long-term purpose is improving the subject's well-being, which presupposes fitness to survive. Concrete choices are motivated by more myopic objectives, notably expectations of hedonic experiences. The processes that yield them are triggered by perceptions of strategic and tactical plans and the momentary state of the organism in connection with an opportunistic view and/or search of the concurrent environment. This is a stimulus-organism-response feedback system that accounts for both gratification of the organism's needs and coping with the environmental stimuli. This paradigm underlines the context dependency of human behaviour.

Choice behaviour can thus be conceived as a mental process that transforms mental representations of alternative courses of action and their expected outcomes into a choice. Its purpose can be defined as providing sustainable guidance for the subject's actions in her environment, adapted to her needs and in the interest of her fitness to survive and happiness. No information was found from any society that demonstrated large-scale deviations from this somewhat self-interested purpose.

Choice behaviour accommodates a large, heterogeneous range of processes. The duration, the complexity and the impact of the individual processes might be considered as moderately correlated elements of a continuum. Depending on their character they might be classified as strategic decision making, tactical or operational choice behaviour. Within each of these three

categories, chains of domain-specific choice processes can be defined that influence each other in a weak hierarchical manner. Here this continuum is named the strategic-operational choice hierarchy.

The process that accounts for choice behaviour is thinking, of which two different modes are distinguished by contemporary social sciences. 'System 1' runs unconsciously, parallel and automatic whilst 'System 2' is conscious, serial, rule-based and severely hampered by man's limited working memory. In several branches of behavioural sciences evidence keeps accumulating that System 1 dominates everyday human choice processes. System 2 might most often only offer an *ex-post* rationalisation of a choice that was already made unconsciously. As unconscious thought is by definition covert and not controlled by consciousness, human choice behaviour appears to be a predominantly covert process. As long as the actual changes in the content of the information brought about by the mind are not physically measurable, no concept exists or can be developed that rightfully claims to provide the 'right' descriptive human choice process theory.

The overall function of choice behaviour (*what* does the mind do to achieve its aim) can be defined as choosing, in each choice situation, one possible course of action (including doing nothing) from a set of alternatives that, in that particular context, meets certain of the subject's concurrent needs. It can be decomposed into four functions: framing, judgment, evaluation-and-choice and choice behaviour strategy. Framing arranges the perceived choice context in a reference state, several alternatives with their perceived outcomes, a preference order related to the subject's concurrent needs and an aspiration level for their gratification. Judgment accounts for assessment of the sizes of the expected outcomes of alternatives and their valuation on some affective, utilitarian and/or importance scale. Evaluation-and-choice attaches an overall value or rating to the alternatives, compares these with each other and with the aspiration level and selects an alternative that meets the aspiration level. Choice behaviour strategy is a coordinating function required because of the decomposition of the overall function. In interplay they transform mental perceptions originating from the senses and from memory into the choice decisions that guide the subject's behaviour.

There are no hard facts that support or exclude any particular sequence in which the functions are completed. Due to the many possible interactions, iterations and/or sequences of its four functions and their sub-functions, choice behaviour should be considered as a complex system (Figure 2 on page 21). This functional perspective of choice behaviour is called the Meta Theory of Choice Behaviour as it covers any set of assumptions about what choice behaviour does to arrive at a concrete choice decision. It does not claim to offer a true-to-life description of the mental processes that perform these functions. It can therefore be used to test the completeness and internal consistency of operational choice theories but not their descriptive-behavioural plausibility.

Concrete assumptions and observations of human choice behaviour

In microeconomic literature there are two different, internally consistent and non-redundant sets of assumptions about concrete operations that are able to perform the overall choice behaviour function. In Table 1 (page 34) the assumptions are listed under Utility Theory and Prospect Theory, respectively. One commonality is that individuals are considered as self-interested, non-satiable maximizers. The most fundamental difference may be that UT assumes that each individual has an idiosyncratic preference order or 'taste template' that is independent of the choice context, while PT assumes context-dependent framing strategies and preference orders. UT's context independency implies that each individual follows the

same choice behaviour strategy in any context and allows predictions by transferring preference orders elicited in one context to any other. The context dependency of PT implies that intrapersonal and interpersonal differences in preference orders as well as choice behaviour strategies may occur in different contexts which, in the absence of assumptions about the transfer of choice findings from one context to another, constrains it to an explanatory-descriptive choice theory.

Many choice experiments in behavioural sciences have demonstrated that the choices of an individual strongly depend on the way in which she frames the context. The elements of framing appear to be strongly interrelated and dependent on the choice context (domain and actual state of the environment, choice task complexity, current needs, moods and aspirations of the subject). UT's premises that each individual considers a complete range of alternatives in terms of expected states of assets and that they have a context-independent, temporally stable and complete preference order against which they can evaluate them has to be rejected in a generic functional-descriptive theory of human choice behaviour. Preference orders should be considered as dependent on the context and the way in which alternatives are presented and perceived. The reference state can be conceived as the subject's expected 'no change' state of assets, and the attributes of alternatives as expected gains and losses with respect to this reference.

Heuristic judgment plays a crucial role in an individual's assessment of the probabilities, contingencies and outcomes of alternatives. It may occasionally result in sub-optimal assessments but in most instances it yields at least satisficing results. For a functional-descriptive model of choice behaviour the UT assumption of exclusively rational and/or belief-based assessment of attribute levels has to be rejected. This also holds for the assumption that all attribute levels can be valued in a commensurable medium, as subjects might frame alternatives as a mixture of cognitive and affective attributes that are valued on non-commensurable dimensions. A functional-descriptive theory of choice behaviour should consider loss aversion, diminishing sensitivity and weighted probabilities.

In many contexts most subjects may compound the characteristics of alternatives in a compensatory way in one overall value and successively select the alternative with the highest value. However, other individuals might evaluate the alternatives attribute-wise and/or select any alternative that meets a satisficing aspiration level. The assumptions of UT and PT concerning evaluation-and-choice should be relaxed in a functional-descriptive model of choice behaviour. Evaluation and comparison of multi-attribute alternatives might be either alternative-wise or else attribute-wise, i.e. based on a sequential evaluation of attributes against a maximizing or elimination criterion.

A person's idiosyncratic choice behaviour strategy is neither stable nor context-independent and the order and sequence of function completion is not necessarily sequential. However, following the assumption that most individuals strive after an *ex-post* cognitively consistent choice behaviour strategy in a particular context, this strategy can be described as a causal sequence of 'final states' of the framing, judgment and evaluation-and-choice functions. This causal sequence by no means pretends to describe the choice process accurately but offers a functional description of what a person may choose in a certain context, most often intuitively.

The comparison of the assumptions of UT and PT with empirical findings and theoretical notions from behavioural sciences showed that most of PT's assumptions provide a better

descriptive performance than their UT counterparts. These assumptions were taken as the starting point for the founding and naming of Extended Prospect Theory (EPT). They were accomplished with some assumptions that appeared to hold according to different studies in behavioural sciences and listed in Table 2 (page 96). The assumptions differ with respect to the range of choice contexts in which they matter. While the context-dependent, change-oriented framing of attributes relative to a reference state is a universal principle, the assignment of non-linear weights to probabilities, for example, only applies to choice under risk or uncertainty. Together they should be sufficient for the functional description and understanding of individual human choices in any particular context.

The assumptions of EPT imply that interpersonal heterogeneity in observed choices may be the combined effect of differences between the applied choice behaviour strategies and differences in the idiosyncratic valuation of alternatives. This impedes the assessment and extrapolation of the individuals' choice behaviour characteristics. EPT adopts three additional assumptions to overcome this problem. The first draws on the cognitive consistency principles of Social Psychology and states that most individuals consistently use the same choice behaviour strategy in recurrent choice processes, at least if these deal with the same or similar contexts. The second exploits the instant endowment observation of Behavioural Decision Theory: individuals adjust their reference state almost immediately to experience changes in their circumstances. The third is related to the recognition-primed decision principle of Naturalistic Decision Theory. It assumes that in a particular context previous choices on the same or a higher level of the strategic-operational choice hierarchy act as constituent elements of the actual reference state, reduce the range of feasible alternatives and yield thresholds for acceptable attribute levels. EPT thus considers successive choices of an individual as an ongoing process, with reference updating after each concrete choice. Together these additional assumptions, which offer a weak substitute for UT's context-independent preference order, extend EPT from an explanatory theory to one that can be used for predictions as well.

The descriptive ability of EPT's assumptions for travel behaviour

Disregarding some less prominent differences and combining others leaves five EPT assumptions that most distinguish its descriptive ability from UT and PT. These assumptions are listed in Table i, along with the corresponding UT and PT assumptions. An extensive literature search yielded empirical observations about travel choices from 85 different studies that allow comparison of the descriptive ability of one or more of these sets of assumptions. Together the range of real-life as well as research contexts of the studies covers the diversity and extent of travel behaviour research approaches.

The framing of alternatives relative to a reference state in connection with loss aversion was found in 70 studies. The majority of these findings were based on a convincing scientific demonstration. The corresponding UT assumption, that all individuals frame the alternatives context-independent, was consequently violated in these studies. The recovered evidence from the remaining cases made it plausible that reference-dependent framing and loss aversion explained the observed behaviour. The remaining fifteen studies offer no clues to accept or reject the appropriateness of this assumption. The loss aversion factors for the most common travel time and cost attributes, i.e. the ratio between the values of a loss in an attribute level and a corresponding gain of equivalent size, appeared in the 1.4 to 2.8 range, which yields the 'average' value of 2.0 as found from observations in behavioural sciences as a useful first estimate for applications in travel behaviour, if specific information is lacking.

Most studies offered no clues for either accepting or rejecting the diminishing sensitivity assumption. Two others tested a power function with an exponent below unity, in agreement with PT and found that it offers good matches with the observed behaviour. The inferences from studies in which the utility function was approached with a second order Taylor series expansion are less straightforward. The overall picture seems to be that diminishing sensitivity may only play a prominent role when the considered changes in attribute levels are large. Just as a linear utility function is usually adequate to approach the diminishing marginal utility principle, a kinked-linear approximation of the value function may commonly suffice.

Table i: Discriminating assumptions of EPT, UT and PT

Extended Prospect Theory	Utility Theory	Prospect Theory
Reference-dependent framing and loss aversion		
Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to an updated reference state, and most individuals value losses higher than gains of equivalent size	Alternatives and attributes are framed context-independent, as post-decisional states, independent of the sign of the change	Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to a reference state, and individuals value losses higher than gains of equivalent size
Size-dependent valuation of attributes		
Diminishing sensitivity: the value function is concave for gains and convex for losses	Diminishing marginal utility: the utility function is concave	Diminishing sensitivity: the value function is concave for gains and convex for losses
Valuation of probabilities		
Most individuals weigh expected probabilities of uncertain outcomes with a subjective non-linear probability weight	Individuals do not weigh expected probabilities	Each individual weighs expected probabilities of uncertain outcomes with a subjective non-linear probability weight
Compounding of attributes		
Affectively salient attributes may be valued in a qualitative affect dimension, other attributes on a monetary or medium scale	All attributes are valued in a commensurable medium	All attributes are valued in a commensurable medium
Heterogeneity in choice behaviour strategies		
Within-context interpersonal differences in choice behaviour strategies occur (framing of attributes, satisficing and maximizing, compensatory and non-compensatory rules, etc.)	Each individual chooses the alternative with the highest (compensatory compounded) overall ordinal utility	Within-context interpersonal differences in framing occur, but each individual chooses the alternative with the highest (compensatory compounded) overall value

Most re-examined research designs did not consider probabilistic outcomes and thus they did not allow validation of the assumption that an individual attaches subjective non-linear probability weight factors to them. In thirteen of the remaining studies this assumption was convincingly observed and in another fourteen plausibly. Evidence of application of this assumption is remarkably absent in studies dealing with strategic decision making related to accessibility and travel, particularly as the long-term effects of such decisions are notably uncertain. One explanation might be that individuals take myopic decisions or disregard long-

term uncertainties, another that researchers are not particularly interested in the way individuals deal with it.

An important role of the affective valuation of some attributes in addition to the utilitarian valuation of others was found in seventeen studies. Convincing demonstrations were almost completely confined to strategic decision making. Most other observations concerned responses to stated preference surveys with explicitly submitted ethically salient attributes, more specifically traffic safety in terms of the number of casualties. Indications for an increasing significance of this assumption at higher levels of the strategic-operational choice hierarchy are also found in other behavioural sciences.

Interpersonal heterogeneity in the application of choice behaviour strategies covers differences in the framing of objectively the same travel situations, differences between loss-aversive and loss-neutral valuation of the same attributes, and the co-occurrence of compensatory and non-compensatory decision rules within a survey population. The occurrence of such interpersonal differences was retrieved from 43 studies. Overall, most studies suggested that a majority of the survey population exhibited loss aversion for all attributes while a minority valued at least a part of these loss neutral. Differences in the reference-dependent framing of different attributes and in the corresponding loss-aversive valuation might thus be the major source of interpersonal choice heterogeneity.

Findings about an EPT-based trip planning prediction model

The travel mode, departure time and route planning of the daily commute by car owners to work in Singapore's Central Business District offer an interesting opportunity to compare the predictive ability of the EPT paradigm compared to UT. The introduction of Road Pricing in 1975 and several changes in its regime and fares in the following decades make it possible to compare the tactical travel choices as a response to the abrupt positive and negative changes in the travel costs. The long-term travel cost and income developments could be retrieved as well as the changes in the number of car trips so the ability to predict the effect of gradual changes in the travel contexts can also be evaluated.

Starting from the first principles of EPT a discrete choice model is deduced that, after appropriate calibration to a particular elicitation context, can be used to predict travel choices by the same traveller in other contexts. In agreement with the comprehensive character of EPT the model is also suited to simulate the corresponding UT premises. This can be achieved by enforcing just one reference state for all choice contexts that an individual encounters and by setting all loss aversion factors at unity. The choice rule of the model is deterministic and compatible with the UT paradigm. The subject is considered to choose the feasible alternative with the highest utility. The value functions could just as well have been applied in a common Logit-type model by adding the appropriate stochastic parameters and rules.

The tactical travel choice circumstances for which the model is developed are such that hardly any non-linear probability weighting has to be expected, thus probabilistic travel attributes are disregarded. A stochastic parameter is proposed to catch the affective valuation of all characteristics of the reference trip that are not covered in the appraisal of the overall travel time *per se*. However, this parameter is disregarded for the actual predictions described in this book, as the aggregated character of the retrieved information does not allow a useful calibration. Regarding the diminishing sensitivity principle it is considered beforehand that a power function would not offer significant improvements compared to a linear value function.

The simplified value function that is finally applied only considered travel time and running cost components for the concerned alternatives.

The Weighted Additive Value rule of Behavioural Decision Theory appears an appropriate formula for the value function. It allows all interpersonal differences in the valuation of the considered attributes as well as in the idiosyncratic attribute decision weights to be assimilated into just one stochastic Value of Travel Time Savings (VTTS) parameter of the time attributes. Conceived in this way the VTTS should be considered as an important element of the subject's pre-choice reference state that should be updated regularly, at least in assessments that adhere to the EPT paradigm.

Starting from EPT's strategic-operational choice hierarchy the duration of the working week and other obligatory activities, as well as the household income, are considered as fixed in tactical travel choice settings. Travel budgets might thus only be traded off with discretionary budgets. Therefore, the VTTS can be conceived as the ratio between the marginal psychological value of the discretionary available time and that of the money for discretionary spending. Following the decreasing marginal utility principle makes the VTTS directly proportionate to the product of discretionary money and the inverse of discretionary time. On the aggregate level of a population of travellers the discretionary available time and money distributions will hardly change over short periods of, say, a year or two. The VTTS can thus be treated as an idiosyncratic constant for predictions of responses to 'sudden' changes in the travellers' circumstances. Over a longer period the changes might be considerable. For Singapore's commuters it is found that in the 1975-2005 period the discretionary available time hardly changed at all. The long-term development of their VTTS is thus proportionate to their available discretionary money. Over the same period there were huge differences between the price and income developments.

By considering several budgeting strategies in connection with hedonic adaptation it is hypothesized that individuals might adjust the psychological value they attached to their discretionary money in an inversely proportionate way to the Consumer Price Index, the monthly household income development or the nominal wage rate increase. For a population of travellers it is hypothesized that the consumer price index might be followed more closely than the income-related indices. The predictions show that this hypothesis has to be rejected. The hourly wage rate development that is commonly assumed in travel behaviour research also appears unsuitable. For Singapore, indexing of the VTTS with the monthly household income development[1] appeared to offer by far the best matches between predictions and actual observations of traveller's responses to long-term changes in their circumstances.

The calibration process that is followed to assess the average VTTS around the introduction of road pricing in 1975 is straightforward. There is no reason to believe that a conventional Random Utility Maximization model, if applied to the same data, would have elicited mean VTTS values of another order-of-magnitude. The same holds for the successive predictions. The predictions according to both models can thus be used for a '*ceteris paribus*' comparison of their predictive abilities.

[1] For these predictions national averages of wages and household incomes were used. In the considered period the average number of workers per household and the average working week remained approximately the same. Indexation with the monthly household income might hold elsewhere for households and (sub)populations provided that the average number of commutes and working days over the considered households remains constant.

The UT model strongly overestimates a sudden shift, amongst others, to public transport after the introduction of road pricing in 1975, while it underestimates the number of car owners who paid the bill to keep on driving during the tolled period. The same occurs in 1976 and 1980 with fare increases and in 1998 with the transition to Electronic Road Pricing. At the same time it predicts the sudden increase in car driving after the 1989 fare reduction accurately. Introduction of transition cost parameters in agreement with Search Theory, Transaction Cost theories, Status Quo or Inertia concepts might annihilate the predicted, actually not occurring, decrease in private car driving in 1976 and 1980 but, if applied consistently, they would also make the correctly predicted 1989 increase vanish. Thus, the eagerness to 'cash' travel time gains as shown by non-driving car owners after the 1989 fare reduction and the unwillingness to accept time losses inherent to a modal or schedule shift by the car drivers after the 1976 and 1980 fare increases cannot be explained by a loss-neutral kind of transition cost. The predictions of the EPT model approach the actual responses of the car owners to all the sudden changes much more closely than the UT implementations. Though this could not have been attained without accounting for loss aversion, the extensive evaluation of the responses to the 1976 fare increase show that loss aversion was not enough to explain the observed behaviour. Reference updating to account for hedonic adaptation[2] appears at least as important.

As according to both paradigms the price and wage rate developments in Singapore appear poor indicators of the long-term development of VTTS, only the calculations that use the monthly household income are considered hereafter. The EPT model follows the development closely (Figure 19 on page 254). For the UT model a better approximation would have been found if a VTTS development index was applied that lagged behind the household income growth, as e.g. suggested by Gunn (2001)[3]. This would, of course, have undermined the *ceteris paribus* character of the comparison of both paradigms.

Conclusions

1. Human choice behaviour can be described as a mental process that fulfils four functions to arrive at a choice: framing, judgment, evaluation-and-choice and choice behaviour strategy. Human reasoning, which goes on predominantly unconsciously, might complete them in any sequence.
2. The concrete assumptions about choice behaviour as accepted in the different forms of Utility Theory and Prospect Theory can be assembled in two different sets that each offer a complete and non-redundant implementation of the four functions of choice behaviour.
3. Most of the assumptions made by Prospect Theory describe the concerned elements of choice behaviour better than the corresponding assumptions of Utility Theory, in both experimental and real-life settings as reported from the behavioural sciences,

[2] The current UT-based traffic models assume that many predicted responses to increases in road pricing fares and other sudden changes in traffic circumstances take effect long after the changes occur, during job changes or moving house, for example. When the EPT paradigm is followed the predicted immediate response to a road-pricing fare increase, for example, will be much closer to the following long-term equilibrium. This is caused by the shift of the fare increase from the loss to the gain domain, which will occur soon after the increase came into effect and will affect the corresponding cost attribute in all relevant successive tactical as well as strategic choice contexts.

[3] See also the Dutch OEI guidelines for the assessment of the economic impact of infrastructure: '*The best estimate of the real growth of the value of travel time over time, both for business and non-business passenger traffic, is equal to half the growth rate of the real wage base. With respect to this point of view additional study is needed*' (VenW 2004:14).

4. Some alternative assumptions proposed in the behavioural sciences offer a better match for the observed choices in the context to which they apply than the corresponding premises of both Utility as well as Prospect Theory. These are assembled together with those of Prospect Theory that show a good descriptive performance into Extended Prospect Theory.
5. Tested against observations from 85 studies retrieved from the transport literature, which cover the whole range of travel behaviour research, the five assumptions of Extended Prospect Theory in Table i, which distinguish it the most from the corresponding assumptions of Utility Theory, show a better descriptive ability. There were virtually no studies found that provided evidence for the reverse.
6. Prospect Theory offers no clear direction about how to deal with the context dependency of choice behaviour when one considers to use it for policy impact analyses and prognoses. By adopting three additional assumptions from different social sciences Extended Prospect Theory is expanded from a descriptive model to one that is also useful for predictions.
7. Discrete choice models can be developed, starting from the assumptions of Extended Prospect Theory, that can also accommodate implementations of Utility Theory by imposing restrictions on parameters in the value function.
8. Such a model was actually developed for the Singapore commuting context. It contains a crucial value-of-travel-time-savings parameter that was calibrated on the travel choices of Singapore's car owners as observed before the introduction of road pricing, both for implementations of Extended Prospect Theory and Utility Theory. The first implementation predicted the observed responses of car owners to both short term and long term changes in their travel conditions better than the second.

Contributions to the field

Several research approaches and theoretical concepts in this book are new contributions to science, as they are, to the author's best knowledge, published here for the first time. Some conspicuous ones are:

- The systems-theoretical interpretation of the development of the philosophical and psychological paradigms about human choice and behaviour from the Renaissance era up until today;
- The functional decomposition of choice behaviour into a complete, non-redundant set of functions and sub-functions[4] that are able to fulfil its overall purpose;
- The Meta-Theory of choice behaviour, developed as a tool to assess the comprehensiveness of the descriptive ability of any theory of human choice behaviour and as a framework for the comparison of theoretical assumptions about functions of human choice behaviour and actual observations;
- The listing of a comprehensive set of assumptions of PT, analogous to a similar listing of UT, both considered as functional-descriptive paradigms of human choice behaviour;
- The foundation of EPT as a synthesis of assumptions that, compared to other assumptions from economics and several behavioural sciences, offered a better

[4] Most of the functions and subfunctions are not new, but their arrangement in relation to each other such that they can fulfil the purpose of human choice behaviour is.

description of observations about human choice and behaviour from a range of behavioural sciences;

- The assessment of the descriptive ability of five sets of discriminating assumptions of UT and EPT in a meta-analysis of the travel behaviour literature;
- The definition of the Value-of-Travel-Time-Savings (VTTS) parameter based on hedonic valuation principles;
- The estimation of the distribution of the VTTS over a population of travellers by a lognormal distribution with a shape parameter equal to the root-mean-square of the shape parameters of the distributions of the income and the inverse of the discretionary time of the travellers;
- A discrete choice model for the prediction of tactical travel choices that can accommodate similar implementations of UT and EPT; and
- The systematic comparison of both short-term and long-term responses to road pricing and changes in socio-economic circumstances by Singapore's commuters with predictions in agreement with the UT and EPT paradigms, which demonstrated a better descriptive ability of the latter.

Recommendations

A better understanding of the basic principles of human choice behaviour might benefit from a more profound re-examination of Spinoza's '*Ethica*' than was feasible within the current research. The functional view(s) on choice behaviour that would follow from such a re-examination of Spinoza's concepts could then be compared with the findings from present-day neuroscientific research to adjust the functional picture if and where required into a comparatively ageless choice behaviour concept. For a successful phase-in of the EPT paradigm in research and policy making the filling up of the following holes in the current knowledge encountered during the supra-disciplinary review of human choice behaviour is commended:

- Are the subjects' post-decisional affective appraisals of losses and gains of equivalent sizes the same or do they differ significantly?
- Does a subject update her reference state faster following an improvement in circumstances than after a deterioration?
- To what extent and how do individuals update their reference during recurrent choices under uncertainty, and are there systematic interpersonal differences in updating?
- Are interpersonal differences in choice behaviour strategies related to relatively stable personality characteristics or not?

Some in-depth studies of subjective consideration choice set formation are also needed, as this is a crucial element of the framing function. Finally, studies of the interpersonal differences in the choice behaviour strategies that subjects apply in different domains and contexts are recommended.

Regarding modelling, the development of a micro-simulation model is recommended that enables the simulation of the choice context of individuals by drawing their VTTS from an appropriate lognormal distribution and by drawing a set of attribute levels from accessibility characteristics distribution(s). Such a micro-simulation model could be useful for the inference of choice behaviour from aggregated choice data in other contexts. The model could

be developed in such a way that simplifying and/or fixing parameters might implement both the UT and EPT paradigms. Both paradigms could therefore be compared in different contexts.

The EPT paradigm can also be applied to policy-making behaviour, enabling the success of a measure intending to stimulate citizens to change their behaviour to be estimated beforehand, by considering the balance of the positive and negative changes that it imposes on different individuals. As a consequence, under many circumstances models in agreement with EPT may predict people's responses to policy interventions systematically differently from models that adhere to the UT paradigm. Compared to models that follow the UT paradigm, similar ones that adhere to EPT will predict, for example, a larger response to measures that 'seduce' people to change their behaviour by offering them an 'instantaneous' direct profit. The reverse is true for the predicted responses to measures that impose a disadvantage on those who refuse to change their behaviour. It is recommended that the EPT paradigm is further developed and used for policy impact assessment studies, as it appears to be able to predict the responses of individual citizens as well as their distribution over different socio-economic segments of the population and thus enables an estimation of both the overall public support and the outcomes of the policy more closely than the actual implementations of the UT paradigm.

Glossary

This glossary defines the interpretation of the words that are listed below as adopted in this book. Unless otherwise stated the definitions are those selections from the common language interpretations in the Shorter Oxford English Dictionary (SOED 2002) that are considered most appropriate in the actual context.

Action: a thing done.
Adaptation: modification to fit new conditions.
Alternative (adj.): of one or more things: available instead of the other.
Alternative (noun): each of two or more possibilities.
Assessment: an estimate of worth, extent, etc. In this book: of attribute size.
Asset: a thing of use or value.
Assumption: the taking of something for being true, for the sake of argument or action. In this book conceived to cover hypotheses (q.v.), postulates (q.v.), premises (q.v.) and implicit assumptions.
Attribute: an inherent characteristic quality or feature of a person or thing. In this book: properties of an alternative, including endowment, conservation etc. of goods, brands, features and contingencies of the decision process.
Behaviour: an observable pattern of actions. If used indiscriminately in this book: of a person or organization.
Bias: a systematic distortion of a result, arising from a neglected factor. In agreement with the heuristics and biases literature used in this book as '*a systematic deviation from normative reasoning*' (Stanovich and West 2000: 646).
Canonical: of the nature of a canon or rule; authoritative; standard; accepted.
Cardinal: showing how many elements there are in a certain set.
Choice: choosing, deciding between possibilities; a thing specially chosen or selected. In this book also more specific: a subject's exertion of the mind to initiate a particular course of action that she has chosen from several alternatives.
Choice decision: used as synonym for the specific interpretation of choice defined above.
Choice behaviour: a mental process that transforms mental representations of several optional courses of action and their expected outcomes into a choice (posited in Section 2.1).
Choice set formation: the process of forming a complete collection of relevant alternatives in a choice context, resulting in either an individual's subjective consideration set or in a theoretical, more inclusive set by an observer (posited here).

Commensurability: measuring by the same standard; having a ratio that might be expressed as the ratio of two integers.

Compensatory (decision) rule: a routine in which low values of one attribute can compensate for high values of another, where in non-compensatory rules they cannot (e.g. Foerster 1979).

Conjunctive (decision) rule: a routine in which the chosen alternative must meet requirements for all attributes.

Consistent: constantly adhering to the same principles of thought or action.

Consistent choice behaviour: means that within a certain choice process a subject always adheres to the same principles of thought or action (posited here). Some travel behaviour researchers (e.g. Sælensminde 2001) use this term as synonym for '*transitive choice behaviour*' (q.v.) but to avoid confusion this practice is not adopted in this book.

Context: ambient conditions, a set of circumstances. In this book: of the mental choice process.

Decision: the action of coming to a determination or resolution with regard to any point or course of action. In this book conceived to include the following meaning of '*will*': the exercising of the mind with conscious intention towards initiating a chosen action. More specifically a decision '*implies that several courses of action have been presented to the mind, and that the choice is now finally made*' (Webster's 1913 dictionary).

Decision making: '*the cognitive process leading to the selection of a course of action among alternatives*' (http://en.wikipedia.org/, acc. November 2006). More specific: a subset of choice behaviour in which the decision maker is aware of at least two feasible courses of action and makes a deliberate, conscious and definite choice from them (posited in Section 2.1).

Deduction: the process of deducing a conclusion from what is known or assumed; inference from the general to the particular.

Deontic: relating to duty or obligation.

Descriptive: (with respect to theories, models etc): consisting of or concerned with description of observable things or qualities; not expressing feelings or valuations. See also normative-prescriptive.

Desensitisation: reduction or elimination of the sensitivity of a person to a stimulus.

Dichotomy: division into two classes, parts, etc.

Discrete: not continuously variable, taking only certain values.

Disjunctive (decision) rule: a routine that accepts any alternative with an attribute value that exceeds a certain criterion (e.g. Foerster 1979).

Elimination-by-aspects (decision rule): a routine that evaluates alternatives in stochastic attribute importance order and rejects those that do not meet relevant attribute cut-off value (Tversky 1972). Also commonly used for routines that follow a lexicographic attribute importance order (e.g. Payne **et al**. 1992).

Emotion: a physical agitation or disturbance; any of the natural instinctive affections of the mind which come and go according to one's personality, experiences, and bodily state. In this book 'feelings' are considered to relate to the conscious mind, 'emotions' to the body.

Environment: the set of circumstances or conditions in which a person or community lives, works, develops, etc.

Evaluation: an assessment of worth. In this book: of an alternative.

Facts: a thing assumed or alleged as a basis for inference. In this book conceived as mental perceptions of concrete information (posited here).

Frame: an established order or system.

Framing: fitting (in this book: of a perceived choice context) into a frame. Also: '*that portion of his or her store of knowledge that the decision maker brings to bear on a particular context in order to endow that context with meaning*' (Beach 1990: 51).

Feeling: the condition of being emotionally affected or committed; an emotion of fear, hope, etc.; a belief not solely based on reason, an attitude, a sentiment. In this book used for '*the mental representation of the physiological changes that characterize emotions…if emotions provide an immediate response to certain challenges and opportunities faced by an organism, the feeling of these emotions provide it with a mental alert*' (Damasio 2001: 781). More specific: mental perceptions of affects, passions and desires (posited here).

Function: intended role of a person or thing.

Functional decomposition: breaking down the over-all function of a system into a complete set of non-redundant operations or functions that together do neither more nor less than performing the function of the system as a whole (posited in Section 2.3).

Glossary: a list with explanation of terms.

Happiness: subjective well-being (q.v.).

Heuristic (adj.): serving to find out or discover something.

Heuristic (noun): '*mediates a judgment when an individual assesses a specified target attribute of a judgment object by substituting another property of that object – the heuristic attribute – which comes more readily to mind*' (Kahneman and Frederick 2002: 53).

Hypothesis: an assumption (q.v.) made as a starting point for further investigation or research from known facts.

Idiosyncrasy: a mental constitution, view, feeling, or mode of behaviour peculiar to a person.

Idiosyncratic: characteristic of an individual.

Induction: the process of inferring or verifying a general law or principle from the observation of particular instances.

Introspection: observation of one's own thoughts, feelings, or mental state.

Isomorphic: equal in form, and in the nature and product of their operations.

Judgment: the formation of an opinion or notion concerning something by exercising the mind on it; the function of the mind by which it arrives at a notion of a thing.

Kurtosis: the degree of sharpness of the peak of a frequency distribution curve (= 3.0 for a normal distribution).

Lexicographic (decision) rule: a routine that evaluates alternatives attribute-wise, in attribute importance order; commonly used to designate the Strong Lexicographic rule (q.v.) (e.g. Tversky 1969).

Lexicographic semiorder (decision) rule: lexicographic decision routine that treats alternatives with small differences in value of most important attribute as equally attractive (e.g. Tversky 1969).

Logit: the natural logarithm of the quotient of a probability and its component.

Loss aversion: the property of human judgment that losses are valued much higher than gains of equivalent size (posited in Section 3.3).

Loss aversion factor: in choice contexts: the ratio between the marginal psychological values of a decrease in a positively valued attribute level of a choice alternative and an equally sized increase in that level (posited in Section 3.3); in trading contexts: the ratio between the selling price (after endowment) and the bidding price (before acquisition) for the traded good (posited in Section 4.3).

Marginal benefit: the additional benefit arising from a unit increase in a particular activity.

Maximax (decision) rule: a routine that in a probabilistic choice setting first identifies for each alternative the best outcome of all possible states of the world, and successively chooses the alternative with the best of all the best outcomes (e.g. Von Neumann and Morgenstern 1944). May also be used to denominate a routine that in a 'certain' choice setting first identifies the highest attribute value of each alternative and successively selects the alternative with the highest of these highest attribute values (e.g. Foerster 1979). Also called the Optimist rule.

Maximin (decision) rule: a routine that in a probabilistic choice setting first identifies for each alternative the worst outcome of all possible states of the world, and successively chooses the alternative with the best worst outcome (e.g. Von Neumann and Morgenstern 1944). May also be used to denominate a routine that in a 'certain' choice setting first identifies the lowest attribute value of each alternative and successively selects the alternative with the highest of these lowest attribute values (e.g. Foerster 1979). Also called the Pessimist rule.

Mental process: a process carried on or performed by the mind.

Metaphysical: not empirically verifiable; immaterial, supernatural.

Mind: the seat of awareness, thought, volition, and feeling; cognitive and emotional phenomena and powers as constituting a controlling system.

Mixed (Multinomial) Logit model: a generalization of the Multinomial Logit model in which several error components are added to the individual's utility function (e.g. McFadden 2001a).

Multinomial Logit model: an econometric model that is a generalization of Logit models that can handle choices from sets with more than two alternatives (e.g. McFadden 2001a).

Non-compensatory (decision) rule: low values of one attribute cannot compensate for high values of another (e.g. Foerster 1979).

Normative-prescriptive: (with respect to theories, models etc): deriving from, or implying a standard or norm; giving definite precise directions or instructions.

Observed choice: the outcome of a choice processes, as found from a subject's explicit statement or actual perceptible behaviour, in an environment where the observer discerns at least two alternative courses of action. The observer should have assumptions about the subject's choice process that allow a prediction of its outcome in the considered context, which prediction may be violated by the observed outcome (posited in Section 1.1).

Optimist (decision) rule: Maximax rule (q.v.).

Ordinal: marking the position in an order or series.

Paradigm: a mode of viewing the world that underlies the theories and methodology of science in a particular period of history.

Paramorphic: distinct in form, but analogous in the nature and product of their operations

Pessimist (decision) rule: Maximin rule (q.v.).

Perception: the intuitive or direct recognition of a moral, aesthetic or personal quality; the neuro-physiological processes, including memory, by which an organism becomes aware of and interprets external stimuli.

Postulate: a fundamental condition or principle; an unproved or necessary assumption; used in this book to denote an assumption (q.v.) that is conceived as true beyond discussion.

Preference: the action or an act of preferring; liking for one thing rather than another. In this book used in choice contexts for that which one prefers with respect to the outcomes of alternatives, though '*decision theorists often use the unadorned word "preferences" to mean preferences over actions*' (Manski 2004: 1330).

Premise: a previous statement from which another is inferred or follows as a conclusion. Used in this book to denote an assumption (q.v.) that supports a theory and that is confirmed by empirical findings in at least some contexts.

Process: a thing that goes on or is carried on; a continuous series of actions, events, or changes; a course of action, a procedure.

Prospect: a mental picture, especially of a future or anticipated event; an expectation, especially of wealth etc.

Purpose: the reason for which something is done or made, or for which it exists.

Reason: the mental faculty that is used in adapting thought to some end.

Reasoning: thinking in a connected or logical manner; using one's reason in forming conclusions.

Representation: an image, likeness, or reproduction of a thing.

Reference: an object, physical property, value, etc. used as the basis for comparative measurement.

Reference point: synonym for reference state (q.v.) as used by Kahneman and Tversky (1979) for a choice from sets with two-attribute alternatives.

Reference state: the expected outcomes (attribute properties, chances, values) of continuation of the actual behaviour in a changing context that is used as the basis for comparative assessment of the expected outcomes of alternative courses of action (posited in Section 3.3).

Salivation: an act of producing an unusual secretion of saliva.

Satiation: the point at which satisfaction of a need reduces or ends an organism's responsiveness or motivation.

Satisficing: deciding on and pursuing of a course of action that will satisfy the minimum requirements to achieve a particular goal.

Skewness: of a statistical distribution: not symmetrical about its mean. The skewness of a normal distribution is zero. Positive values indicate data that are skewed right.

Strategic decision making: a long-lasting type of choice behaviour that goes on intermittently for a long time, is generally deliberate and conscious, at least in the final 'deciding' stage, and results in decisions which have long-term impacts on successive choice behaviours that are lower in the strategic-operational choice hierarchy (posited here).

Strategic-operational choice hierarchy: the arrangement of the continuum of an individual's choice processes in a weak hierarchical order that ranges from strategic decisions, like family formation, to operational choices, like lane keeping in motorway traffic (posited here).

Strong Lexicographic (decision) rule: a routine that selects the alternative with the highest value on the most important attribute or, in the case of a draw, the next important one, even if the difference in attribute values is small (e.g. Foerster 1979).

Subadditivity: the property that the sum of two or more values of a function is smaller than the value of the sum of the corresponding coordinates (posited here). In the choice contexts discussed in this book: the value of the level of a covering attribute is smaller than the sum of the values of its constituent parts.

Subjective well-being: the self-report of an individual to questions like '*All things considered, how satisfied are you with your life as a whole these days?*' (e.g. Frey and Stutzer 2002).

System: a group or set of related or associated material or immaterial things forming a unity or complex whole; a set of objects or appliances arranged or organized for some special purpose.

Systems dynamics: a discipline that draws on the premise that the complex interrelationships of its subsystems/components can be just as important for the behaviour of the system as a whole as the individual components *per se*.

Systems Theory: a transdisciplinary/multiperspectual theory that studies structure and properties of systems in terms of relationships from which new properties of wholes emerge (http://en.wikipedia.org/, accessed November 2006).

Thinking: '*the creation of mental representations of what is **not** in the environment*' (Dawes 1988: 3, his emphasis).

State of the World: future events or conditions that can influence an outcome or payoff but cannot be controlled by the decision maker.

Thought: the process of thinking; formation and arrangement of ideas in the mind.

Transitive choice behaviour: means that a subject should always choose A over C when she chooses A over B and B over C in the same sequence (e.g. Tversky and Kahneman 1986).

Valuation: appraisal or estimation of something in respect of excellence or merit (in this book: of an attribute in terms of its psychological value).

Value of Travel Time Savings (VTTS): ratio of an individual's psychological value arising from a unit decrease in travel time and her psychological value arising from a unit decrease in monetary travel expenses (elaborated in Subsection 7.4.2).

Weighted-additive (decision) rule, Weighted additive value (decision) rule: a routine that assesses the sum of the products of the individual attribute values and their subjective decision weights (e.g. Foerster 1979).

Willingness-to-Pay: amount of money that an individual is prepared to pay for the acquisition of a good (posited in Subsection 4.3.4).

Willingness-to-Accept: amount of money that an individual is prepared to accept for the renunciation of a good that she owns (posited in Section 4.3.4).

Symbols and Abbreviations

This overview explains the symbols and abbreviations that are used in this book. Each entry is followed by its naming in full, its meaning or the location in the book where it is defined and the chapters and annexes in which it occurs. Abbreviations and symbols that only occur in a single subsection in which they are explained are omitted here.

Symbols and abbreviations frequently used in many places

ALS	Area License Scheme; Section 7.1; Chapter 7, Annexes C … G.
a.m.	Before midday; from Latin, *ante meridiem*; Chapter 7, Annexes C … G.
e.g.	For example; from Latin, *exempli gratia*; widely used.
EPT	Extended Prospect Theory; Section 5.1; Summary, Chapters 1 and 3 … 9, Annex F.
et al.	and others; from Latin, *et alii*; widely used in references.
h	hour; symbol for unit of time accepted for use in agreement with the International System of Units; Chapters 6 and 7, Annexes C … G.
km	kilometre; symbol for unit of length in agreement with the International System of Units; Chapters 6 and 7, Annexes C … G.
min	Minute; symbol for unit of time accepted for use by the International System of Units; Chapters 6 and 7, Annexes D and F.
p.m.	After midday; from Latin, *post meridiem*; Chapter 7, Annexes C … G.
PT	Prospect Theory; Section 3.3; Summary, Chapters 1 and 3 … 9.
S$	Singapore dollar; national currency; Chapter 7, Annexes D …G.
UK	United Kingdom of Great Britain and Northern Ireland; Chapters 4, 6 and 7, References
US$	American dollar; USA national currency; Chapters 4, 6 and 7.
UT	Utility Theory; Section 3.2; Summary, Chapters 1 and 3 … 9, Annex F.
VTTS	Value of travel time savings; Glossary; Summary, Chapters 6 … 8, Annexes D … G.
λ	Loss aversion factor with respect to attribute or alternative; Glossary; Chapters 3, 4, 6 and 7; Annexes B and F.

Symbols and abbreviations used in few places

c	Cost attribute in value function; Subsection 7.4.9; Chapter 7, Annex F.
KYMS	The keep-to-your-mode-and-schedule alternative for car owners in Singapore; Section 7. 3; Chapter 7, Annex F.
LA(1,1)	Attribute valuation rule with loss aversion factor 1 for time and 1 for money; Section 7.4.4; Chapter 7, Annex F.
LA(2,1)	Attribute valuation rule with loss aversion factor 2 for time and 1 for money; Section 7.4.4; Chapter 7, Annex F.
LA(2,2)	Attribute valuation rule with loss aversion factor 2 for time and 2 for money; Section 7.4.4; Chapter 7, Annex F.
p	Probability; self-evident; Chapter 4.
t	Time attribute in value function; Subsection 7.4.9; Chapter 7, Annex F.
V	Overall value or utility of choice alternative; Subsection 7.4.9; Chapter 7, Annex F.
λ_{time}	Loss aversion factor with respect to time attributes; Subsection 7.4.4; Chapters 6 and 7, Annex F.
λ_{money}	Loss aversion factor with respect to monetary attributes; Subsection 7.4.4; Chapters 6 and 7, Annex F.
σ_{n}	Standard deviation of normal distribution; self-evident; Chapter 4.
σ	Shape parameter of lognormal distribution (with subscript: for distribution that applies to the indicated phenomenon); Subsection 7.4.8; Chapter 7.
€	Euro; European currency; Chapters 4 and 6.
£	Pound Sterling; UK national currency; Chapter 6.

Abbreviations for institutions that are mentioned incidentally

AMR	Accent Marketing and Research (nowadays Accent); British market research agency; Chapter 6, References.
AVV	Adviesdienst Verkeer en Vervoer (Transport Research Centre); nowadays RWS Centre for Transport and Navigation; References.
HCG	Hague Consultancy Group; former British-Dutch consultancy firm; Chapters 6 and 7, References.
LTA	Land Transport Authority; Executive department under Singapore's Ministry of Transport; Chapter 7, References, Annex G.
RWS	Rijkswaterstaat (Directorate-General for Public Works and Water Management); Executive department of VenW; Preface.
SCP	Sociaal Cultureel Planbureau (The Netherlands Institute for Social Research); Dutch government agency; Chapter 9.
SOED	Shorter Oxford English Dictionary; self-evident; Glossary, Chapter 2 … 4, References.
USDA	United Stated Department of Agriculture; Executive department of the US Government; Chapter 4.
VROM	Dutch Ministry of Housing, Spatial Planning and the Environment; self-evident; Chapter 9.
VenW	Verkeer en Waterstaat (Dutch Ministry of Transport, Public Works and Water Management); self-evident; Summary, References.

Chapter 1
Introduction

The feedback from the empirical study of choice behaviour to the economic theory of the consumer has begun, through behavioural and experimental economics, but is still in its adolescense

Daniel McFadden (2001b:374)

Context: Final observation of the retrospective of the development of discrete choice models based on Random Utility Maximization in McFadden's Nobel Prize reading.

1.1 Background

To date, Utility Theory (UT) has been the most widely used and generally accepted paradigm for the understanding of human behaviour in economics as well as in transport sciences and many other disciplines. UT was originally developed as a normative-rational theory (i.e. giving definite precise instructions based on reasoning) about how a decision-maker should maximize her utility, based on a strict logic-analytic deduction from some strong postulates with respect to her knowledge of the environment, her interests and so on. It would be hard to find evidence that refuted this paradigm. However, for a long time UT, in different guises, has been predominantly used as an approximate descriptive-behavioural model (i.e. concerned with the description of human choice behaviour). In this book it is conceived in the latter sense, unless otherwise stated. Its main assumptions are summarized in Chapter 3.

Since the 1950s there has been growing concern in the behavioural sciences[5] about UT's descriptive performance for real-life choice behaviour. The introduction of the '*satisficing*' decision rule (Simon 1955) and the '*Bounded Rational Decision-Making model*' (Simon 1960) gave rise to an ever-increasing flow of empirical findings about human choice and

[5] '*Behavioural sciences*' is commonly considered these days to encompass all the disciplines that explore the activities of and interactions among organisms in the natural world. In the context of human choice behaviour these include psychology, psychobiology, cognitive and social neuroscience and management science. It can be conceived as either a subdivision or sister field of *social sciences* that encompasses economics, sociology and history, amongst others.

behaviour, reported from all behavioural sciences. Many theories and models aiming for a better description of the choice behaviour process were published in books, journals and conference proceedings. These included, for example, different non-compensatory decision rules that were at variance with the assumptions of UT (e.g. Montgomery and Svenson 1989a; Payne *et al.* 1993; Gigerenzer and Todd 1999).

In the transport literature of the early 1980s, several publications showed a keen interest in '*the possibility that non-utility theories of choice may describe travel behaviour more accurately than does utility*' (Horowitz 1985: 441) and addressed this explicitly as a topic for future research (see also Williams and Ortúzar 1982b). There was no follow-up to these suggestions in mainstream travel behaviour research for over a decade, until at the beginning of this century renewed interest in non-utility maximizing approaches arose (e.g. Fujii and Gärling 2003; Viti and Van Zuylen 2004; Zhang *et al.* 2004; Stern and Richardson 2005). Nowadays there is, for example, renewed interest in the incorporation of such non-compensatory decision rules in discrete choice models (e.g. Stern 1999; Swait 2001; Yamamoto *et al.* 2002; Cantillo and Ortúzar 2005), after an early surge in the late 1970s and early 1980s (Foerster 1979; Recker and Golob 1979; Williams and Ortúzar 1982a; Hensher 1983; Timmermans 1983).

In economics, Prospect Theory (PT) was developed in the 1970s (e.g. Kahneman and Tversky 1979; Tversky and Kahneman 1992) as a behavioural-economic alternative to UT. Many assumptions of PT differ strongly from those of UT. Its descriptive performance of human choices was demonstrated in many different fields. Kahneman (one of its founders) received the Nobel laureate in economics in 2002 and since then it has also been provisionally tested in several domains of travel behaviour research. It is these days possibly the most frequently applied non-utility theory in transport (e.g. Katsikopoulos *et al.* 2000; De Blaeij and Van Vuuren 2003; Senbil and Kitamura 2004; Van de Kaa 2004; Arentze and Timmermans 2005; Avineri and Prashker 2005). It might offer an improved description of travellers' choices, but there are also alternative descriptive theories and empirical findings on human decision making from behavioural sciences, for example from marketing research, social psychology and, particularly, from cognitive psychology.

Most researchers in economics and transport sciences are well aware of the violations of UT in several contexts, but these are only incidentally considered. In travel behaviour modelling, for example, the alternative behavioural approaches referred to above are an almost exhaustive list. Mainstream travel behaviour research adheres to the principles of UT. Particularly after their introduction in the early 1970s to transport by McFadden (1974), discrete choice models based on Random Utility Maximization Theory soon became the informal world standard for the modelling of travel behaviour (e.g. Ben-Akiva and Lerman 1985; Ben-Akiva and Bierlaire 1999; Arentze and Timmermans 2000; McFadden 2001a).

In the past decades tremendous progress has been achieved in ever more detailed discrete choice models as tools to put this theory into operation for purposes of research, design, management and policy advice. These Random Utility Maximization models outdated the previously dominant aggregated travel models and appeared to be very useful in almost any domain of travel behaviour. However, though several adjustments aimed to improve their descriptive-behavioural adequacy, the rational-analytic basic principles of the theory, such as a concave utility function and temporally stable, context-independent preference orders of individual decision makers, have not changed since the 1940s. The statistical fit of the

outcomes of these models with the observed travel choices[6] they strive to simulate remains rather weak (e.g. Swait 2001; Rizzi and Ortúzar 2003), unless many empirical parameters of the models are calibrated on survey results, with the risk of 'over-tuning'. Either of these phenomena may mean that the explanations and predictions of travel behaviour with such models may differ from the actual developments, depending on the extent to which the context of the behaviour changes. This could imply that these sophisticated models still leave room for improvement with respect to the description of the behaviour of actors in different contexts.

1.2 Purpose

This book aims to examine whether the assumptions of PT, superadded with insights from other social sciences, might be synthesized into a theory that both offers a better explanation of observed human choices compared to UT and, after parameter estimation, could be put into operation to predict travellers' choices. If so, this could enlarge the range of theoretically explained travel behaviour compared to Random Utility Maximization Theory and thus reduce the inductive component of travel behaviour models, reduce the risks of over-fitting to particular contexts and improve the opportunities for estimation, prediction and extrapolation.

Though the ambition is to synthesize a generic theory that might be applied in many different domains of human choice behaviour, this book focuses with respect to its applicability on its possible contribution to the understanding of travellers' choice behaviour and explores its potential for context-dependent travel choice prediction and travel-related demand estimation.

1.3 Bird's-eye view of this research

The ambition of this research requires an extensive multi-disciplinary literature review of choice behaviour theories and assumptions from different sciences. A well-balanced judgment of their position, relevance and interrelationships requires a supra-disciplinary concept of choice behaviour. In addition to a consistent set of definitions of relevant terms, the historical development of the scientific concepts of choice, behaviour and their interaction was recorded (Annex A), resulting in a diagram depicting the current scientific insights. Building on this foundation, a meta-concept of human choice behaviour was developed, following a systems-theoretical analysis. This '*Meta Theory of Choice Behaviour*' was successively used as a coordinating framework for the interdisciplinary review of the literature on choice behaviour.

The Meta Theory was conceived as a functional-descriptive perspective on the choice behaviour of individuals. It does not pretend to give a concise and factual picture of the mental processes that support this, as this appears to be predominantly covert. This functional-descriptive character makes it also suitable as a descriptive account of decision making by households and groups with less strong bonds. Consequently, it does not provide a model for the pre-decisional processes within organizations and groups, as studied in Game Theory, Social Networks Theory and similar disciplines.

[6] Unless stated differently '*observed choice*' in this book refers to outcomes of choice processes, as found from subjects' explicit statements or their actual perceptible behaviour in an environment where the observer discerns at least two alternative courses of action. The observer is considered to have assumptions about the choice process that allow a prediction of the outcome in the considered context that may be violated by the observed outcome.

The following stage of this research started with an inventory of the assumptions of UT and PT, resulting in a concise listing and mapping of the functions of the Meta Theory. Next, empirical findings and corresponding theoretical inferences on human choice and behaviour were re-examined to clarify the question of whether PT provides better opportunities than UT for the understanding of travellers' choices and, if so, whether its assumptions should be extended to cover recent findings on choice behaviour. This revealed a huge stream of information on violations of UT, but also several shortcomings of PT in view of recent theoretical and empirical findings. It also showed some ambiguity about the decision rules that an individual might use after valuation of the alternatives.

This research refrains from listing and discussing the many different mathematical formulae that were proposed to estimate the theoretically assumed real-life human choice behaviour approximately. This is to prevent a proper appraisal of the behavioural assumptions of the underlying theory becoming blurred by a discussion on the appropriateness of the applied simplifying assumptions to allow for its mathematical simulation.

The assumptions of PT were extended and partly adapted to cover the recovered empirical findings, resulting in Extended Prospect Theory (EPT). Empirical findings from the transport economical and travellers' behaviour research literature were then reviewed, enabling a comparison of the performance of UT and EPT as descriptive-behavioural models. These re-examinations demonstrate the higher performance of five discriminating assumptions of EPT compared to UT in many real-life and research contexts of travel behaviour. Apparently, the assumptions of EPT compared to those of UT thus offer a better explanation of observed human choices in general, including travellers' behaviour. This offers a perspective on the potential benefits of EPT for choice prediction and demand estimation in transport sciences, obviously after its assumptions are incorporated in practicable software and the parameters required to put them into operation that are relevant in the context at hand are estimated.

The basic assumptions of EPT were considered in connection with developing a model that enabled the prediction of tactical travel choices. It was applied to compare the predicted and actual responses of car owners in Singapore to several road-pricing measures. The number of parameters was kept as low as possible and the model was calibrated on observed choices in the period before the initial introduction of road pricing. This was done assuming different choice behaviour strategies in terms of reference framing and loss-aversive valuation, which yielded implementations adhering to the EPT and UT paradigms. Comparison with the actual responses to the introduction of road pricing and to several changes in fares confirmed the high predictive performance of the EPT concept compared to UT as well as to applications of PT without updating the reference state.

1.4 Contents of this book

Chapter 2 starts with a discussion of the basic notions of human choice and behaviour. Successively the findings from a historical review[7] of the development of the scientific insights into human choice and behaviour are summarized from a systems-theoretic perspective. This makes clear that human actions (i.e. behaviours) are governed by choice behaviour, which is conceived as a purely mental system. It has mental representations, based on perception, as inputs and choices with respect to actions as outputs. The processes that

[7] The historical review itself is described in Annex A.

arrange for the functioning of this system appear to be more often than not unconscious. The reviewed literature revealed many different process theories about how the 'choice behaviour system' works, but due to the relative covertness of these processes no incontestable observations were found that support the selection or exclusion of any of these. However, by straightforward logic-analytic reasoning, the overall-function of choice behaviour could be distinguished as four (complete and non-redundant) interrelated functions: framing, judgment, evaluation-and-choice and a coordinating choice behaviour strategy. This resulted in the functional-descriptive Meta Theory of Choice Behaviour. The assumptions[8] of any conceivable choice behaviour theory about '*what* the choice process does' do fit into this generic Meta Theory. This theory and its supporting notions and perspectives are deemed essential as a reference for comparing and synthesizing elements of human choice behaviour from the different disciplines that are reviewed in the rest of this book.

In Chapter 3 the assumptions about what individuals do to put the functions of the Meta Theory of Choice Behaviour into operation, according to UT (in its descriptive-behavioural guise) and its most popular competitor, PT, are compiled and compared. It appears that they can be attributed to the generic functional-descriptive Meta Theory, which eases comparison. Where required assumptions are disaggregated over Meta Theory functions and/or completed with assumptions from implicit inferences in the literature. This chapter does not discuss the descriptive-behavioural performance of the assumptions of UT and PT with respect to human choice behaviour; it just investigates whether those might arrange for the generic choice behaviour function in one way or another. Though many of the assumptions of these theories are at odds with each other, both UT and PT appear feasible implementations of the Meta Theory. Chapter 3 concludes with a summary for the convenience of readers with only a superficial interest in these matters.

Chapter 4 reviews empirical findings and corresponding theoretical inferences about human choices and compares them with the assumptions of UT and PT and with additional assumptions encountered in the review, for each of the four functions of the Meta Theory successively. The assumptions about human choice behaviour are considered here as hypotheses for a more generic descriptive-behavioural theory of choice, and the comparison with the published findings acts as meta-hypothesis-testing. Co-occurrence of choice behaviours which conform to conflicting hypotheses is assumed for such a generic theory, if empirically demonstrated. Most often restricted formulations of choice behaviour hypotheses had to be rejected and replaced by wider (e.g. 'and/or') assumptions.

In Chapter 5 the assumptions about the way in which an individual puts the functions of choice behaviour into operation as retained in the previous sections are synthesized into Extended Prospect Theory (EPT). A series of descriptive-behavioural process theories are then compared with this functional-descriptive EPT. It appears that EPT covers these as well, though only in a functional way: EPT is not apt to describe the assumed mental processes. Chapter 5 is completed with some observations on elicitation/parameter assessment and modelling of EPT.

The objective of Chapter 6 is to assess the extent to which the assumptions of EPT also allow for a better description of travellers' choice behaviour. To that aim the travel behaviour

[8] Propositions that support a theory are called *assumptions* here. An assumption that is conceived as true beyond discussion is called a *postulate*, one made as a starting-point for further investigation or research from known facts is denoted as *hypothesis* and an assumption that is confirmed by empirical findings in at least some contexts is called a *premise*.

literature is reviewed for information about the observed choices of travellers and the application of assumptions in modelling. From 85 studies enough information on the choice context, research design and observed choices could be retrieved to compare the descriptive performance of at least one of five basic principles of EPT with that of the corresponding UT assumption. The re-examinations demonstrated the descriptive ability of the five most discriminating assumptions of EPT, as established in Chapter 5, and the violation of those of UT in all the travel choice behaviour domains and contexts considered. After a discussion of the potential relevance of the applicability of EPT to travel behaviour research, this chapter finishes with the overall conclusion that the joint application of the examined EPT assumptions to the prediction of travel behaviour might be a promising way to arrive at a better understanding of the travellers' choice behaviour and might boost the opportunities of private and public actors to improve their policy and operations with respect to different elements of the transport system.

In Chapter 7 such a joint application of EPT assumptions is examined for the prediction of the real-life responses of car drivers to road-pricing measures in Singapore. The chapter starts with a brief introduction to the context in which the measures were taken and the responses observed. Next, it describes the development of a conceptual and mathematical model for the prediction of tactical travel choices in which the assumptions of EPT as well as UT can be implemented. This model was successively calibrated to the travellers' behaviour before road pricing was introduced and applied to the introduction of road pricing, a fare increase that occurred shortly after the introduction and the long-term responses of the travellers. Basic information about the actual responses and about the relevant travel conditions is assessed in Annexes C, D and G. The predictions of a model implementation in agreement with the EPT paradigm approached the observed responses much better than a similar implementation of the UT paradigm.

Chapter 8 offers a summary of the findings and conclusions. The book ends with an epilogue which includes reviews of the choice concept, a critical discussion of theoretical choice constructs, the potential range of application of EPT within travel behaviour research, economics and management science, and suggestions for the further development of EPT-based econometric models.

Chapter 2
Towards a Meta Theory of Choice Behaviour

The mind tries, as much as it can, to imagine those things that increase or promote the body's power to act
(Mens quantùm potest, ea imaginari conatur, quae Corporis agendi potentiam augent, vel iuvant)

Benedictus de Spinoza (1677, Ethica Pars III Propositio XII; author's translation)

Context: Part 3 of the Ethics discusses the origin and nature of human feelings. Here Spinoza apparently posits that individual people conceive and frame their contexts in a functional, ecologically rational way such that their choice processes can promote their fitness and survival.

Theoretical concepts about choice behaviour are and have been developed in many social sciences, giving rise to sometimes quite subtle interdisciplinary differences in the definition of the same utterances. Moreover, scientists appear to differ greatly in the way they conceive the choice processes. Therefore, a well-balanced judgment of the position, relevance and interrelationships of choice behaviour theories and assumptions from different sciences requires a supra-disciplinary concept of choice behaviour. This is even more true when one aims to create a synthesis of the most relevant assumptions.

Before indulging in the extensive literature from social and behavioural sciences on choice behaviour, this chapter offers such a supra-disciplinary concept, in terms of a consistent set of definitions of relevant notions as well as a meta-concept or coordinating framework. That framework consists of two connected systems-theoretical 'models'. The first model deals with the interrelationship of the subject and her environment. The second model is embedded in the first. It describes a purely mental process that the subject is more often than not unaware of. This Meta Theory of Choice Behaviour will be used as a coordinating framework for the interdisciplinary review of the literature on choice behaviour in the following chapters.

2.1 Definitions and categories of choice behaviour

Where feasible, common language definitions from the Shorter Oxford English Dictionary (SOED 2002) are followed. They are listed in the Glossary, together with some more specific interpretations that are deemed essential for the understanding of this book. The latter extensions are either directly cited from a reference or posited after examination of relevant sources.

2.1.1 Definitions

Drawing on the definitions and interpretations in the Glossary and borrowing from Systems Theory it is conceived as true beyond discussion that:

- Choice is a subject's exertion of the mind to initiate a particular course of action that she has chosen from several alternatives;
- Choice behaviour is a mental process that transforms mental representations of several courses of action and their expected outcomes into a choice;
- Decision making is considered a subset of choice behaviour in which the decision maker is aware of at least two feasible courses of action and makes a deliberate, conscious and definite choice between them[9].
- The mental process of choice behaviour (*how* does it do what it does) consists of reasoning;
- Its purpose (*why* does it do so) is to provide sustainable guidance for the subject's actions in her environment, adapted to her needs and in the interest of her fitness to survive and happiness;
- Its function (*what* does it do towards achieving that aim) is to choose in each choice situation one possible course of action (including doing nothing) from a set of alternatives that, in that particular context, meets certain of the subject's concurrent needs.

Choice behaviour in this book is considered to cover any kind of intuitive, automatic and impulsive choice behaviour as well as conscious-deliberate decision making. It thus includes a large, heterogeneous range of processes, lasting from months for long-term, multi-alternative, multi-attribute decisions (e.g. relocation of firms or households) to split seconds for short-term choices with few alternatives and few attributes (e.g. route-choice underway). The duration, the complexity and the impact of the individual processes could be considered as moderately correlated elements of continuums. Depending on the character and impact of the choice decision this book discerns strategic, operational and tactical choice behaviour. No attempt will be made to establish super fine dividing lines between these categories, as these are not deemed necessary for the purpose of this book and any such delineation within the continuum might rightfully be disputed. Therefore the categories will be characterized rather than defined in the following subsections. One should note that, though the functions of these choice categories to some extent differ, as indicated hereafter, the same mental processes carry them out.

[9] This common-language definition is e.g. supported by the experiments performed by Niedermayer and Chapman (2001: 306) in which most experimental subjects (lay people) demonstrated that '*decisions are viewed as thoughtful, intentional behaviour that is not reflexive*'. However, one should realize that in most other publications decision-making is used indiscriminately for any kind of choice behaviour.

2.1.2 Strategic decision making

Strategic long-term choice behaviour is generally deliberate and conscious, at least in the final 'decision' stage. It is therefore here called strategic decision making. It encompasses processes like family formation, residence location, employment issues or car ownership that may last from days to months, are mostly made at the household level and where affective valuation often plays a decisive role (Zajonc 1980; Slovic 1995; Slovic *et al.* 2002; Dijksterhuis 2004). Obviously, during such long-lasting choice processes people are engaged in other activities most of the time. The specific strategic decision-making task occupies their 'choice behaviour system' only intermittently, for relatively short periods. Most individuals will consider or 'frame' such choices as one decision-making process, even though they will quite commonly organize it as a series of bi-optional comparisons of one alternative at a time with a reference state (e.g. Beach 1990; Klein 1993). Strategic decision making results in outputs like formal decisions, strategic plans, behavioural intentions and unconscious scripts that may have a strong impact on many aspects of everyday life as they influence other strategic decisions, tactical and operational choices, in connection with relevant contextual factors. Such decisions may precede a series of sequential concrete follow-up choices to put them into operation.

Taking the choice of residence as an example, the choice set will contain alternative residences that by definition are at other locations than the present home, which most often acts as a null alternative. The attributes that will be considered are an array of certain and uncertain consequences that may affect the interests of the subject once the strategic decision is put into operation. In addition to the conveniences of the residence and its neighbourhood, these include accessibility attributes like the proximity of shops and other amenities, travel mode and road links to the workplace etcetera. Though many attributes like those related to commuting will only be considered superficially during the strategic choice process, an individual will generally be roughly aware of the constraints and opportunities that the decision puts on her successive day-to-day behaviour[10]. This implies that strategic decision making may strongly restrict the choice sets that subjects consider during those successive choice processes in different fields of choice behaviour.

2.1.3 Tactical choice behaviour

Tactical choice behaviour is conceived here to have an intermediate position between strategic decision making and recurrent operational choices. For example, Albatross' mid-term decisions (Arentze and Timmermans 2000) might be understood in this sense. It is considered to set up the conditions for operational choice behaviour and includes discrete choices as well as the establishment of mental scripts or habits that govern the idiosyncratic patterns of operational activity planning, like commuters' home departure times. It is also considered to accommodate constructs like willingness-to-pay or value-of-travel-time derived from stated or revealed preference studies. Such constructs are commonly elicited from surveys in which travellers are asked to state their choices from alternatives of which some attributes, like commute duration, differ from their everyday experienced levels. The research setting in which these constructs are commonly elicited mostly concerns a series of recurrent choices in which the subject, if she so wishes, is allowed sufficient time for a deliberate consideration. Obviously, such choice tasks closely resemble real-life tactical choices like the acquisition of a travel pass or those following a change of job location. In this sense it often

[10] For an overview of travel behaviour considerations during residence relocation decisions, see e.g. Stanbridge (2006).

appears a useful tool to describe and simulate actual strategic and/or operational human choice behaviours and/or their interaction.

Tactical choice behaviour may be initiated to put a more strategic decision into operation or can be triggered by another structural change in the choice context. Once such a structural change threatens or a strategic decision is effectuated, the decision-maker is confronted with its consequences in everyday life. She now has to choose how to cope with these. This 'learning' process is here called tactical choice behaviour. To illustrate this, imagine that the main tenant in the residential choice example above bought a residence near a highway approach, because her office, following the right-hand city ring road, was located near an exit, a 40-minute commute in uncongested traffic, allowing her to leave home at 8 o'clock. Suppose that she finds out, either through her own experience or making inquiries, that this route meets her expectations on most days, except for Tuesdays and Thursdays, when she would regularly experience 20 to 30 minutes congestion. She may take the left-hand side of the ring road (say a 50 minutes non-congested drive) on those days, which may have at most only 10 minutes congestion. She may also try out and/or inquire about public transport and find out that this requires an 80-minute commute at least. She may develop a script (choice pattern, habit) to leave home at 8 o'clock and take the right-hand side ring except on Tuesdays and Thursdays, when she leaves 10 minutes earlier and takes the left-hand side ring. As this tactical choice process is essentially a sequence of daily recurrent operational choices that most often gradually evolve into the execution of a script, most people will not recognize the script as the result of a, predominantly intuitive, tactical choice process. Of course, a subject might also choose the same script immediately once she starts working and stick to it from that moment on, in which case the choice process seems less interrupted and the tactical character is more obvious. This implies that tactical choice behaviour may restrict the choice sets that subjects consider during successive 'operational' choice processes.

Several travel behaviour researchers adopted a bipolar strategic versus operational distinction (e.g. Gärling *et al.* 2002), which may be indicated by lifestyle-and-mobility versus activity-and-travel choices (Salomon 1983) or long-term versus short-term travel decisions (Ettema *et al.* 1997). Such a view implies that tactical choice behaviour as conceived above should be attributed to operational choice behaviour.

2.1.4 Operational choice behaviour

The mental process that precedes and governs concrete everyday actions like departure time postponement, route change underway, or lane switching is called operational choice behaviour here (see also Gärling *et al.* 2002). It may last for minutes or might require just a split-second. To illustrate this, imagine that a commuter has arrived at the tactical choice described above. If there is no apparent reason to deviate from the script she will generally choose her departure time and route accordingly. But when on a particular Friday work-in-progress is announced on the right-hand side ring, she may leave earlier and/or take the left-hand side. When she is already en-route and is informed about the work and/or congestion ahead, she may choose, for instance, to take the next exit and find her way via the regional road system or phone the office and keep on the highway. Moreover, every once in a while she may choose an alternative departure time and/or route, due to constraints imposed by other obligations, by mistake or just by impulse. All these operational choices are from choice sets that are constrained by earlier strategic decisions and tactical choices.
Though some operational choices may be a consequence of deliberation, most are supposed to be intuitive and/or automatic, be it script-based/habitual or impulsive (e.g. Aarts 1996; Gärling *et al.* 1998; Jacobsson 2003). As illustrated above, a strategic decision and successive

tactical choices might to a large extent determine the successive operational choice behaviour. However, a contextual factor may often influence operational choice behaviour as well. Thus when a traveller arrives at a firm 'strategic' conclusion to keep to the speed limit from now on after being fined again, this decision may influence her speeds during a successive trip but another behavioural intention or contextual factor, like the fear of being too late for an interview for a new job, may dominate her 'operational' driving.

Several authors do not distinguish the, often unconscious, cognitive process that immediately precedes and/or accompanies actual behaviour (e.g. Fujii and Gärling 2003). In this book it is assumed that actual human behaviour is always accompanied by a related mental choice behaviour process, the outcome of which may be incompatible with preceding strategic decision making and/or tactical choices.

2.1.5 Connection: the strategic-operational choice hierarchy

As illustrated above, the three functional choice categories in which the choice processes of individuals might be classified constitute a weak hierarchy. One should realize, however, that these categories might better be considered as ranges within a continuum than as isolated discrete processes. Within each of the three categories, chains of domain-specific choice processes can be defined that influence each other in a similar weakly hierarchical manner. Some examples from the travel behaviour domain include the influence of strategic residence and work location decisions on vehicle ownership which in turn influences daily travel mode choice (e.g. Axhausen *et al*. 2004), and the impact of operational pre-trip departure time, destination and route choices on route choice when underway (e.g. Bonsall and Palmer 2004).

2.2 Paradigms of choice-and-behaviour

Concepts and findings that one might encounter when studying the literature of an unfamiliar field may seem to reflect the prevailing opinions in the discipline at hand but on closer inspection might rely on insights that once were dominant but are out of date these days. One way to reduce this risk of misapprehension is to examine the development over time of the scientific paradigm in the disciplines of interest. This also allows for a proper assessment of a current generic, 'supra-disciplinary' paradigm of human choice and behaviour.

2.2.1 Historical development of the study of human choice and behaviour

Annex A explores the development of the scientific views on human choice and behaviour from the Renaissance era up until today. It appears that three periods can be discerned: pre-20^{th} century, early 20^{th} century up to the 1960s, and late 20^{th}/early 21^{st} century. In each of these periods the scientific insights appeared to develop into what in broad outlines may be considered as dominant supra-disciplinary paradigms, the Rationalist's, Behaviorist's and Cognitivist's paradigms of choice and behaviour. These paradigms were compounded according to the principles of Systems Theory; see e.g. Weinberg (1975) for an introduction. This interdisciplinary science offers a methodology to accentuate the understanding of all kinds of processes by analysing these as systems that transform inputs into outputs within an environment. It studies the relationships of systems as a whole as well as the interrelationships of their subsystems and was successfully applied to many fields, including mental processes (e.g. Block 1995) and Management Science; see e.g. the handbook of Hellriegel *et al.* (1999). In Annex A the foundations and compositions of these paradigms are extensively described and sketched in diagrams. Here the Rationalist's and Behaviorist's

paradigms are briefly recapitulated, as one may encounter many relics of them in the modern scientific literature. The Cognitivist's paradigm will be discussed in more detail, as this is currently the most relevant one.

2.2.2 The Rationalist's paradigm

Though the term 'rationalism' might suggest differently, this paradigm stems from a metaphysical tradition and its assumed causal relationships are almost completely based on introspection, thus lack 'objective' empirical validation. It reigned from Descartes (1642) up to the early 20th century and may be characterized by an autonomous, conscious, literally 'reasonable' mind that acts as a 'controller' that controls the 'machine' of the human body to attain happiness. The inputs of the mind consist of facts (mental perceptions of concrete information) and feelings (mental perceptions of affects, passions and desires). One category comes from the senses and arrives in the mind as experienced characteristics, either of objects in the body's environment (creatures or material goods) or of changes in the state of the person's 'own' body. Another category concerns similar experiences retrieved from memory. Choice behaviour is the conscious reasoning that transforms the facts and feelings into expected outcomes associated with different behaviours (courses of action executed by the body) and successively into the choice (volition, will) of one alternative behaviour that offers the highest expected cardinal utility as a consequence of the expected state of wealth. The realized change in a subject's wealth, as expressed in terms of cardinal utility, is considered to result in a proportional change in her happiness. Most prominent in this paradigm is the absence of feedback loops, thus in control-theoretical terms this paradigm is an open-loop controller. The functioning of the subject as a whole requires some apparently unconscious transformations, of sensory perceptions into mental representations and of (mental) choice into behaviour/actions of the body that the paradigm does not explain.

2.2.3 The Behaviorist's paradigm

Metaphysics and introspection as sources of knowledge were rejected by behaviourists (e.g. Watson 1913). This implied that concepts like the mind, consciousness, mind-body interaction, feelings as motives and happiness or cardinal utility as purpose became obsolete research topics in this paradigm. Research of human behaviour should solely rely on observable, empirical, measurable evidence in combination with formal scientific reasoning. Behaviourism became the most important (though not the only) scientific approach in the social and behavioural sciences until the 1960s. Humans, like animals, were essentially considered as 'black boxes' in which choice is a covert process. This black box also contains an innate, organism-specific and context-independent preference order. In one way or another it accounts for the transformation of perceived stimuli into behaviour that results in needs gratification according to the preference order. Choice behaviour is thus conceived as an 'automatic' response of individuals to the goods and opportunities available in the environment rather than as situation-dependent, purposive, deliberate judgment and reasoning. In systems-theoretical terms it is essentially an open-loop controller without feedback, containing a reactive process of behaviour with a measurable output in terms of material assets.

2.2.4 The current Cognitivist's paradigm

Cognitivism adheres to the Behaviorist's principle that research into human behaviour should solely rely on observable, empirical, measurable evidence in combination with formal scientific reasoning. However, inspired by the rapid development of computers and new insights from linguistics this paradigm focuses on rather than rejects the influence of the mind

and it's functioning on behaviour; see e.g. Chomsky (1959). This mental functioning is conceived as the manipulation of mental representations of the 'external reality' with rules or routines, analogous to information processing models. Evidently the mind-body dichotomy, the mind-consciousness identity and the black box model are now inadequate concepts to understand human behaviour. From the last decades of the 20th century up to today cognitivism has dominated the social and behavioural sciences much more than behaviourism ever did before.

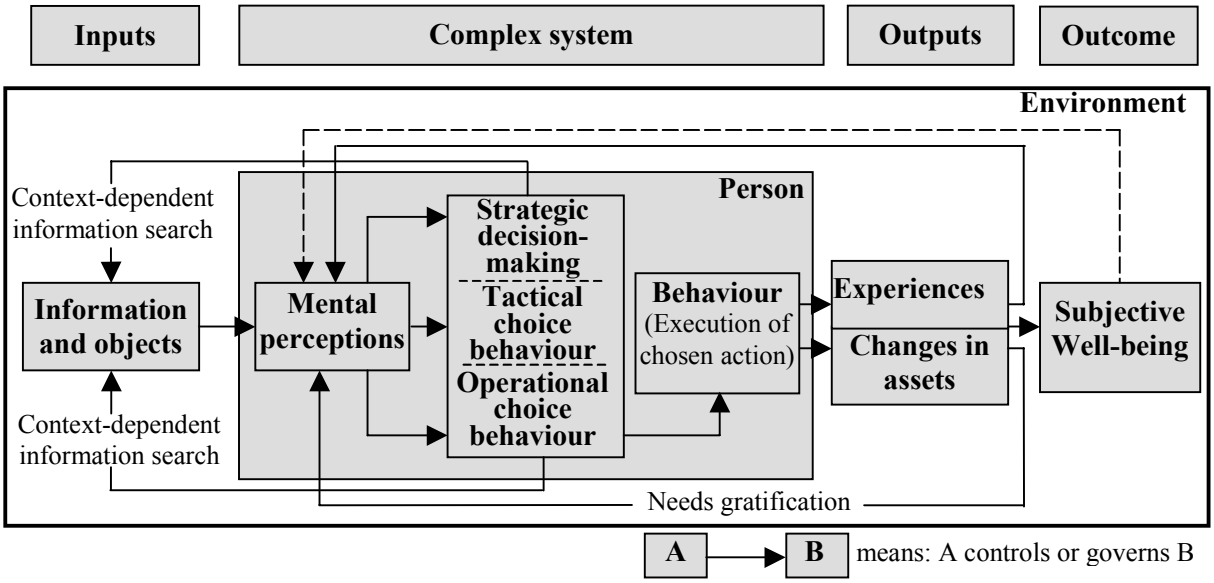

Figure 1: A current systems-theoretical outlook on choice and behaviour

Though within almost all relevant disciplines impressive progress was made in the understanding of the mind and its interrelationships with other human endowments, the knowledge about *how* conscious and unconscious mental, physiological, physical and chemical processes within the body interact is still by far insufficient for a true-to-life description. However, much information is available nowadays about *what* humans do in terms of choice and behaviour. Assuming that mind and body, conscious and unconscious processes are features of one organism that acts as one organized whole, one might discern several functions that arrange for this. One of these is mental perception, that transforms the essentially physical sensory information into mental representations and arranges for the storage in and retrieval from memory. Another is choice behaviour, which takes care of a heterogeneous range of concrete strategic decision making, tactical and operational choice processes that constitute the strategic-operational choice hierarchy. It results in decisions (plans, scripts, behavioural intentions) with respect to concrete behaviour. Choice behaviour transforms the mental representations of actual contextual information (environment and body) and contextually relevant earlier strategic and tactical decisions into operational choices which activate relevant motor functions. These in turn arrange for the concrete behaviour in terms of the execution of the chosen actions. When this is required for the progress of a particular choice process, whether supporting strategic decision making or operational choice behaviour, these functions can initiate an information search. In connection these functions and their interrelationships and sub-functions arrange for the interaction of the human being, conceived as a 'complex system', and the world.

The ultimate purpose or final outcome of this system is the improvement of the person's subjective well-being, which presupposes fitness to survive. However, though one might assume that there is a weak feedback to mental perceptions, this does not directly influence its

social and economic behaviours. Concrete decisions and choices are motivated by more myopic objectives, notably expectations of hedonic experiences. These are 'expected utilities' or 'decision values' attached to changes in assets[11] as well as experiences encountered during the execution of the chosen action. During and following action completion the actual experiences are fed back to the subject by transformation into mental representations that are stored in the memory. The context-dependent search process initiated during concrete decision making and/or choice behaviour arranges for the feedback to the inputs.

In systems-theoretical terms, this view of human behaviour might be conceived as a set of functions of a complex system that together account for the interaction between the organism and its environment. As far as one might speak of 'response' this is a stimulus-organism-response system that accounts for both the organism's needs and the environmental stimuli. From this it seems clear that any human behaviour is determined by the momentary state of the substructures of the organism as well as by its perception of the concurrent environment. This underlines the context dependency of human behaviour as conceived in this paradigm.

2.3 A systems-theoretical analysis of choice behaviour

2.3.1 Human choice behaviour conceived as a system

Following a systems-theoretical approach, strategic decision making and operational choice behaviour can be described as identical transformation systems. The inputs of both consist of information in the form of mental representations, of the subject's objective choice context *and* of her concurrent needs; their outputs are choices. Both systems are reactive with respect to their environment, as the choice *per se* does not change the environment – its subsequent actions may do, of course. To avoid confusion with common interpretations of 'environment' the more generic term context is used here to denote the environment of the choice behaviour system. This encompasses the environment of the subject (the 'state of the world') as well as the 'state of her organism' (concurrent moods, needs, beliefs…) and thus also the character of the choice task (complexity, relevance…). Clearly, an individual's concurrent choice behaviour processes belong to the same choice context.

Thus, both categories of human choice behaviour can be analysed along the same lines. In Systems Theory and its current derivatives like Business Architecture development it is quite common to base the description of a system (e.g. a society, mind, person) on an analysis of both the underlying processes, i.e. *how* does it work, and its functions[12], i.e. *what* does it do; see e.g. Block (1995) or McDavid (1999). This convention is followed below to see whether a generic descriptive theory for human choice can be conceived that fits into the current paradigm of human choice and behaviour as depicted in Figure 1.

2.3.2 The choice behaviour process

The mental process that underlies the function of choice behaviour is reasoning. This is often conceived as consisting of deliberate, conscious and logic-analytic thinking. However, in

[11] Note that this is closer to the neo-classical ordinal utility concept than to Bentham's or Bernoulli's cardinal utility concept. However, it differs in being change-dependent instead of state-dependent, and based on context-dependent rather than context independent preference orders.

[12] In organizations '*functions are idealized conceptual structures that are stable over time and in the face of managerial reorganization whims*' (McDavid 1999), which might be a good metaphor for the functions of human choice behaviour as well.

concordance with its common language definition most behavioural sciences nowadays appear to conceive reasoning[13] as an interplay of intuitive, unconscious and deliberate, conscious processes, as will be demonstrated hereafter.

Dual Process Theory in cognitive psychology

Stanovich and West (2000: 658-659) synthesized twelve theories from cognitive psychology that discern two '*dual*' modes of reasoning into the Dual Process Theory of reasoning. They typified the types of reasoning as follows: '***System 1*** *is characterized as automatic, largely unconscious, and relatively undemanding of computational capacity ... It conjoins properties of automaticity and heuristic processing ... These properties characterize ... interactional intelligence ... The system has as its goal the ability to ... make rapid interactional moves.* ***System 2*** *conjoins the various characteristics that have been viewed as typifying controlled processing ... It encompasses the processes of analytic intelligence ... Construals triggered by System 1 are highly contextualized, personalized and socialized ... System 2's more controlled processes serve to decontextualize and depersonalise problems*'). Later Sloman (2002: 391, 394) proposed another dual-process distinction, of an associative and a rule-based system, that fits into the System1-System 2 dichotomy. He concluded that: '*even when one is attempting to be rule-governed, associative responses encroach on judgment ... associative reasoning predominates when rules that might prove more definitive or certain are inaccessible*'. Kahneman (2002) adopted Stanovich and West's proposal and highlighted the similarity of System 1 processes, which he labelled '*intuition*', and mental perception: both are fast, parallel, automatic, effortless, associative and difficult to control or modify, while System 2 processes are relatively slow, serial, controlled, effortful, rule-governed and flexible. Evans (2003: 454) characterizes these systems as: '*System 1 ... comprises a set of autonomous subsystems that include both innate input modules and domain-specific knowledge ... System 2 ... permits abstract reasoning and hypothetical thinking, but is constrained by working memory capacity*'.

Dijksterhuis (2004) considered that the processing capacity of consciousness is very low relative to that of the entire human system. This led him to the discrimination of '*unconscious thought*' and '*conscious thought*' that might as well be attributed to Systems 1 and 2, respectively. Following the interpretations above System 1 covers both impulsive and habitual choice behaviour as often discerned in transport (e.g. Fujii and Gärling 2003; Jacobsson 2003). Some scientists considered '*intuition*' and '*analysis*' as extremes in a continuum (e.g. Hammond *et al.* 1987) but the '*quasi-rationality*' in between these seems more a mixture of Systems 1 and 2 than a principally different mode.

Feeling and thinking in social psychology

The social psychologist Zajonc (1980: 167) formulated a '*dual-process hypothesis*' of feeling and conscious thinking as two Systems long before Stanovich and West (2000). In his opinion this distinction was equivalent to that between '*hot cognition*' or '*affect*' and '*cold cognition*' that he retraces to the English translation of Wundt (1896) and that returns in social psychology under different guises, for example as the distinction between '*beliefs*' and '*attitudes*' in Attitude Theory (Ajzen and Fishbein 1980). Zajonc (1980:172) demonstrates '*the separation of affect and cognition, the dominance and primacy of affective reactions*' and incidentally posits that '*there seem to be at least two different forms of unconscious processes. One emerges where behaviour…is entirely under the influence of affective factors…Another form of*

[13] Combining definitions from the Shorter Oxford English Dictionary (SOED 2002; see the Glossary) yields the following 'formula': Reasoning = using one's reason (= the mental faculty which is used in adapting thought (= formation and arrangement of ideas in the mind (= cognitive and emotional phenomena and powers as constituting a controlling system)) to some end) in forming conclusions.

unconscious process is implicated in …automated sequences of information processing…And there may be other forms of process in which the separation between affect and cognition prevents the individual from apprehending the potential connection between them'. Though the latter predecessor of the impulsive-habitual distinction (e.g. Fujii and Gärling 2003) seems plausible, Zajonc offers no clues to discern these two unconscious processes in everyday choice behaviour, nor does he explain why the dominance and primacy of affect would not determine habitual behaviour as well.

Lieberman *et al.* (2002) distinguished a '*reflexive*' X-system versus a '*reflective*' C-system as an explanation of human behaviour in relation to the subject's '*enduring*' character and the temporary context in which the behaviour is observed. They proposed that the X-system governed everyday behaviour but that '*the C-system performs three interrelated operations: identifying when problems arise in the X-system, taking control away from the X-system, and remembering situations in which such control was previously required*' (Lieberman *et al.* 2002: 228). They also describe the parallel processing of the X-system in terms of neural pathways in dedicated parts of the brain, and the serial processing of the C-system along other pathways elsewhere.

Conceived in this way and following Evans (2003), one could accommodate both the uncontrolled unconscious processes according to Zajonc as well as those described in System X according to Lieberman *et al*. (2002) into System 1 and the deliberate, controlled, conscious processes as described by Zajonc and accommodated in System C by Lieberman *et al*. into System 2. Consistent with this view, Kalidindi *et al.* (2005) proposed considering Dual Process theory's System 1 and the 'affect system' as largely synonymous.

Dual process concepts from other behavioural sciences

A similar distinction of mental 'Systems' found its way into several other sciences. It is a basic proposition in humanistic psychology that '*in the healthy human being, rationality and impulse are synergic, and strongly tend to come to similar conclusions rather than contrasting ones. The nonrational is not necessarily irrational or antirational; it is more often prorational*' (Maslow 1954: 3). In management science Mintzberg (1989) reported the role of intuition in the decision making of managers but advocated the incorporation of analytic-conscious reasoning in their decision process.

Damasio's (1994) Somatic-Marker Theory from cognitive neuroscience considers feelings as '*the mental representation of the physiological changes that characterize emotions…if emotions provide an immediate response to certain challenges and opportunities faced by an organism, the feeling of these emotions provide it with a mental alert*' (Damasio 2001: 781). Bechara *et al.* (1997: 1294) '*suggest that the sensory representation of a situation that requires a decision leads to two largely parallel but interacting chains of events*', one of which appears to be unconscious and based on '*dispositional knowledge related to the individual's previous emotional experience of similar situations*' while the other draws on the overt recall of pertinent facts and '*the application of reasoning*[14] *strategies to facts and options*'. This seems an explanation that perfectly fits into the same Dual Process picture rather than an alternative for it; see Kalidindi *et al.* (2005) for a similar opinion.

[14] These authors apparently conceived reasoning as a deliberate-conscious System 2 process.

Efficacy of System 1 and System 2 processes

Very few studies compared the efficacy of the application of the System 1-type reasoning with that of the System 2-type by the same person. Hammond *et al.* (1987) did so for expert highway engineers and found that in several tasks analytical cognition was often outperformed by intuitive (and/or quasi-rational, see above) cognition in the same person.

From his extensive observation of how managers spend their time, Mintzberg (1989) reported essentially the same decisive role of unconsciousness in their decision making. He assumed that managers had developed implicit, holistic models of judgment and choice unconsciously over time. One might gather from his observations that this mental process, that he called intuition, will estimate rather than exactly calculate outcomes, but is less prone to make dramatic mistakes than a deliberate-analytical process.

From experiments concerning the choice between multi-attribute apartments Dijksterhuis (2004) found that the decisions of subjects who had to decide immediately after examination of the attributes and alternatives, as well as those of subjects who were urged to think consciously over the decision for three minutes after examination, were normatively inferior to the decisions of subjects who were charged with another task for three minutes after examination, to 'force them' into unconscious thought. Moreover, '*conscious thinkers reported that their decisions were often based on a few specific relevant attributes, whereas unconscious thinkers reported forming a more global judgment based on much more information*' (Dijksterhuis 2004: 596).

Recently, Dijksterhuis *et al*. (2007) demonstrated the '*deliberation-without-attention*' effect in two real-life contexts. Measured in post-choice satisfaction terms, '*unconscious thinkers*' performed better in choices of complex products (like an apartment, furniture) while '*conscious thinkers*' performed better in the choice from simple products (shampoo, CD). In the Supporting Online Material of the *Science* article the considered products are listed on a complex-simple product scale This listing suggests a decreasing affective salience and might fit into the strategic-operational choice hierarchy proposed above.

Use of System 1 and System 2 processes

The inclination of people to use '*experiential*' (i.e. System 1-type) reasoning, even if the appropriateness of '*rational*' (System 2-type) reasoning should be obvious, was demonstrated convincingly by Schul and Mayo (2003). Their findings are consistent with the opinion of Wundt (1896) as cited by Zajonc (1980:152, 172): '*the clear apperception of ideas in acts of cognition and recognition is always preceded by feelings*' who successively demonstrated '*the dominance and primacy of affective reactions*'. This also agrees globally with the observations of Mintzberg (1989) who advocates that managers should cherish their intuitive-holistic abilities but should complement it more often with (the results of) deliberate-analytic judgments. Just like Zajonc (1980), Bechara *et al.* (1997: 1293) hypothesised the primacy of System 1, considering that '*overt reasoning is preceded by a nonconscious biasing step*'. They and several other neuroscientists consider System 1 processes as the default mode of reasoning that primarily determines everyday behaviour (e.g. Lieberman *et al.* 2002). The general inclination towards System 1 reasoning is also reflected in the view of Chater *et al.* (2003: 65; emphasis added) on choice behaviour: '*Fast and frugal algorithms are one end of a continuum of options from which the decision maker may choose – **given sufficient time**, **cognitive resources and motivation**, participants may choose strategies which integrate the information that they have been given in more elaborate ways*'.

Significance of System 1 and System 2 processes

From the experiments of Dijksterhuis *et al*. (2007) one might infer that System 1 often either controls or overrules System 2 processes or makes them superfluous[15]. On the other hand, Dijksterhuis (2004: 587) himself remarks: '*With decisions ... conscious interventions can be highly effective. Faced with the opportunity to buy an apartment with many wildly positive attributes and a single negative critical one (it is much too expensive), consciousness will be good at quickly deciding against it*'. This can be conceived as a perfect illustration of the role of System 2 as described by Kahneman (2002: 451) who suggests: '*One of the functions of System 2 is to monitor the quality of both mental operations and overt behaviour ... The monitoring is normally quite lax, and allows many intuitive judgments to be expressed, including some that are erroneous*'. His suggestion is close to the assumed role of reasoning in the final or post-decisional phases of, for example, Cognitive Dissonance theory (Festinger 1957), Dominance Search theory (Montgomery 1989) and Differentiation and Consolidation theory (Svenson 1992), though the reasoning as conceived there often seems to be aimed at corroborating an earlier, maybe intuitively, chosen alternative at the expense of testing it.

As far as System 2 has a control function, it is a relatively weak one. This was, for example, demonstrated by the mediocre performance of university students to three questions regarding the rational assessments of objective, non-affective facts (Stanovich and West 1999). Even after supplying arguments for both normatively correct and wrong answers, the percentage 'correct' answers in these groups increased by only approximately 15%, from 34-58% in the first round to 48-67% in the second one. In the light of the relatively high intelligence of the survey panel and the relatively simple judgment tasks in the experiments one might infer that the alleged monitoring by System 2 was very lax here, indeed. Overall, Beach (1990: 126) might be right: '*We suspect that, as a general rule, if intuition conflicts with analysis, analysis seldom wins*'.

Leads for a descriptive choice behaviour theory

There is a collective view among behavioural scientists that two modes of reasoning exist, of which System 1 appears to be both unconscious and often dominant. As unconscious thought is by definition covert and not controlled by consciousness, it seems impossible to make any statement about whether or not its operations are similar to the normative-rational rules that the System 2 cognitive processes are considered to follow. The Dual Process theory is thus a far cry from the classical normative-rational concepts of reasoning as presumed in Utilty Theory. These latter '*concepts of logic, probability, decision theory and the like do not appear to mesh naturally with our everyday reasoning strategies*' (Chater *et al.* 2003: 63).

Human choice behaviour appears to be, therefore, most often predominantly a covert process. This relative covertness may explain the array of process theories about choice behaviour (see Chapter 5) that differ in the assumed sequence of function completion. As the concepts conceived to describe them are currently not physically measurable, it is not feasible to develop a concept that rightfully claims to provide 'the' isomorphic[16] descriptive theory of individual choice behaviour. Doherty and Brehmer (1997: 546) even claim that all scientific

[15] These and similar findings made Dijksterhuis (2007) to doubt the advantages of conscious attention and thinking in the development of important decisions. Note, however, that Dijksterhuis and colleagues considered conscious thinking as 'operational' processing of information into choices, without, for example, paper and pencil at hand to overcome the limitations of working memory. See Franklin's (1772) famous letter about how to make a sound rational choice among affectively salient alternatives.

[16] I.e. equal in form, and in the nature and product of their operations (SOED 2002).

models and thus '*all models of judgment are paramorphic*[17] *representations*' anyhow. The available information about the mental processes that support choice behaviour thus offers no leads for a generically applicable behavioural-descriptive choice process theory. This may still hold when decision neuroscience has localized the neural activities that constitute choice behaviour (Shiv *et al.* 2005). Though this will definitely boost our understanding of how these mental operations work, an undisputable isomorphic theory would require localization of the concurrent changes in the content of the information in the different circuits as well. The next section examines whether *what* the mind does, without simulating *how* it does it, might nevertheless yield an acceptable functional-descriptive theory of choice behaviour.

2.3.3 The choice behaviour function

Functional decomposition

An analytical technique from Systems Theory that has proven its worth in several applications, for example as a means to identify the crucial role of information for the functioning of organisations, is functional decomposition (e.g. McDavid 1999). This means that the overall-function of a system is broken down into a complete set of non-redundant operations or functions that together do neither more nor less than performing the function of the system as a whole (posited here). The overall-function of choice behaviour is defined above as to choose in each choice situation one possible course of action from a set of alternatives that, in that particular context, meets certain of the subject's concurrent needs. Limited functional decomposition of this concept yielded four mental functions of choice behaviour:

i. **Framing** of the perceived choice context. Elements of the choice frame are: some reference state; alternatives or prospects (i.e. mental representations of possible courses of action and their expected outcomes in terms of probabilities and attributes); a preference order related to the subject's concurrent needs, desires, goals and beliefs; and an aspiration level for their gratification.

ii. **Judgment**, consisting of: assessment, if it results in quantitative knowledge of the sizes or levels of the expected outcomes (attributes and probabilities); and valuation of these probabilities and attribute levels to arrive at psychological values on some affective and/or monetary scale. One should, however, note that subjects might miss the assessment and employ a System 1 process for direct valuation of the framed alternatives and/or attributes.

iii. **Evaluation-and-choice**, equivalent to a decision rule as it is called by most decision theorists. The evaluation of alternatives implies the assessment of the relevant outcomes of the alternatives, like their overall utilities and/or a rating of their preference order, such that they can be compared with those of other alternatives and tested against the aspiration level. Choice accounts for the subsequent selection of the potential course of action that meets the aspiration level.

iv. **Choice behaviour strategy**, a coordinating function required because of the decomposition of the overall function of choice behaviour into the three preceding mental functions. In its conscious sense, this function is equivalent to the '*decision strategy*' of Payne *et al.* (1993), which is about '*deciding how to decide*'.

[17] Distinct in form, analogous in the nature and product of their operations.

Interrelationships of the decomposed functions

Starting from a phenomenological-psychological perspective, Karlsson (1989: 61, his emphasis) came to a similar mapping of the mental processes that underlie choice behaviour on functional phases[18]: '*the processes are "closer" to the subject's experiences in that they describe the cognitive acts or experiences of the subjects ... whereas the phases are more abstract in that they describe the **function** (meaning) of these processes seen in the light of the whole decision-making procedure*'. It is tempting to consider also Karlsson's four functions (i) to (iv) as phases of the choice process, but one should not expect that subjects follow these sequentially in all contexts. Several theories describe mutually divergent sequences of partial completion of these functions (e.g. Montgomery 1989; Beach 1990; Payne *et al.* 1996). These can be conceived as particular expressions of the '*constructed preference*' approach to choice (Slovic 1995; Payne *et al.* 1999). Moreover, referring to the Cognitivist's paradigm (Figure 1) one should take into account that at any time during the choice process an active (not necessarily conscious), context-dependent information search may be initiated resulting in adjustment of the initial input or mental representations. Accordingly, the choice behaviour strategy could be conceived as an observation from the rear rather than as the preparatory planning of a sequence of functions.

Functional description of human choice behaviour

Figure 2 summarizes the functions and relationships discussed above. It depicts choice behaviour as reactive with respect to the choice context, as the choice *per se* does not change the environment of the subject – the subject's subsequent actions may do, of course. Because of the many interactions between the functions it is conceived as a complex system, just as the complex system depicted in Figure 1, in which it is embedded.

The diagram offers a generic functional description of human choice behaviour that covers any set of assumptions that is able to put a particular choice behaviour into operation. As such it can be used to test the completeness and internal consistency of operational choice theories but definitely not their descriptive-behavioural plausibility. The reader might e.g. observe that the classical normative-rational interpretation of Utility Theory (under the postulates of an omniscient subject with perfect perception, unlimited processing power and so forth) can serve as a concrete implementation of this choice behaviour concept, even though its descriptive-behavioural credibility is not particularly convincing.

2.4 Summary: a Meta Theory of Choice Behaviour

From a semantic interpretation of some key notions it appeared that choice behaviour, including its subset decision making, can be interpreted as strictly mental processes that serve to guide a subject's behaviour in the interest of her well-being and fitness to survive. Concrete choice processes can be arranged in a continuum that constitutes a weak hierarchical order. At one side of the continuum are processes that can be classified as strategic decision making. These influence the other, tactical and operational, choice behaviour processes. This influence may have the character of explicit decisions, strategic plans, behavioural intentions, etc.

[18] Karlsson discerned: (a) mapping out of information; (b) preparatory; (c) execution of choice, as well as rejection of non-chosen alternatives; (d) strengthening of the choice. Roughly speaking (a) can be compared to framing combined with the assessment of expected probabilities and attribute sizes; (b) with the valuation of attributes and probabilities and the evaluation of alternatives; and (c) with choice proper. In the choice behaviour process as conceived in this book Karlsson's phase (d) is covered by iterative execution of the functions (i), (ii) and/or (iii) described above.

Operational choice behaviour governs the concrete human actions that constitute the interrelationship of each individual with her environment. In between are tactical choice processes that lead to scripts, habits or default alternatives to put a more strategic decision into operation or to cope with a structural change in the choice context. These interrelationships are illustrated in a diagram (Figure 1 on page 13) that depicts the current paradigm of choice and behaviour. Together with many other processes, choice behaviour and concrete actions are functions of the human organism, that is conceived to operate as one organized whole and might be characterized as a complex system.

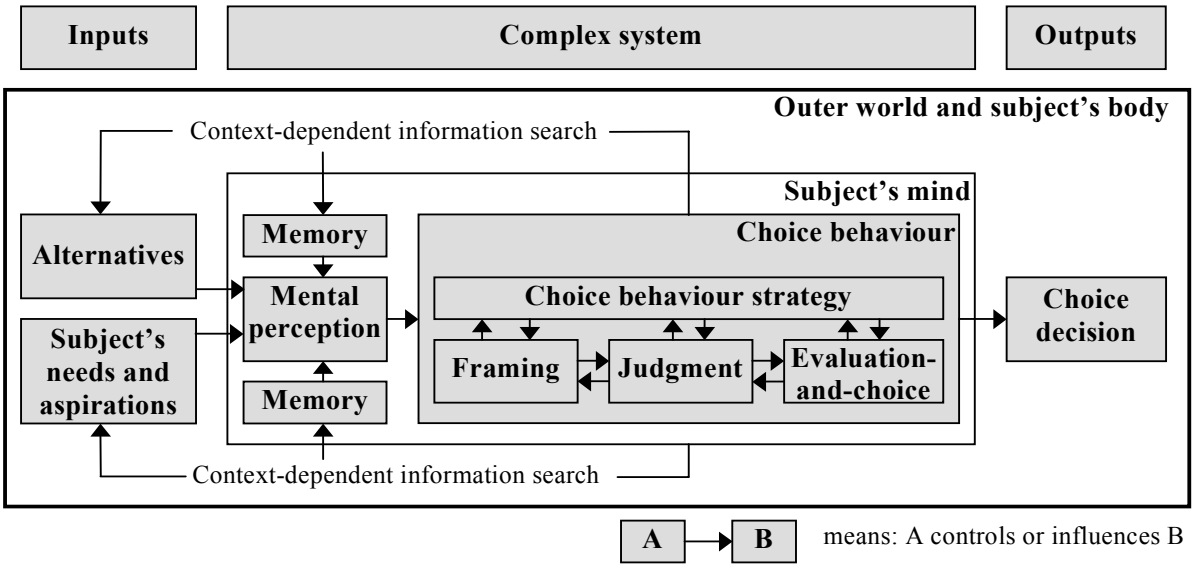

Figure 2: A functional model of human choice behaviour

Strategic decision making, tactical and operational choice behaviour can be conceived as equal complex systems on their own, embedded in the human organism. In systems-theoretical terms they have the same function and rely on the same underlying processes. The mental process that supports this individual choice behaviour is reasoning. There is much empirical evidence that this is predominantly unconscious and covert, though deliberate conscious reasoning might quite often account for its final phase. Thus far there is no decisive evidence to favour one of the many different process descriptions of human choice behaviour. Currently, therefore, the choice behaviour process offers no clues for a generic descriptive process theory of choice behaviour.

The choice behaviour function can be divided into a coordinating choice behaviour strategy function, and framing, judgment and evaluation-and-choice functions. Limited further decomposition of these functions yields a generic functional-descriptive concept that covers any set of assumptions able to put the overall choice behaviour function into operation (Figure 2). One might, for example, observe that the classical normative-rational interpretation of Utility Theory (under the postulates of an omniscient subject with perfect perception, unlimited processing power and so forth) complies with this concept of choice behaviour, though its descriptive-behavioural credibility is not particularly convincing. This functional concept is firmly embedded in the Cognitivist's paradigm of choice-and-behaviour (Figure 1). It depicts choice behaviour as reactive with respect to its context, as the choice *per se* does not change the environment of the subject – her subsequent actions may well do so, of course.

The main findings in this chapter are synthesized here into a Meta Theory of Choice Behaviour. It assumes that human choice behaviour provides sustainable guidance for the

subject's actions in her environment, adapted to her needs and in the interests of her fitness to survive and happiness. In pursuit of that purpose, the mental processes of reasoning transform mental perceptions into a choice between feasible alternative courses of action. The individual's reasoning is assumed to operate largely unconsciously and might be highly iterative, adaptive and contingent, and interpersonal differences may abound. The Meta Theory assumes that the overall function of human choice behaviour is the same, however different the processes that carry them out may be, and that is to choose in each choice situation one possible course of action from a set of alternatives that, in that particular context, meets certain of the subject's concurrent needs. This function can be described as a set of four functions and their interactions. Any theory or model in applied sciences such as economics and transport that aims to understand and predict the behaviour of people has to assume specifications of the operations of this function in the considered contexts but may do so without even trying to specify the mental reasoning processes that perform them. The explicit assumptions of each theory and model can be complemented with implicit assumptions and rearranged such that they specify the four functions of the Meta Theory of Choice Behaviour and their interactions.

The meta character of the Meta Theory of Choice Behaviour allows the completeness and internal consistency of any choice theory to be tested, but not their descriptive-behavioural plausibility. As such it will be used in Chapter 3 to analyse the operational versions of Utility Theory and Prospect Theory. In Chapter 4 the Meta Theory will be used as a framework to examine the descriptive ability of assumptions of Utility Theory, Prospect Theory and other descriptive theories against observations of actual choices as reported from behavioural sciences.

Chapter 3
Assumptions from Economics about Human Choice Behaviour

The value of an item must not be based on its price, but rather on the utility it yields. The price of the item is dependent only on the thing itself and is equal for everyone; the utility, however, is dependent on the particular circumstances of the person making the estimate.

Daniel Bernoulli (1738:24, in Sommer's translation from Latin)

Context: Bernoulli introduced here the utility concept and distinguished it from the monetary value of assets. Apparently he intuitively related the psychological value of wealth to the just noticeable difference concept. It would be more than a century before that principle was established with the founding of psychophysics.

3.1 Introduction

Obviously the choice behaviour of individuals is an important topic in Economics, '*the branch of knowledge that deals with the production and distribution of wealth*' (SOED 2002). Within its branch microeconomics, the mainstream paradigm is neo-classical economics that covers several theories about the behaviour of consumers and their households. These describe each individual's behaviour in the labour and consumer markets in terms of a 'rational' maximization of 'ordinal utilities' under budget constraints; see also Annex A. In this book, these theories are discussed and assembled under the cover of a general '*Utility Theory*' (UT). By far the most important alternative paradigm currently is behavioural economics. It explains many deviations ('biases') of observed actual choices from the corresponding choices as predicted by neoclassical economics. As the backbone of behavioural economics is '*Prospect Theory*' (PT), this is the heading under which this alternative paradigm is discussed below.

This chapter aims to inventory two comparable lists of assumptions about human choice behaviour, according to UT and PT, respectively, which are both feasible implementations of the functional Meta Theory of Choice Behaviour as developed in the previous chapter. Each inventory starts with a functional positioning of these economic theories in the corresponding,

broader choice models from decision theory and management science. Methodologically, the inventories are sourced from a series of qualitative secondary analyses[19] of a limited number of handbooks, anthologies and seminal articles. The secondary analyses concern the assignment of the assumptions to the different functions of the Meta Theory, where required after limited rearrangements and additions without affecting the assumptions' original functions. They refrain from judgments about the descriptive abilities of the different assumptions for real-life choice behaviour.

The next sections successively list the basic assumptions of UT and PT and adds assumptions that enable a subject to put all the functions of the Meta Theory of Choice Behaviour into operation by following either of these sets of assumptions. The chapter concludes with a summary and comparison of the assumptions of both UT and PT (Table 1 on page 34). In Chapter 4 these will be compared with the findings on observed human choices.

3.2 Utility Theory

3.2.1 The function of UT in choice behaviour

The different versions of UT are all rational choice theories, i.e. they presume that conscious decisions determine human behaviour and that these decisions follow some general rules or postulates. They are apt to flesh out major elements of the generic Rational Decision-Making model from decision theory and management science. A typical materialization of this model is the sequential seven-step process[20] used in the contemporary management textbook by Hellriegel *et al.* (1999): '*a. Define and diagnose the problem; b. Set goals; c. Search for alternative solutions; d. Compare and evaluate them; e. Choose among them; f. Implement the solution selected; g. Follow up and control*'. UT accounts for phases d. and e., mostly by taking the knowledge of a limited number of alternatives for granted.

The Rational Decision-Making model was initially based on the '*unbounded rationality*' concept that assumes an omniscient[21] decision maker, who knows his goals and all alternatives and their probabilities, has an unbounded computational power and a stable preference-order over all possible outcomes of her decisions; see several critiques, e.g. by Simon (1955) and Gigerenzer and Todd (1999). Nowadays '*Optimisation under constraints*' is the dominant concept behind this model: the assumption of omniscience of the decision maker is dropped, her future is uncertain, her time is precious and her limited knowledge with respect to the alternatives and the characters, the probabilities and values of their outcomes has to be supplemented by a deliberate search for information. Search Theory applies the assumptions of UT on this pre-decisional search process (step c.): as soon as the costs of time, computation, information acquisition and other resources outweigh the benefits the search should be stopped (Stigler 1961). As Gigerenzer and Todd (1999) point out, a normative-

[19] 'Secondary analysis is the re-analysis of data for the purpose of … answering new questions with old data' (Glass 1976).

[20] Also other versions of this model are proposed, mostly in terms of splitting up or combining one or more steps. Originally a sequential completion of its steps was presumed but nowadays it is conceived that parts of the process may also be passed through in several iterations.

[21] Of course, omniscience does not exist. Thus, in management science only the procedural rationality of this model is followed. Normative calculations require drastic simplifying assumptions about real-life decision settings and rules to avoid intolerable computational burdens, thus generally an optimal decision for a simplified world will be found: '*In-principle unattainable optimization is sacrificed for in-practice, attainable satisfaction*' (Simon 1978: 351).

rational approach of this principle would require much more knowledge and computation than the unbounded rationality concept. Thus, here too, many drastic simplifying assumptions of the real-world environment are required to make the application of UT as an implementation of Search Theory feasible. The transport literature, amongst others, offers some illustrations of the extent of these simplifying assumptions required to arrive at realistic assessments of the choice sets that are considered by subjects, including satisficing rather than maximizing choice criteria, though mostly without providing empirical observations supporting these assumptions (e.g. Richardson 1982).

Three different categories of descriptive models for choice behaviour in conformity with UT are nowadays discerned, depending on the character of the choice task:

i. **Neo-classical Utility Theory**, for the choice behaviour of individuals and households on the consumer and labour markets;

ii. **Subjective Expected Utility Theory**, for the choice behaviour of individuals and households from alternatives with uncertain outcomes; and

iii. **Random Utility Maximization Theory**, for the choice behaviour of individuals and households from choice sets composed of discrete alternatives.

All these versions presume that each individual follows one deterministic, static choice behaviour strategy. Interpersonal differences in concrete choices may be caused by differences in idiosyncratic preferences or taste templates. We will now look at the assumptions on which these versions of UT are based, after which the section is concluded with a comparison.

3.2.2 Neo-classical Utility Theory

This theory is also called neoclassical consumer theory, the standard model (or rational model) of economics (McFadden 2001b) and Neoclassical Economic Theory (Ben-Akiva and Bierlaire 1999). It is elaborated for continuous alternatives, e.g. choices with respect to the quantity of a particular good (in the economic sense, i.e. including services etc.) to be purchased within budget constraints. Neo-classical Utility Theory describes a deterministic choice process and assumes that the idiosyncratic preferences of consumers are stable over time. In most practical applications interpersonal differences are accounted for by segmentation of the public in homogeneous groups with similar preferences. Actual microeconomic textbooks posit that principally different demand patterns of individuals will then be 'outnumbered' by the 'normal' demand pattern of the majority of consumers, using this as the rationale that allows them to refrain from explicitly coping with stochastic differences in consumer behaviour; see e.g. Katz and Rosen (1998: 68): '*the fact that some individuals' behaviour is inconsistent need not prevent us from making good predictions about the group*'.

In Neo-classical Utility Theory's contemporary version, Preferences ('*What the individual wants to do*') are conceived as the first step in an individual's decision making, followed by the assessment of his Budget Constraint ('*what the individual can do*'). Both are evaluated in the last step, the Decision ('*Taking constraints into account, individual attempts to reach the highest feasible level of satisfaction*') (Katz and Rosen 1998: 23). This implies that the economist does not need knowledge about the cardinal utility that consumers may or may not attach to the acquisition or selling of goods. Just an ordinal utility in terms of their preference order of relevant alternatives will do. A central notion is diminishing marginal utility, say the last item

of a good that is consumed within a subject's budget (Gossen 1854). This is reflected by the assumed convex-declining consumer demand for a particular good as a function of its price.

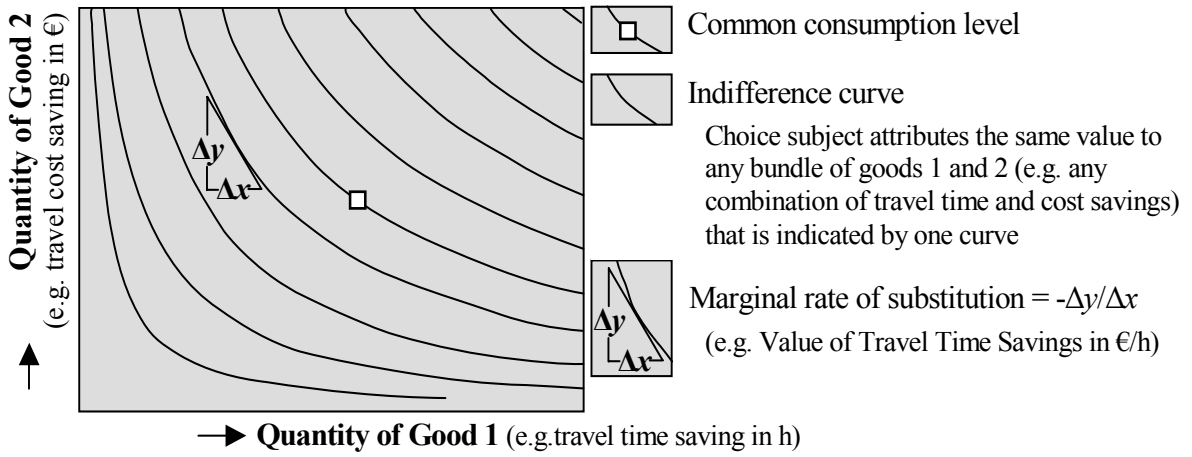

Figure 3: Example of an indifference map

The convex, downward sloping form of the indifference curves that depict the combinations of quantities of two different goods that are equally preferred by a consumer also reflect this diminishing marginal utility or marginal rate of substitution. An example of such a set of indifference curves is depicted in Figure 3.

According to Neo-classical Utility Theory individuals are considered to strive after the highest possible satisfaction of their needs ordered as preferences, within their budget constraints. Further assumptions are: temporally stable idiosyncratic preferences that are context-independent (i.e. independent of choice set composition, the way the alternatives are described, and other environmental influences, as well as independent of internal states, fleeting moods and emotions etc. of the subject) and complete for all imaginable goods; non-satiation of consumers: more is better, and the 'diminishing marginal rate of substitution' of goods as illustrated in Figure 3 (or its mathematical equivalent of convex consumer preferences). The 'utility' of attributes does not depend on size or sign of expected choice-induced changes with respect to some reference state but solely on the expected state of the subject's corresponding assets after the choice. The assessment of the preference order in a choice situation is done by application of rational calculations. As the choice criterion is to choose the alternative that is highest in that preference order, attribute levels of the alternatives are assumed to be commensurable, i.e. quantifiable by individuals in a common medium that enables them to be compounded in some compensatory manner. In doing so the subject is supposed to apply a subjective attribute decision weight to take the relative importance of different attributes into account. These assumptions imply that the choice behaviour of individuals in similar contexts is consistent over time; their choices are transitive (i.e. if A is preferred to B and B to C, A is always preferred to C) and independent of irrelevant attributes[22]. See e.g. the handbook of Katz and Rosen (1998) for further details on the assumptions and consequences listed above.

[22] The definition of 'Independence of irrelevant attributes' adopted here is that the aggregated appraisal of an alternative's attribute levels does not change when irrelevant attributes are added or excluded. Note the difference with the 'Independence of Irrelevant Alternatives (IIA)' principle of Random Utility Maximization models in which the blue/red color of the bus, for example, is treated as an alternative rather than an irrelevant attribute.

One might note that assumptions like completeness and transitivity of consumers' preferences are mathematically dispensable in an explanation of market equilibrium (e.g. Mas-Colell 1974), but are a straightforward consequence of the assumption of a context-independent, stable idiosyncratic preference order and as such are commonly taken for granted in elicitation or parameter estimation of UT-based models from observed choices.

3.2.3 Subjective Expected Utility Theory

According to Expected Utility Theory, as originally developed by Bernoulli (1738), the utility of each possible outcome of a probabilistic[23] alternative should be multiplied with the probability of its occurrence before combining them compensatory into one weighed utility of the alternative; see Annex A. Though Expected Utility Theory deals with probabilistic outcomes of alternatives, the choice process is, just as in Neo-classical Utility Theory, conceived as strictly deterministic. Von Neumann and Morgenstern (1944) axiomized and elaborated this theory further and extended it into Game Theory, which describes how decision makers should maximize their expected utility by taking the potential reactions of other decision makers into account. This is the dominant theory for rational decision making within oligopolies of suppliers; see e.g. Katz and Rosen (1998).

Savage (1954) extended Expected Utility Theory further into a general Theory of Decision making under Uncertainty which also became known as Subjective Expected Utility Theory[24] He considered that a subject has to make a choice from an 'action set' that contains several alternatives in terms of courses of action. She can choose only one of the alternatives. Each alternative will have consequences (outcomes) for her in some future period. In that future, several 'states of the world' are feasible, of which only one will emerge. The consequences depend on the state of the world that will occur. The subject has no influence on which state will appear, but she is assumed to have beliefs about the probabilities of emergence of each of these states. The best she can do is to compare the prospects of each available alternative, i.e. the combination of all possible consequences and corresponding probabilities of each individual alternative. Savage posited that the subject values the consequences affectively in terms of a numerical utility measure and that her beliefs about a numerical (subjective) probability measure for each state-of-the-world are independent from the utility measure of the outcomes. Once the subject has assessed the numerical probabilities and consequences the applied algorithms are identical to Expected Utility Theory: the subject is assumed to calculate the expected utility of each alternative by adding up the product of the utility of each outcome and its subjectively expected probability. This allows for the evaluation of the different courses of actions with uncertain outcomes by the assessment of their expected utility, followed by the selection of the alternative that yields the highest expected utility.

The theory does not allow any change in the character (concave or convex) of the function that describes the utility of positive and negative consequences or outcomes when modelling the choice behaviour. Apart from that, Expected Utility Theory follows the Neo-classical Utility Theory assumptions like completeness, non-satiation and transitivity. An assessment of expected utilities by the linear-additive treatment of utilities of outcomes and probabilities of states-of-the-world shows that the preference relation over expected utilities adheres to the same assumptions.

[23] i.e. with explicitly given probabilities of all its possible outcomes.
[24] However, most often the term Expected Utility Theory is used for the choice between probabilistic as well as uncertain prospects, see e.g. Machina (1987).

In most situations where an individual has to choose between alternatives with uncertain outcomes a majority of the subjects are risk averse, in concordance with Bernoulli's utility concept and the corresponding concave utility function; see Annex A. However, most often a distinct minority appears to be risk seeking (characterized by a convex utility function) while some other people may behave risk neutrally. Mainstream economics attributes these differences to idiosyncratic interpersonal differences in risk appraisal; see e.g. Katz and Rosen (1998). This cannot explain the observation that many individuals are buying lottery tickets (risk seeking) as well as insurances (risk avoiding). To explain this behaviour, Friedman and Savage (1948) proposed a utility function that is concave at very low and high wealth and convex in between. This definitely explains several particular kinds of insurances and lotteries that the same individual may acquire. However, this would imply that such an individual should accept several probabilistic propositions of which it is hard to believe that they should do, as was brightly explained by Markowitz (1952). He explained the risk seeking in lotteries and risk avoidance in insurance acquisitions by differences in the valuation of gains and losses. Even then this could not explain why many individuals prefer the prospect of a certain gain to a prospect with an overall expected larger gain if that prospect contains a small probability to gain nothing, while the same individuals choose the prospect with the highest expected utility from alternatives with about equal probabilities for gains and winning nothing (Allais 1953).

Later on a host of other violations of Expected Utility Theory were found; see e.g. Machina (1987) for an overview. Though Savage (1954) was aware of several of these, including the '*Allais paradox*', and of Markowitz's article, he considered that the application of his method by individuals would improve their choice behaviour. His Subjective Expected Utility concept was thus meant as a normative-prescriptive theory rather than as a descriptive-behavioural one. In the latter sense it is, however, currently applied in economics and other fields, commonly with risk seeking or risk avoidance solely explained as stable, idiosyncratic preferences of individuals.

3.2.4 Random Utility Maximization Theory

Random Utility Maximization Theory constitutes a further elaboration of the Neo-classical Utility Theory by adding stochastic approximations to the description of real-life choice behaviour. Marschak (1960) proposed Random Utility Maximization Theory for discrete choices, and McFadden (1974) introduced it to travel behaviour in a transport mode choice context. In an overview of the development of this theory, to which he himself might have made the most important contributions, he defines these choices as follows: '*I consider discrete choice from feasible sets containing finite numbers of mutually exclusive and exhaustive alternatives that are characterized by their observed attributes*' (McFadden 2001b: 357).

Random Utility Maximization models determine for each alternative the probability that it is chosen by an individual, as a function of the utility derived from its attributes, including unobserved ones. This utility is equal to the sum of a deterministic part, which can be determined from a compensatory evaluation of the alternative's known attributes, and a stochastic part capturing the uncertainty experienced by the analyst. However, just like in Neo-classical Utility Theory and Expected Utility Theory, the decision rule that individuals are assumed to follow is deterministic: '*Random utility models assume, as does the economic consumer theory, that the decision maker has a perfect discrimination capability. However, the analyst is assumed to have incomplete information and, therefore, uncertainty must be taken into account*' (Ben-Akiva and Bierlaire 1999: 7). The individual subjects are thus considered to follow the same assumptions as Neo-classical Utility Theory and Expected Utility Theory

with respect to non-satiation, transitivity, temporally stable and context-independent preference orders and so on. Possible probabilistic elements in the decision rules employed by the subject as assumed by Luce (1959) are not deliberately accounted for. Random Utility Maximization Theory thus only relaxes the UT assumption of a temporally stable idiosyncratic preference order by accepting interpersonal random variations around a mean.

The incomplete information of the analyst thus concerns interpersonal differences in preferences. McFadden (2001b: 356-357) states that Random Utility Maximization models take into consideration '*unobserved heterogeneity in tastes, experience, and information on the attributes of alternatives*', in such a way that '*mild regulatory conditions allow us to represent preferences by a continuous real-valued utility function of the characteristics of the consumer, and consumption levels and attributes of goods*'. He also mentions an important restriction to the applicability of Random Utility Maximization Theory: '*I will assume that the unobserved characteristics vary continuously with the observed characteristics …this is an assumption that unobserved characteristics are a continuous random field indexed by the observed characteristics*'.

Random Utility Maximization Theory is nowadays the dominant modelling approach for discrete choices, in economics as well as in many applied sciences. Different assumptions about the random and the mean term have produced many different Random Utility Maximization models that are able to assess human choice behaviour more or less accurately (e.g. Ben-Akiva and Lerman 1985; Ben-Akiva and Bierlaire 1999; Train 2003). In many applications Random Utility Maximization models interpret interpersonal and intrapersonal variations in preferences in the same manner as random variations around a mean, but present-day implementations like Mixed Logit can cope with different sources of stochastic interpersonal variations in preference orders; see e.g. Hensher and Greene (2003).

3.2.5 Covering assumptions of UT

Obviously all the assumptions of Neo-classical Utility Theory are shared by the other versions of UT. Expected Utility Theory extends it with principles that can cope with risk and uncertainty, while Random Utility Maximization Theory slightly relaxes the principle of idiosyncratic context-independent preferences. The assumptions listed above were supplemented with some obvious assumptions concerning applicability as a descriptive-behavioural theory, to allow for comparison with other behavioural theories. All these assumptions of UT are assembled in the left side of Table 1 (page 34). They appear to cover all elements of the Meta Theory of Choice Behaviour.

3.3 Prospect Theory

3.3.1 The function of Prospect Theory in choice behaviour

PT was deliberately developed as a descriptive-behavioural theory, i.e. it tries to describe how an individual makes choices in real life rather than how they should do it to optimise some 'objective' interests. As such it may be employed to account for several steps in a procedurally rational interpretation of the Rational Decision-Making model, but it fits better in the descriptive Bounded Rational model. This aims at a closer similarity of described and observed choices in which the decision maker experiences '*uncertainty about relevant exogenous events and inability to calculate consequences*' (Simon 1978: 356).

The first theory within this paradigm was the Bounded Rational Decision-Making model of management science as proposed by Simon (1960). It assumes that the decision maker lacks knowledge about many feasible alternatives and corresponding consequences and has a limited capacity of the mind. Bounded rationality also postulates that a decision maker has an aspiration as to how good the outcome of an alternative should be. Instead of effortful striving for the outcome that maximizes utility, the decision maker now accepts the first satisficing outcome: as soon as she discovers an alternative that meets this aspiration level it is chosen and the search for alternatives is stopped. This aspiration level may relate to a threshold value for the compounded utility of an alternative, or to a set of thresholds for the values of all relevant attributes of the alternative (Simon 1955).

As a descriptive-procedural concept, the Bounded Rational model discerns three phases:

i. **Intelligence**: finding occasions calling for a decision;

ii. **Design**: inventing, developing and analysing possible courses of action;

iii. **Choice**: selecting a particular course of action from those available.

It is not hard to see that these phases can be found by an aggregation of the steps in the rational model[25]. However, Simon explicitly assumes that the phases may be followed in a partly iterative or even reverse order, as actually observed within organizations; see e.g. Pen (2000; 2002)[26]. PT largely covers the 'design' and 'choice' phases in this model.
The Bounded Rationality concept actually marked the origin of Behavioural Decision Theory as founded by Edwards (1961), later followed by Behavioural Economics, in which PT is by far the most common conceptual model. Several behavioural concepts of decision making were developed within these fields that fit into the descriptive-bounded rational concept. In addition to PT the most well-known might be the Heuristics-and-Biases approach, the Adaptive Decision Maker concept, Naturalistic Decision Theory and the Fast-and-Frugal Heuristics program (see overviews in successively Kahneman and Tversky 2000a; Gilovich *et al.* 2002; Payne *et al.* 1993; Klein *et al.* 1993; and Gigerenzer *et al.* 1999). All these approaches show a strong contextual dependency and, compared to UT, a strong interrelation of choice set assessment, attribute valuation, evaluation of alternatives and choice.

3.3.2 Range of application

PT was developed some decades ago (Kahneman and Tversky 1979; 1984). It is a descriptive theory, predominantly based on findings from cognitive psychology laboratory experiments. It soon became the most influential theory in behavioural economics. Like its UT counterparts all versions of PT assume that the subject follows a deterministic choice process. A comment might be that reading through the many articles that deal with aspects of the theory, so far one will find few recipes and examples of the integral application of these theoretical building blocks in operational simulation models of choice behaviour. Thus, the theory can hardly be called an operational theory for choice simulation and prediction and is still predominantly an explanatory choice theory.

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[25] '*Intelligence*' roughly complies with '*a. Define and diagnose the problem*'; '*Design*' might be considered to cover '*b. Set goals; c. Search for alternative solutions*' while '*Choice*' takes care of '*d. Compare and evaluate them; e. Choose among them*'. In later editions of his book Simon added a fourth step, '*Review*', that might cope with '*f. Implement the solution selected; g. Follow up and control*'.

[26] Pen identified seven phases in a firm relocation decision-making study of almost 200 firms in the Netherlands, of which *Identification and Diagnosis* might be attributed to Simons step i; *Search, Development and Evaluation* to step ii; and *Strategy and Implementation* to step iii. Firms discerned at least three and at most seven phases, and each firm followed one or more phases in each of the three categories discerned above.

Just as UT, PT initially focused on the choice between simple alternatives with probabilistic outcomes, i.e. between two prospects with explicit given probabilities of monetary outcomes. As such it offered an alternative for Von Neumann and Morgenstern's (1944) version of Expected Utility Theory. Later it was extended to prospects with uncertain outcomes (Tversky and Kahneman 1992) and certain outcomes (Tversky and Kahneman 1991).

The first extension is called Cumulative Prospect Theory. It allows for the evaluation of prospects with many different outcomes. Obviously, this is a more generic version than the original PT as presented in 1979. In this book this version is submerged into PT and considered to be its implementation to choice contexts with uncertain outcomes. It may be conceived as a descriptive-behavioural alternative of Savage's (1954) Subjective Expected Utility Theory.

The choice between alternatives with certain outcomes is considered here as a specific case of this more generic version. Kahneman and Tversky never extended the definition of PT to include reference-dependent and change-oriented framing and valuation of alternatives with 'certain' outcomes. This part of their work is occasionally called Reference-Dependent Theory[27] (e.g. Bateman *et al.* 1997; Köszegi and Rabin 2004) and is an alternative for Neo-classical Utility Theory. Here the equally common practice is followed to include it in PT (e.g. Mellers 2000 and List 2004).

PT presumes that each individual follows a deterministic choice behaviour strategy, which remains stable during a concrete choice process but may differ from one choice in a sequence to the next. Interpersonal differences in choices from equal choice sets may be caused by differences in idiosyncratic valuation (or tastes, preferences) and differences in framing (see below). Recently, some scientists investigated ways to fit PT into a stochastic, econometric model setting. An overview is given by Stott (2006), who also compared the explanatory performance of several formulations of PT combined with several stochastic models (Constant Error, Probit, Logit, Luce) to account for interpersonal heterogeneity. Each combined model was fitted to 90 stated choices of 96 different people, and the explanatory performance of the models that was found was compared for the population. To account for the investigated intrapersonal stochastic variation in choice behaviour, the Logit formulation yielded the best match. In travel behaviour research, Michea and Polak (2006) compared Expected Utility Theory, PT, and several other non-Expected Utility concepts, each combined with the Random Utility Maximization Logit concept for taste heterogeneity. This latter was considered to take care of interpersonal as well as intrapersonal stochastic choice heterogeneity. Compared to Expected Utility Theory, PT and the other non-Expected Utility models showed a better match with the survey results of public transport passengers. Though we definitely have not had the last word about the best way to cope with choice heterogeneity, the different assumptions of PT can apparently be modelled smoothly within a discrete choice framework.

3.3.3 Basic principles

Elsewhere Van de Kaa (2004) established six assumptions of Prospect theory that seemed the most basic and discriminating from those of UT:

[27] Prospects (expectations) are crucial for the assessment of the reference state and the expected changes in it as a consequence of choice decisions. Prospect Theory thus seems to be an adequate utterance for a reference-dependent concept of choice behaviour.

i. **Context-dependent preferences**: an individual's preference order is dependent on the context of the choice situation and the way alternatives are presented and perceived, '*choice is a constructive and contingent process*' (Tversky and Kahneman 1992:317).

ii. **Change-oriented framing**: an individual frames alternatives in terms of the expected change in their assets rather than on the expected state of them, '*the carriers of utility are not states (owning or not owning the wine), but changes: getting the wine or giving it up*' (Kahneman 2000b: xiii).

iii. **Reference dependency**: expected outcomes of choice decisions are valued relative to some reference state[28]. An expected increase in satisfaction, utility or positive affect relative to the reference state is valued as a gain, a decrease as a loss, '*the objects of choice are prospects framed in terms of gains and losses*' (Tversky and Kahneman 1992: 316).

iv. **Loss aversion**[29]: losses are valued much higher than gains of equivalent size, '*the (value) function is sharply kinked at the reference point, and loss averse – steeper for losses than for gains by a factor of about 2-2.5*' (Kahneman 2002: 462).

v. **Diminishing sensitivity**: '*the marginal value of both gains and losses generally decreases with their magnitude*' (Kahneman and Tversky 1979: 278). Thus the value function is considered to be concave for gains and convex for losses.

vi. **Non-linear weighted probabilities** or Certainty effect: an individual over-weights outcomes with low probabilities (say $p < 0.35$) and under-weights outcomes with high probabilities relative to certain outcomes: '*Over-weighting of small probabilities contributes to the popularity of both lotteries and insurance. Under-weighting of high probabilities contributes both to the prevalence of risk aversion in choices between probable gains and sure things, and to the prevalence of risk seeking in choices between probable and sure losses*' (Tversky and Kahneman 1992: 316).

The first three assumptions above relate to the framing function of the Meta Theory of Choice Behaviour, the other three to its judgment function. All these assumptions are incompatible with the corresponding UT assumptions. In retrospect, Kahneman and Tversky (2000a: xiii) considered loss aversion as their most important contribution to the understanding of general decision making: '*We introduced loss aversion reluctantly…We realized only much later that loss aversion is the element of Prospect Theory that has the richest implications beyond its narrow domain.*' The degree of loss aversion is often indicated by the factor[30] λ for which 2.0 appears a useful first estimate in many contexts. One might also note that Kahneman and Tversky (1979: 276) acknowledge Markowitz (1952) as '*the first author to propose that utility be defined*

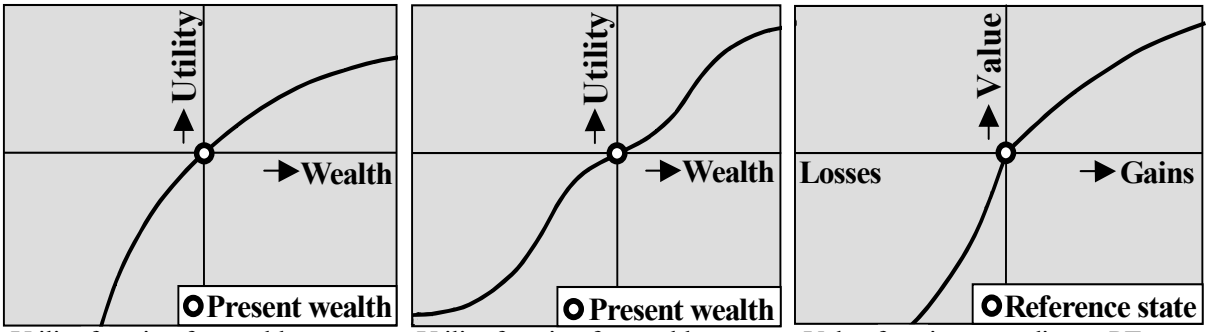
[28] Reference state is defined as: the expected outcomes (attribute properties, chances, values) of the continuation of the actual behaviour in a changing context that are used as the basis for the comparative assessment of the expected outcomes of alternative courses of action (posited here). Kahneman and Tversky (1979) commonly called this phenomenon the '*reference point*' which is appropriate for mapping the reference state on an indifference map, as well as for choosing between two-attribute alternatives. Following Kahneman and Tversky (1984: 343 and following pages) the term '*reference state*' is used in this book, because it is more appropriate for multi-attribute alternatives.

[29] Loss aversion may be defined as: the property of human judgment that losses are valued much more highly than gains of equivalent size (posited here). Not to be confounded with risk aversion, a concept which explains the choice of subjects who prefer prospects with a certain outcome over prospects with probabilistic or uncertain outcomes, even if the expected value of the latter is to some extent higher. Loss aversion may occur in the choice between certain alternatives, but also between prospects with uncertain outcomes.

[30] The loss aversion factor λ is defined as the ratio between the marginal psychological values of a decrease in a positively valued attribute level of a choice alternative and an equally sized increase in that level (posited here).

on gains and losses rather than on final asset positions.' Another precursor was Vickrey (1969), who considered that the travel times of commuters that necessitate home departures before a desired time, or result in arrivals at the office after the desired starting time, are valued between twice and four times as highly as reductions in travel time of an equivalent size. Less explicit notions about loss aversion have lingered in the background of the scientific literature ever since Machiavelli (1513) considered that once a ruler comes into power he should choose any moral or immoral course of action to ensure that he does not lose control.

To grasp an idea of the similarities and differences between UT's loss-neutral, state-dependent, diminishing marginal utility concept and PT's loss-averse, change-based value concept subject to diminishing sensitivity, both functions are assembled in Figure 4, together with Markowitz' proposal for a loss-aversive utility assessment.



Utility function for wealth (satisfying Fechner's Law before it was posited in 1860)
Source: diagram in Bernoulli (1738)

Utility function for wealth (postulated, shape not empirically tested)
Source: Figure 5 in Markowitz (1952)

Value function according to PT (theoretical shape, confirmed in experiments)
Source: Figure I in Kahneman and Tversky (1991)

Figure 4: Reference-dependency of UT's utility and PT's value concepts

Several authors, like Bleichrodt *et al.* (2001: 1498, 1500), conceive loss aversion as a bias from '*the right normative model for decision under uncertainty (which) is expected utility*', a bias that leads to '*discrepancies between elicited preferences and the true preferences according to a rational model,*' but they implicitly accept it as the best descriptive model to correct for these discrepancies. As this book aims to contribute to the understanding of real-life human choice behaviour it refrains from normative judgments about how an individual should choose[31] and considers opinions such as cited from Bleichrodt *et al*. as supportive for the descriptive appropriateness of PT.

3.3.4 Ambiguities

The assumptions formulated in the original publications of PT focus on differences with respect to UT. The axioms imply that Kahneman and Tversky (1991) implicitly adopted the non-satiation principle for consumer satisfaction, as follows, for example, from their treatment of indifference curves. For several other choice phenomena the consulted publications of PT yielded no explicit assumptions. Kahneman and Tversky are, for example, rather ambiguous in their view on the decision rule that should be applied to wind up the choice process. Some of the 'missing' assumptions apparently correspond to the equivalent

[31] The reader might examine the vivid description by Markowitz (1952: 152ff) of some kinds of choices that people make in cases of an inconsiderate, loss-neutral application of the principles of Expected Utility Theory to form an opinion about the 'rationality' of such choices.

Table 1: Assumptions of Utility Theory and Prospect Theory

Assumptions	Utility Theory	Prospect Theory
Perception		
Subject's environment	(Complete, as it is)	(E.g. dependent on subject's needs, recall, experience, attention, …)
Subject's state	(Changeless)	(E.g. dependent on current mood, ease and content of recall…)
Framing		
Reference state	(Irrelevant)	Expected 'no change' state of assets
Alternatives, outcomes, attributes	Complete range of expected states of assets, independent of reference state	Context-dependent range of expected changes (gains and losses) relative to reference state
Subject's needs	Non-satiable; Temporally stable, context-independent, complete preference order of all goods	Non-satiable; Preference order dependent on the context and the way in which alternatives are perceived
Aspiration level for needs gratification	Maximal ordinal utility within budget constraints	(Maximal decision value within budget constraints)
Judgment		
Expected attribute levels & probabilities	Rational measured,calculated or belief-based expectations	(Subjective belief-based expect-ations partly drawing on heuristics)
Valuation of attribute characteristics	In commensurable medium; Diminishing marginal utility for expected increases in assets; Independent of size and sign of changes in state of assets	(In commensurable medium); Diminishing sensitivity: concave for gains, convex for losses; Independent of size, dependent on sign: loss aversion
Valuation of attribute importance	Subjective attribute decision weights	(Subjective attribute decision weights)
Valuation of expected probabilities	(Unweighted)	Variable weight factor, dependent on probability
Evaluation-and-choice		
Comparison of multi-attribute alternatives	Alternative-wise, based on a compensatory compounded ordinal utility measure	(Alternative-wise, based on a single compensatory compounded decision value)
Choice criterion	Highest ordinal utility	(Highest overall decision value)
Choice behaviour strategy		
Choice of strategy	(Temporally stable, context and reference-independent)	(Dependent on context and the way in which alternatives are perceived)
Order of function completion	Conscious, rational, sequential	(Sequential: framing + judgment followed by evaluation + choice)
Successive choices in the same context	One choice behaviour strategy for each individual; Intrapersonal consistent choice behaviour, transitive	Interpersonal differences in framing, same choice behaviour strategy for all; (Intrapersonal consistent choice behaviour, may be intransitive)

Statements between brackets: implicit assumptions as reviewed in this chapter.

ones from UT; others might be considered conditional or consequential to the six assumptions above. In Table 1 the assumptions listed above are completed with these implicit assumptions. Together these assumptions appear to cover all elements of the Meta Theory of Choice Behaviour.

3.4 Summary

The sets of assumptions of UT and PT that were discussed in this chapter are listed in Table 1. Though at a first glance PT and UT, the latter conceived as a descriptive-behavioural theory, appear to differ in many respects, they have some main outlines in common: subjects are considered as self-interested, non-satiable maximizers; their choice behaviour strategy is deterministic and static (i.e. once a particular choice process has started there are no stochastic or time-dependent changes).

The most fundamental difference is that UT assumes that each individual follows the same choice behaviour strategy in all contexts, while PT allows for context-dependent intrapersonal and interpersonal differences in the framing of alternatives. Where UT attributes all interpersonal differences in choice behaviour to differences in idiosyncratic preference orders or 'taste templates', PT can explain these from differences in the individuals' combinations of the context-dependent framing of reference states and prospects, and the context-dependent valuation of alternatives. However, hardly any empirical research reviewed in this book tried to establish within-context interpersonal differences in the adopted reference state according to PT. Thus, both theories are commonly applied as if each individual follows just one choice behaviour strategy. This reduces the main difference to a distinction between UT's context-independent framing and the valuation of alternatives in terms of final states of assets and PT's context-dependent framing and valuation of alternatives in terms of changes relative to a reference state.

A thorough inspection shows that both sets are internally consistent, complete implementations of the Meta Theory of Choice Behaviour and thus may be considered as models that after parameter estimation can simulate and predict choices. However, as many assumptions of UT and PT are at odds with each other their descriptive-behavioural quality might differ strongly. For example, an individual that frames her attributes independent of a reference state and values them loss neutral cannot value the same attributes loss aversive in the same context. On the other hand, from a functional-descriptive point of view both theories have at least some overlap: they predict the same choice if all attributes in a choice set with certain outcomes are in the 'gain-domain'.

A further comparison shows that several assumptions of UT can be conceived as constrained versions of those of PT. For instance, reference-independent framing of outcomes (UT) is functionally equivalent to the assessment of a reference state (PT) where all attribute levels are valued loss neutral (loss aversion factor $\lambda = 1.0$). If PT's probability weight factor is set at unity UT's treatment of expected probabilities emerges. But also some assumptions of PT are behaviourally rather restrictive. For example, Kahneman and Tversky (1979: 277) disregard diminishing marginal utility, as '*the preference order is not greatly altered by small or even moderate variations in asset position*' though '*strictly speaking, value should be treated as a function of two arguments: the asset position that serves as reference point, and the magnitude of change from that reference point*'. In fact, only PT's change-dependent diminishing sensitivity principle for

attribute valuation cannot be reduced to UT's state-dependent diminishing marginal utility principle.

The combined assumptions of UT and PT as fitted into the functional-descriptive perspective of the Meta Theory of Choice Behaviour will be compared in the next chapter against empirical findings and empirics-based theoretical notions of human choice behaviour to see which ones are most appropriate.

Chapter 4
Findings from Behavioural Sciences about Human Choice Behaviour

It is shown that, under specified experimental conditions, consistent and predictable intransitivities can be demonstrated.

Amos Tversky (1969: 31)

Context: With this statement Tversky commenced an article in which he proposed a non-compensatory decision rule to explain the behaviour of the subjects who violated the basic assumption of a context-independent ordinal utility scale that underlies Utility Theory.

4.1 Introduction

In the previous chapter two sets of assumptions were found that are both internally consistent, complete implementations of the Meta Theory of Choice Behaviour and thus may be considered as models that, after parameter estimation, can simulate and predict choices. However, the assumptions listed in Table 1 under Utility Theory (UT) and Prospect Theory (PT) differ in many respects. A comparison of the descriptive performance of both sets as a whole in a particular context might be biased, for example if an underestimation of a behaviour was predicted by one assumption with a poor descriptive performance but counterbalanced by an equal overestimation caused by another assumption of the same theory with an equally poor descriptive performance. Such a comparison thus requires observations of behaviour in different contexts in which all the relevant circumstances that are considered in the many different assumptions of both theories are documented. No studies were found that allowed such a comparison.

This chapter carries out a less complicated analysis. It compares the assumptions listed in Table 1 pairwise with each other and, where appropriate, also with the corresponding assumptions from other behavioural sciences. The comparisons concern their ability to describe the functions of human choice behaviour. The assumptions are treated as hypotheses concerning the framing, judgment, evaluation-and-choice and choice-behaviour-strategy functions. The descriptive efficiency of each of these hypotheses is compared with the

corresponding assumptions that perform the same function, but in a different way. The material for comparison consists of empirical findings and the corresponding theoretical inferences of choice behaviour as published in the literature of the behavioural sciences. This comparison may call for the rejection, accentuation or complementation of the individual assumptions as constituent premises of a more generic descriptive-behavioural theory. It does not, however, allow a solid comparison of the applicability and descriptive ability of comprehensive implementations of either the UT or PT paradigm.

The methodology followed for the different comparisons is similar to the systematic review that is nowadays popular in medical and educational sciences[32] and outlined, for example, in Higgins and Green (2005). Publications containing data, empirical findings and corresponding inferences about choice behaviour that allowed for a comparison of hypotheses were collected by means of a full-text internet query on scientific search engines. For each considered subfunction BOOLEANS were designed from the keywords of the function and the hypotheses that are considered to take care of the same function. The internet survey was supplemented with a conventional backward literature research.

Carrying out the systematic reviews by means of a classic meta-analysis[33] or one of its later derivatives (see e.g. Becker 2007) was considered. This would have implied the formulation of hypotheses, the assessment of some criteria and the application of a statistical test for their acceptance or rejection. Such an approach is very useful for the establishment of the relationship between two variables from a large number of empirical studies. Brons (2006: 20, his emphasize), for example, underlines that '*a meta-analytical approach is particularly attractive in cases where a* ***sufficient number of studies*** *report* ***comparable*** *research results in a* ***quantitative*** *format.*' It was clear beforehand, however, that the recovered studies would not comply with this requirement. In addition, from a methodological point of view a meta-analysis seemed less appropriate for a comparison of assumptions that are meant to be approximative descriptions of actual behaviour, in view of the disputable acceptability criterion for the degree of approximation. That is why the traditional approach of a qualitative, narrative discourse is followed for the reviews of the recovered findings.

The core of the systematic reviews in this chapter consists of secondary analyses (see definition in Glass 1976: 3) of the findings in the original publications. Most of the recovered studies contained analyses of empirical choice data with generally accepted scientific principles like statistical significance and hypothesis testing. Many of these led to a straightforward confirmation or rejection of one or more of the considered assumptions in the concerned contexts. Published observations from several other studies could be used to compare the performance of an assumption that described a different realization of the same function as the assumption that was considered in the original publication. For some subfunctions no empirical data were recovered that allowed a comparison of the assumptions in Table 1. Here, the collected literature was reviewed and inferences about the plausibility of the relevant assumptions were based on additional deductive reasoning. For each function a

[32] Most systematic reviews in these fields concern studies about the effects of treatments and use quantitative methods for their synthesis although a qualitative approach for it is not uncommon for other kinds of evidence and/or in other fields.

[33] According to Glass (1976: 3), who coined the term, a meta-analysis refers '*to the statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings*'. Though this type of systematic research is often considered superior to the traditional qualitative-narrative reviews a meta-analysis does not guarantee reliable results. These may be biased, for example, in the case of an inferior design of the reviewed studies.

qualitative narrative review of the relevant secondary analyses results in inferences about the descriptive ability of the considered assumptions.

The literature mentions several reasons why a reviewer's application of the narrative review method may be unsound:

- she may omit to describe the method used for the review;
- she may miss relevant publications and unpublished studies due to unclearly stated inclusion criteria and/or only consider a small subset of the retrieved studies because the total number is too large;
- she may cite the conclusions of previous reviews or studies without reviewing these critically;
- she may adopt subjective judgments, for example because she is often an expert in the reviewed field and might give insufficient weight to findings that are contrary to her own convictions; and
- her readers cannot replicate the review and/or judge its quality.

It is easy to see that these objections might also apply to a quantitative meta-analysis. This section aims to avoid the first criticism. The examined studies were found by an exhaustive keyword search. Though for most considered functions the number of recovered studies discussed in this chapter is rather large it appeared feasible to apply a secondary analysis as discussed above to most of them. Only occasionally outcomes of earlier reviews are cited to back-up inferences[34]. This leaves little reason to believe that the results of the present chapter are flawed extensively by the first, second or third of these weaknesses. When he started this systematic review the present author had a background in hydrodynamic research and management and had definitely no expertise in the field of choice behaviour. This reduces, but does not exclude, the possibility that subjective judgments will encroach on the analyses of this chapter, as this remains an inherent possibility in any meta-analysis or other literature review. The narrative discourses of the secondary and the covering analyses in this chapter aim to supply sufficient information to allow the reader to evaluate the possible extent of unintentional remaining biases. The consequent length and information density of the texts, which might impede their comprehensibility, is thus considered an acceptable price to pay for the clarity provided in the performed considerations.

In Section 4.2 the framing function is discussed, followed in Section 4.3 by the judgment function and in Section 4.4 by the evaluation-and-choice function. The choice behaviour strategy function that coordinates the other ones is discussed in Section 4.5. Each section concludes with a summary of the findings with respect to the ability of the considered assumptions as descriptions for the completion of the relevant function according to a functional-descriptive theory. Conclusions regarding a more generic choice behaviour theory are discussed in Chapter 5.

4.2 Framing

Except for Savage's assumptions on which the Subjective Expected Utility Theory was founded (see Section 3.2), framing is not explicitly considered as a constituent activity of

[34] See, for example, in Subsection 4.2.6 the conclusion about the sensibility of individuals to different descriptions of the same alternatives found in a review by Levin *et al*. (1998).

human choice behaviour in Utility Theory (UT). Prospect Theory (PT), however, was conceptualised as a sequence of a framing phase (originally termed '*editing*'), followed by an evaluation phase. Initially, Kahneman and Tversky (1979: 274) stated that '*The function of the editing phase is to organize and reformulate the options so as to simplify subsequent evaluation and choice*'. Later on Tversky and Kahneman (1992: 299) defined a decision frame as '*a representation of the act, outcomes and contingencies that are relevant to the decision maker*'. This includes the framing of research designs by the researcher. Still later on Kahneman (2000b: xiv) aptly remarked: '*Framing is a common label for two very different things: an experimental manipulation and a constituent activity in decision making*'. This book conceives it in the latter meaning, which principally includes the reframing of research designs by the interviewees.

Several elements that Kahneman and Tversky (1979) attributed to PT's framing phase evidently fit into other elements of the functional-descriptive character of the Meta Theory of Choice Behaviour. This definitely holds for the simplification of prospects by rounding off probabilities or attribute levels and for the screening of alternatives on inferior (dominated) ones, including their rejection. Rounding off is conceived as an element of judgment here while rejection of alternatives evidently belongs to evaluation-and-choice. The reviewed concepts and findings about framing in this constrained sense are successively assembled here under its elements: reference state, alternatives, subject's needs and aspiration level (see Table 1). In view of the relevance of framing for the understanding of choices, including in experimental contexts, these reviews are followed by a discussion of the re-framing by the interviewees of the choice situation as provided to them according to the research design.

4.2.1 Reference state

The endowment status[35] of assets strongly influences the framing of the reference state. Endowment rights have a strong effect on the socio-economic system. For example, the perception of consumers and employees of the fairness of profit-improving economic behaviour appears to be largely determined by their interpretation of the resulting changes in the endowment situation of both parties involved (e.g. Kahneman *et al.* 1986). Kahneman *et al.* (1991) found that the judgment by the lay public as to whether the actions of economic agents were '*fair*' or '*unfair*' is strongly influenced by whether the rationale for the behaviour is perceived as a reduction in a gain or an actual loss. More generally, they pointed out that '*the old expression that "possession is nine tenths of the law" is reflected in many judicial opinions*' (Kahneman *et al*. 1991: 204).

To demonstrate the relevance of endowment for jurisdiction, Cohen and Knetsch (1992: 436) refer, for example, to Adam Smith: '*(We) naturally depend more on what we possess than what is in the hand of others. A man robbed of five pounds thinks himself much more injured than if he had lost five pounds by a contract*'. They show that endowment, even in the case of adverse possession, is a decisive criterion in most fields of jurisdiction, as it has been for ages. They exemplify this clearly with descriptions of a large body of jurisprudence.

In view of the observed importance of endowment it seems common sense that the subject will choose the actual state of her assets as the reference state. Thus, this state is often defined as the status quo. Mellers (2000: 911), for example, even states: '*According to Prospect Theory, psychological value, formerly called utility, is assessed relative to the status quo*.' However, according to Tversky and Kahneman (1991: 1046), the reference state is more accurately defined as the expected outcome of the relevant choice situation, if the actual choice context

[35] i.e. whether/to what extent material or immaterial 'things of value or use' belong in someone's possession.

of the decision maker and her actual behaviour and preferences are continued: '*Although the reference state usually corresponds to the decision makers current position, it can also be influenced by aspirations, expectations, norms, and social comparisons*'. Paraphrasing Köszegi and Rabin (2004:2) one might argue: '*a person's reference state is her recent beliefs about her future assets*[36]'. Similar to the reference state is the '*plan concept*' of Image Theory's '*framing of the context: Identifying the relevant subset ... of the decision maker's sizeable stock of principles, goals and plans ...to establish what is going on*'. Beach (1990: 4, 53) defines this subset as the status quo in a choice context. Also similar is the null alternative or reference alternative concept as employed in environmental impact assessments and project appraisal studies.

Thus, the reference state that a person is supposed to adopt is the expected 'no change' endowment state of her assets[37] that she expects will emerge if she sticks to her previous choices. One should realise that in many choice contexts interpersonal differences in the adopted reference state are common. Intercultural differences, amongst other factors, play a role, as found in health insurance choices by Chinese and American citizens (Wang and Fischbeck 2004). Also the perceived content and salience of contextual information that is not relevant for the choice process may have a profound effect on the framing of the reference state and consequently the alternative (e.g. Stapel and Koomen 1998; Liberman and Ross 2006).

In a particular choice situation, the reference state adopted by the subject will be influenced by the outcomes of previous strategic decisions, tactical choices and operational choices. For example, transfer of ownership of assets to or from the decision maker may result in an instant endowment effect with a corresponding instantaneous reference shift[38] (e.g. Tversky and Kahneman 1991). Barkan and Busemeyer (2003) showed that such a reference shift explains the observed instantaneous change in the willingness of subjects to engage in a second gamble, compared to their stated willingness before the first gamble. Examples from the travel behaviour domain are the influence of the previous residence location on actual location choice (Axhausen *et al.* 2004), vehicle acquisition decisions on transport mode choice (Srinivasan and Bhargavi 2006) and pre-trip route and destination choices on the successive route choice when actual en-route information is provided (Bonsall and Palmer 2004; Mahmassani and Srinivasan 2004).

The often myopic (i.e. short-sighted) updating of the reference state in a recurrent choice context with varying attribute levels may be illustrated by a subject's daily morning commute. Most often the habitual or script-based home departure time, transport mode and route alternative may be adopted as the reference state, with the associated commonly experienced averages and ranges of trip durations and arrival times. However, for choices in a 'tactical choice' stage following the implementation of a strategic decision (see Section 2.1), or after an experience that strongly deviates from the common pattern, or when the subject knows about unusual circumstances (a stormy weather forecast, an early morning assessment interview etcetera), many subjects may update their reference state while framing the choice

[36] Köszegi and Rabin (2004: 2) applied the reference dependency to consumer choice behaviour and used the wording '*a person's reference point is her recent beliefs about future incomes. An employee who confidently expects a 10% pay raise might assess a raise of only 5% as a loss.*'

[37] Assets are conceived in a very extensive meaning, including memories of experiences, entitlements to future services etc.

[38] To complicate matters, people may even use several reference states at a time, e.g. when comparing a salary offer with similar offers to two colleagues (Ordóñez *et al.* 2000).

contexts. They might employ the '*Peak-End Heuristic*[39]' (Kahneman 1999) to arrive at a more suitable reference. This implies averaging the value of the attributes that resulted in the peak affective response during the previous periods and the last experienced value, disregarding the duration of the experiences. Transformed and simplified to an actual recurrent route choice context: the '*decision value*' of travel time on a congestion-prone route alternative for the daily commute is found by averaging the maximum delay due to congestion experienced in the past few years and yesterday's experienced delay. The underlying '*extension neglect*' has been demonstrated in several different domains (Kahneman and Frederick 2002). One of the caveats mentioned by Kahneman (2000a) is that the experiments on which the Peak-End heuristic has been tested mostly involved only aversive experiences. As negative affect (pain, loss) and positive affect (pleasure, gain) are valued and experienced quite differently and can occur simultaneously (Kahneman 1999), one might consider taking both peaks into consideration to assess the peak-end value.

4.2.2 Alternatives

So far no empirical research findings have been found of generic applicable context-dependent choice set formation by individual choice subjects. According to the normative UT assumptions, subjects have a complete perception of their objective environment and perfect expectations about all possible 'states of the world', and thus might frame their alternatives and corresponding outcomes as expected states of assets. The consideration of such extensive choice sets is obviously not plausible as a descriptive-behavioural hypothesis and cannot be handled in choice models either. To arrive at 'manageable' choice sets for discrete choice models following the compensatory random utility maximization rules, Manski (1977) formulated a two-stage approach for choice set formation that was later put into operation by Swait and Ben-Akiva (1987), amongst others. In particular when there are many different alternatives, the development of reliable choice set generation models under the UT paradigm is a challenge for the analyst, see e.g. Bovy (2008) for a state-of-the-art of route choice set generation. According to the Meta Theory of Choice Behaviour one should, however, conceive this choice set reduction process as an element of evaluation-and-choice instead of framing. This was demonstrated by Horowitz and Louviere (1995), who surveyed visitors to a shopping mall to list the alternatives (supermarkets in one survey and toothpaste brands in the other) that they considered to buy, and to rate the alternatives with respect to their performance on some attributes (e.g. price, merchandise quality). Horowitz and Louviere (1995: 51) showed that the elicited '*consideration sets are indicators of preferences*'.

To arrive at a sufficiently 'complete' choice set in a particular choice context, an individual has to retrieve the relevant beliefs about the significant courses of action from her memory to supplement her perceptions of the outside world. Even when one accepts that the mental perception system is able to conceive such a choice set on the spot, it will contain only a small subset of all the possibly relevant information. Moreover, people's personal knowledge of each alternative and its attributes will strongly differ as it is composed during several events and choice processes.

Travel behaviour researchers commonly consider choice sets that contain just those alternatives that they deem most relevant in the research setting. Incidentally, a theoretical choice set formation concept has been developed for a particular domain, such as learning in terms of the dynamic updating of '*mental maps*' in travel and destination choice (Arentze and

[39] Actually, Kahneman coined it as the Peak-End Rule but as he classified it as a prototype heuristic the designation Peak-End heuristic is used here to prevent confusion with decision rules.

Timmermans 2005). Two-stage decision rules might simulate the individual's framing of alternatives to some extent (e.g. Swait and Ben-Akiva 1987; Cantillo and Ortúzar 2005). A more thoroughly elaborated concept from transport sciences is the control-theoretical model of route choice in which '*information acquisition*' reduces the '*objective*' complete choice set to '*known alternatives*' and '*attribute perceptions*', followed by a succession of perception, elimination and evaluation steps that reduce the choice set until only a few alternatives remain (Bovy and Stern 1990). The branch-and-bound approach to route choice set generation is an implementation of this concept, in which potential routes are eliminated from the choice set when they violate threshold values of attributes in terms of detours, travel time or path lengths increases relative to an optimal route (e.g. Hoogendoorn-Lanser 2005). In several circumstances this yields better coverage of an individual's consideration sets and chosen alternatives than other approaches (e.g. Bekhtor and Prato 2006). It can be considered as an approximate way to account for the outcomes of preceding strategic decisions and tactical choices in the context of an operational choice situation modelled in conformity with the principles of UT.

According to the UT-paradigm of context independency, one homogeneous set of alternatives at a time can be considered for model estimation and prediction. In the route choice domain, for example, a person is assumed to always choose the same alternative from the same set of route alternatives for the daily commute, whether it is before the first trip after a residential remove or in the context of a pre-trip choice on a day two years later. The same premise allows these results to be combined with those from similar evaluations of transport mode alternatives and route alternatives. This paradigm has proven to yield useful models for the approximate description of aggregate real-life route choice behaviour.

In agreement with the Cognitivist's paradigm of choice and behaviour, PT considers that the '*true objects of evaluation and choice are neither objects in the real world nor verbal descriptions; they are mental representations*' (Kahneman 2000b: xiv) in terms of '*prospects framed in terms of gains and losses*' (Tversky and Kahneman 1992: 316) [40]. But PT and other behavioural theories of choice are vague in examining how a subject actually conceives choice sets. They generally focus on how individuals deal with a few alternatives that are apparently intuitively selected (e.g. Kahneman and Tversky 1979). In some choice contexts the general character of the alternatives may be self-evident, such as transport mode, transport vehicle or place of residence. For example, with respect to transport mode choice it is hard to imagine an inhabitant of Rotterdam who is not familiar with the availability of metro, taxi and bus, even if she has never set foot in any of them. In other contexts, e.g. choices between consumer products with the same function and content but different brands, subjects might categorize the complete range in one 'reference brand', a few known alternatives and one 'other' or 'unknown brands' alternative. In most contexts, however, the objectively available number of alternatives is almost infinite. The attributes of any alternative may comprise a host of expectations of attribute levels and probabilities of possible outcomes as well as characteristics contingent to the choice context.

All the preceding concepts of choice set formation consider each choice context as if it is an isolated process. However, choices might be better conceived as discrete events that fit within a strategic-operational choice hierarchy that applies to the type of context in the situation at hand. Most often a change in the subject's context that affects her interests is the trigger

[40] In this chapter the term '*alternative*' is meant as alternative courses of action and is used for 'choice objects' as well as 'choice options'.

which starts a choice process. The only alternatives that matter in that context are those that allow the subject to cope with the change at issue. From this perspective an individual has no need to conceive all possible courses of action and corresponding attributes from scratch. She can use her recognition of previous strategic decisions and tactical and operational choices in a similar context to select just those alternatives that may cope with the trigger that initiated the actual choice. Several recent theories on judgment and choice behaviour rely on this recognition principle (e.g. Klein 1993; Gigerenzer and Todd 1999). Most often it results in a 'subjective consideration set' that contains several small, heterogeneous adjustments in the subject's actions (Beach 1990). For example, in a tactical travel context a choice set may consist of a range of combinations of some departure time adjustments, a few alternative routes and transport modes and their expected outcomes/attributes, the range of which is constrained by the outcomes of previous choices and excludes all alternatives that are not conspicuously helpful in the particular context. Such an approach constrains the considered choice set to a small subset of the theoretically feasible alternatives. The concept is close to Bovy and Stern's (1990) perception filter but rather than reducing a more complete generated choice set with an elimination process it draws on Simon's (1955) and Gigerenzer and Todd's (1999) more frugal principle of ending the set formation process once a satisficing number of alternatives is found.

From this perspective the UT assumption of completeness of the almost infinite objectively available information seems implausible as a descriptive concept of choice behaviour. The consulted articles dealing with PT did not provide a helping hand to deal with this challenge, and neither did those from the heuristics-and-biases school and other branches of behavioural decision theory. The more 'naturalistic' perspective on subjects' context-dependent framing of a 'satisficing' list of alternatives might yield better coverage of real-life idiosyncratic choice behaviour. The applied sciences provide hardly, if any, generally applicable approaches or empirical research findings of the context-dependent framing of alternatives. In most choice contexts a dedicated search for the way in which individuals frame their choice sets seems a prerequisite for a better understanding of their choice behaviour. Researchers might then follow an open interview approach to elicit *what* alternatives and attributes were considered by the subject in a particular context. Hoogendoorn-Lanser (2005), for example, followed such an approach for multi-modal route choice. An interesting way to retrieve the way in which individuals might frame their choice alternatives to some extent is the linguistic information processing approach as proposed by Takao and Asakura (2005) in a transport mode choice context. A caveat that holds for this and any other open interview approach is that causal explanations provided by individuals for their choices are notably unreliable; see Nisbett and Wilson (1977) for an extensive documentation of this phenomenon. To overcome this problem one might use verbal protocols as a means to infer possible decision frames, and even choice behaviour strategies in general, but rely for inferences about their use on an outcome-oriented elicitation approach (see Section 4.4).

4.2.3 Choice bracketing

Choice bracketing describes how an individual organizes decisions and outcomes by lumping some together, and segregating others in different mental accounts (Read *et al.* 1999; Kahneman 2000b; Thaler 1999). Mental accounting captures the assignment of activities to specific accounts, the frequency with which accounts are evaluated and how outcomes are perceived and experienced (Thaler 1999). By and large people are prone to treat problems as unique and to make one choice at a time ('*narrow bracketing*' or '*narrow framing*'). This may cause myopic (short-sighted) valuation, e.g. by neglecting the possibility to pool risks (Kahneman and Lovallo 1993; Read *et al.* 1999; Thaler 1999). Thaler calls this behaviour

narrow framing, resulting in myopic loss aversion. Langer and Weber (2001) observed this behaviour when they investigated the acceptance rate of students for repeated mixed gambles. This rate was generally higher when the aggregated distribution of the possible outcomes was presented. However, they showed that there are some domains where the reverse relation holds. Read *et al.* (1999) discern four determinants of bracketing: cognitive capacity limitations in perception, attention, memory and analytical processing; cognitive inertia, just dealing with the problems in the way they are presented; pre-existing socially acquired heuristics, e.g. work-week vs. weekend; and motivated bracketing, mostly to overcome problems of self-control. They conclude: '*Our lack of insight into the factors that influence bracketing even in mundane choices suggests that developing a theory of how people bracket is a crucial direction for future research*' (Read *et al.*: 187).

In practice, choices are usually made sequentially, and therefore temporal bracketing and/or the frequency with which mental accounts are evaluated and balanced are of the utmost importance for choice behaviour. Typical examples are: the approximately annual account that, in connection with loss aversion, can explain the large share of bonds in the portfolio of investors compared to stocks that are more profitable in the long term (Benartzi and Thaler 1995); and the daily income target that leads cab drivers in New York and Singapore and bike messengers in Switzerland to work until the target income is attained, thus they work longer hours if the hourly income is lower (Camerer *et al.* 1997; Chou 2002; Götte and Huffman 2003). In Camerer's study a majority of the drivers employed the daily bracketing behaviour but significant parts of them, in particular the most experienced ones, bracketed wider. Similar interpersonal differences and experience effects were found in other observations of choice bracketing behaviour (List 2004). However, Chou (2002) and Götte and Huffman (2003) did not find similar changes in framing behaviour with growing experience amongst Singapore cab drivers and Swiss bike messengers.

Choice bracketing is usually dependent on how alternatives and their consequences are offered to and/or perceived by the subjects. This in turn may lead to different choices from 'objectively' equal choice sets. Schul and Mayo (2003) carried out experiments in which subjects chose 100 times from alternatives with probabilistic outcomes and were informed after each 10 choices about the outcomes. The optimal strategy was to apply a simple rule ('choose the same colour') consistently during all choices. Only a minority of the participants followed the optimal strategy, even of those who were informed beforehand about the chances of positive outcomes *and* showed after the experiment that they understood the optimal rule. Most participants adapted their strategy to irrelevant aspects of the outcomes of previous choices. These findings are in line with previous research, see Schul and Mayo's article for some references. Barron and Erev (2003) observed intrapersonal differences between the *ex-ante* choices of the same subjects from probabilistic alternatives, depending on whether they were offered just one choice (myopic frame), one sequence of 100 choices (wide frame) or 200 successive individual choices, though in all these settings the offered alternatives had the same expected utility. They explained these changes from a PT-consistent loss-aversive valuation of the outcomes, together with a simple learning algorithm that relied heavily on the 'last' experienced outcomes. Avineri and Prashker (2005) largely replicated Barron and Erev's experiments. Experienced drivers each had to make 100 successive route choices. They found that PT, applied to the sequence of 100 choices with a constant reference state, matched the on average observed choices the best, though it apparently could not predict the observed shifts in average preference that occurred between the first and last choices of each individual. Elsewhere Avineri and Prashker (2006) showed that a significant part of the

participants consistently chose the same route alternative in the last rounds while the majority kept switching from one alternative to the other.

Neither Barron and Erev nor Avineri and Prashker considered that some respondents might have learned to apply an optimal 'wide frame' strategy while most respondents might have stuck to myopic updating of the reference state between successive choices. In combination with loss-aversive valuation and the Peak-End Heuristic (Kahneman 1999) this latter principle might offer an even better device for the description of recurrent choices under uncertainty of those individuals than so-called 'learning' models that rely strongly on the last experienced outcomes.

4.2.4 Subject's needs and preferences

Reading through the many articles in Kahneman and Tversky (2000a) that relate to PT one gets the impression that the needs and aspirations of subjects with respect to a certain choice setting are attributed to perception rather than to the choice behaviour process. In view of the similarity and covertness of mental perception and System 1 reasoning processes an attribution to either of these is beyond discussion (Kahneman 2002). Here these phenomena are considered as part of the framing function of choice behaviour.

In Decision Theory needs, motives and goals receive little attention. A listing in a recent book review (Nickerson 2004: 203) concludes that '*decision makers want to be safe and healthy, they want to have fulfilling relationships, and they want to experience some successes in the domains of education, career pursuits, personal development, and leisure activities*'. Refraining from details one might recognize the hierarchy of needs (Maslow 1954) in this listing. Following Maslow, needs are conceived here in a broad sense, encompassing derivatives like wants, desires, motives and ethics propagation, with respect to physical goods, services, fairness, social order etcetera. Near equivalents are the '*value image*' of Image theory (Beach 1990) and the '*value system*' of Differentiation and Consolidation theory (Svenson 1992). These concepts imply that in a particular choice setting an individual selects an appropriate subset of needs that can be conceived as a context-dependent preference order.

Context-dependent preference-order reversals are reported from many studies; see e.g. Machina (1987) for an economic perspective and Schwarz and Strack (1999) for striking examples in judgment tasks. The general pattern is that many individuals prefer prospects of which uncertain outcomes, attribute characteristics or goals are described in positive terms rather than objectively the same prospects described in affectively less appealing terms. Levin *et al.* (1998) analysed 85 different articles in which all but ten observed a statistical significant framing effect in at least some experiments. A famous category of these reviewed experiments was the Asian Disease experiment (Tversky and Kahneman 1981) where strong affective feelings and/or ethical norms seemed to pop up. Each participant had to choose between two alternative programmes, one leading to a certain outcome in terms of the number of people saved, the other in terms of the chances that all the people either survived or died. They found that a significant number of respondents changed their preference when the wording of alternatives was changed from positive (saved) to negative (died), without changing the 'objective' outcomes of the alternatives. Many other researchers repeated this experiment with the same results; see Dawes (1988) and Svenson and Benson 3rd (1993a) for some more examples. Other studies showed that contextual information, even though not pertinent for the choice process, may influence choice behaviour (Stapel and Koomen 1998) while in another experiment adding non-favoured channels for free to pay-TV packages diminished their attractiveness (Liberman and Ross 2006). Some authors showed that

personality characteristics could explain part of the observed interpersonal differences (Levin *et al.* 2002; McElroy and Seta 2003).

Overall, it is obvious that the context-independent ordinal preference concept of UT cannot be maintained as a generally applicable premise in a descriptive model of choice behaviour.

4.2.5 Aspiration level for needs gratification

A trade-off between the subject's needs and the perceived concurrent opportunities for their gratification yields aspiration levels, or individual goals, related to the outcome of a particular choice process (Simon 1955). Gärling *et al.* (2002) placed behaviour in a feedback loop where decisions about actions are the result of a comparison between the perceived actual state-of-the-world and a reference value with respect to the desired situation. This is not essentially different from Kahneman (2000a: 687), who assumes that an individual has an aspiration level: '*a value on a scale of achievement or attainment that lies somewhere between realistic expectation and reasonable hope*'.

Up to a certain extent aspiration levels are compatible with the '*trajectory image*' of Image theory. From the formal description of PT, the aspiration level of a subject appears to be maximization, just as in UT. But Kahneman (1999: 14) defines it as the boundary between '*satisfactory and unsatisfactory events*', which is similar to Simon's (1955) '*satisficing*' concept. A satisficing aspiration level may mean that the subject disregards all the alternatives that do not comply with her idiosyncratic 'constraints' and stops her search for alternatives as soon as the subjective consideration choice set has a satisficing range of feasible and acceptable alternatives, and/or that she uses non-compensatory decision rules drawing on attribute cut-offs. Neither manifestation of satisficing aspiration levels can be distinguished when only the 'objective' choice context of the subject and her final choice are observed. Non-compensatory decision rules are reported abundantly from choice experiments and actual consumer behaviour in many fields, but maximizing rules are even more frequently observed. Thus a descriptive choice theory has to accept the co-existence of both satisficing and maximizing aspiration levels.

4.2.6 Re-framing of experimental research questions by interviewees

The context dependency of choice behaviour asks for a very careful design of experiments and research questionnaires by the researcher. There is no reason why subjects should not frame a research choice context such that it suits their interests, just as they do in real-life choice contexts. Researchers should thus be alert to assessing the extent of re-framing behaviour by interviewees during the interpretation of the outcome of experiments and surveys.

In particular the editing of questionnaires is of crucial importance for the credibility of the intended use of survey results, as in inquiries the participants appear to take the wording of the questions for granted: '*Passive adaptation of the formulation given appears to be a general principle*' (Kahneman 2002: 458). This does not mean that the subject will also adopt the meaning as intended by the researcher. An interviewee will not search for this purport but interpret questions according to her own understanding of common language. For example, at least in the Dutch language 'travel' ('*reizen*') is primarily associated with leisure and/or exceptional business trips, including wining and dining and with a certain adventurous appeal. Dutch people do not 'travel to their work': everyday mobility is normally described as 'going to', 'driving to', 'taking the train/bus/car to' etc., e.g. for commuting 'going to my office' and

'going home'. Transport researchers define all these trips as travel, whilst long-lasting 'all-in' stays are often excluded from their definition. Thus, the inquirer should be attentive to differences in the interpretation of words in her discipline and in common language and should give great care in 'translating' the research questions into common language to prevent an unintended reframing of her questionnaire by the interviewees. Thus, in an inadequately edited survey aimed to elicit preferences with respect to the duration of daily recurring trips, some people who report that they would enjoy spending more time travelling might have been triggered by sweet dreams about nice outings instead of by their boring, lengthy daily commute.

The importance of the right wording in questionnaires was illustrated over and over again, for example in Tversky and Kahneman's famous '*Asian disease*' problem. This concerns two choice sets (A, B) each consisting of two health programmes (1,2) intended to treat a number (say 600) of patients. The outcome of each program is logically the same in both choice sets. In set A both outcomes are framed in positive terms, in set B in negative terms, for example:

A1. 200 patients survive; A2. 1/3 chance that no patient is saved, 2/3 chance that 600 are saved.

B1. 400 patients die; B2. 1/3 chance that no patient dies, 2/3 chance that 600 die.

Confronted with choice set A, most participants typically choose the sure alternative 1 whilst most prefer the uncertain alternative 2 from choice set B. Dawes (1988: 34-37) refers to several experiments, including a large-scale one in which he was involved personally, that supports the conclusion that '*framing effects are particularly strong in matters of life and death*'. Svenson and Benson 3rd (1993a) used a similar design to investigate whether time pressure played a role in this framing bias. Their subjects were given four different health problems, with different levels of gravity of the consequences. They found that, with or without time pressure, on average approximately 65% choose the A1-type alternative and 25% the B1-type. This deviation from the 50% ratios, which would follow from a risk-neutral assessment in agreement with Expected Utility Theory, was larger in the choice sets where more people might live or die. Surprisingly, in those choice sets the percentages moved 5 to 15% further away from the normative outcome when there was no time pressure. Moreover, the 'within-choice set' attractiveness difference[41] between the positively and negatively edited alternatives increased strongly when the time pressure diminished. The 'extra' time was thus apparently not used to deliberately de-bias the offered decision frame but to strengthen the affective valuation of the alternatives offered! Levin *et al.* (1998) gave an overview of many '*framing experiments*' that demonstrate the sensibility of individuals to different descriptions of the same alternatives.

A related bias in stated preference surveys are anchoring effects[42] due to unintentional cues in questionnaires. McFadden (2001b: 364-368), for example, reported a strong impact of this on the willingness-to-pay for environmental goods. In one experiment, several groups of citizens were asked how much they were willing to pay for annually saving the lives of 50,000 seabirds. The average of the respondents that answered an '*open-ended*' questionnaire was US$64, those groups that responded to questionnaires containing numerical cues ranging from

[41] a measure for the affective valuation of the different outcomes.

[42] In the context of a survey or experiment anchoring is the phenomenon that the judgment of a subject is influenced by a salient but uninformative number presented to him, see e.g. Tversky and Kahneman (1974) and Chapman and Johnson (2002). For the anchoring and adjustment phenomenon in everyday life, see the next subsection.

US$5 to US$400 yielded averages from US$20 to US$143. For an overview of anchoring effects found in experimental settings, see Chapman and Johnson (2002).

Venkatachalam (2004) treats some other sources of biases caused by the framing of questionnaires like the sequencing, information and elicitation effects and lists some recommendations to contain them. Several effects and recommendations are equally applicable to any kind of stated and revealed preference survey.

4.2.7 Summary of findings about framing

In the behavioural sciences, surprisingly little attention is paid to interpersonal differences in framing. Analyses and inferences about choice behaviour are most often concerned with the explanation of the average response, though almost any table with basic results of experiments shows one to several dozens of percents of responses that differ from the average and might indicate a different framing strategy. Thus, in a particular content-context situation a majority of subjects will presumably frame roughly in the same, predictable way, but significant numbers of individuals may apply one or more alternative combinations of alternatives, reference state, preference order and aspiration level. At least a preliminary survey of how different (groups of) individuals arrive at a choice set and organize their choices in the content-context situation at hand should be considered when an alternative approach to choice behaviour is applied to a new field.

Many choice experiments demonstrate that the choice statements of each individual strongly depended on the way in which she framed the research context, particularly in connection with the interpretation of the wording of questionnaires. This requires the utmost care in the design of new surveys and experiments. It also asks for a critical re-interpretation of the conclusions drawn from many earlier research findings rather than taking their applicability to real-life choice behaviour for granted.

The elements of framing appear to be strongly interrelated and dependent on the choice context (domain and actual state of the environment, choice task complexity, current needs, moods and aspirations of the subject). The availability of a complete range of alternatives in terms of expected states of assets as well as context-independent, temporally stable and complete preference orders, as presumed in UT, has to be rejected as a premise for a generic descriptive-behavioural theory of choice. Preference orders should be considered as dependent on the context and the way in which alternatives are presented and perceived. The reference state can be conceived as the expected ‘no change’ state of assets, and the attributes of alternatives as expected gains and losses with respect to this reference. Previous choices on the same or higher levels of the strategic-operational choice hierarchy will act as constituent elements of the actual reference state. In different domains and choice contexts the same subject may adopt different reference states, but interpersonal differences will presumably be more prominent. Some individuals may frame the outcomes of alternatives as expected states of assets. This is functionally indiscriminate from a change-oriented frame where these individuals value the attributes loss neutral (loss aversion factor 1.0). The latter description is adopted hereafter as an extension of the premises of PT. The co-occurrence of maximizing and satisficing aspiration levels is presumed for such an extension.

4.3 Judgment

Most behavioural theories of judgment and choice behaviour take the availability of the subject's beliefs concerning the attribute levels and the attachment of utilities or values to these for granted, or disregard them. Examples are Attitude Theory (Fishbein 1963) and its extensions Theory of Reasoned Action (Ajzen and Fishbein 1980) and Theory of Planned behaviour (Ajzen 1991), and Dominance-Search Theory (Montgomery 1989) and its closely related alternative Differentiation and Consolidation Theory (Svenson 1992). However, the valuation of attribute levels of alternatives might be the essence of choice behaviour.

This section starts with a review of heuristic judgment, in view of its importance for valuation. It is followed by an introduction to the concepts of attribute values and dimensions. Successively the assessment of attribute levels and probabilities, their valuation and the employed dimensions, the loss aversion principle and the valuation of probabilities will be reviewed. A summary of findings about the judgment function in human choice behaviour concludes this section.

4.3.1 Heuristic judgment

Heuristics are often described as context-specific operational 'rules-of-thumb'. When such rules are elicited in particular contexts without reference to a more general judgment principle this might result in completely inductive descriptions of choice behaviour. However, '*no one wishes to pursue the idea of context dependence to the point of nihilism. Choices are not nearly as coherent as the notion of a preference order would suggest, but they are far from random*' (Kahneman 2000b: xvi). A similar opinion is expressed by Gigerenzer and Todd (1999: 19-20): '*Simple heuristics are meant to apply to specific environments, but they do not contain enough detail to match any one environment precisely ... A computationally simple strategy that uses only some of the available information can be more robust, making more accurate predictions for new data, than a computationally complex, information-guzzling strategy that overfits*'.

Kahneman and Frederick (2002: 53) defined heuristics as: '*judgment is mediated by a heuristic when an individual assesses a specified target attribute of a judgment object by substituting another property of that object – the heuristic attribute – which comes more readily to mind*'. They posit that heuristic judgments occur 'spontaneously' in System 1 processes, but may also be a deliberate System 2 strategy. Heuristics are thus similar to intuitive rules that individuals use to simplify choice processes. This book adheres to this interpretation, which is close to its semantic meaning. In his Nobel Prize lecture, Kahneman (2002) underlines the association of heuristics with the accessibility of information in perception and memory. Schwarz and Vaughn (2002) illustrate the importance of accessibility of information for heuristic judgment by demonstrating that often the ease of recall instead of the content of recall is used to assess the heuristic attribute. This salience of accessibility is quite similar to that for beliefs in Attitude Theory, Theory of Reasoned Action and Theory of Planned behaviour (Fishbein 1963; Ajzen and Fishbein 1980; Ajzen 1991).

Kahneman and Tversky (1974: 1124, 1127) originally described three '*general-purpose*' heuristics: the Representativeness heuristic, '*in which probabilities are evaluated by the degree to which A is representative of B, that is, by the degree to which A resembles B*'; the Availability heuristic: '*Availability is a useful clue for assessing frequency or probability, because instances of large classes are usually recalled better and faster than instances of less frequent classes*'; and the Anchoring-and-adjustment heuristic that people use when they estimate the probability of an event, not by starting from scratch but by adjusting an earlier estimate or even any readily

available numerical prompt that may serve the purpose[43]. These general-purpose heuristics are primarily tools for cognitive assessments. All general-purpose heuristics draw on '*natural assessments (which) include physical properties as size and distance, and abstract properties as similarity, cognitive fluency, causal propensity, surprisingness, affective valence and mood*' (Kahneman and Frederick 2002: 55).

After 1974 many more heuristics were proposed in cognitive psychology, see Gilovich *et al.* (2002) for an overview. One that is noteworthy is the Affect heuristic, introduced by Slovic *et al.* (2002), where according to Kahneman (2002: 470) '*a basic affective reaction is used as the heuristic attribute for a wide variety of more complex evaluations*'. This affect heuristic might assess affective values rather than cognitive knowledge about attribute levels. Kahneman and Frederick (2002: 57, 50) remarked that the affect heuristic is in fact a holistic aggregate of '*closely related but distinguishable evaluative attributes (like goodness, kindness, outrageousness) that can give rise to closely related but distinguishable heuristics*' and assigned many heuristics to a '*broad family of prototype heuristics, in which properties of a prototypical exemplar dominate global judgments concerning an entire set*'. Prototype heuristics often exhibit extension neglects, notably scope neglect in Willingness-to-pay for environmental and other public goods and duration neglect in the evaluation of experiences.

When Tversky and Kahneman (1974: 1131) introduced heuristics to the literature about judgment and decision making they concluded: '*these heuristics are highly economical and usually effective, but they lead to systematic and predictable errors*'. By 'errors' (biases[44]) they meant systematic differences between observed and 'normative-rational' judgments. Since then the '*heuristics-and-biases*' tradition seems primarily interested in the description and understanding of heuristics compared to classical rational reasoning. This may be illustrated by several comparisons of everyday predictions and their outcomes by laymen as well as experts, in medical settings, meteorology, legal judgment, business settings and sports (Koehler *et al.* 2002), and of the annual frequency of causes of death, environmental risks and so on (Fischhoff 2002). These authors demonstrate that there are systematic differences between predictions and outcomes that can be attributed to heuristic judgment and suggest several measures to improve predictions that, certainly for expert judgments, make sense. One might however just as well read these articles as demonstrations of how well the outcomes match the heuristics-based predictions of professionals and laymen, even in very complex circumstances. With respect to the understanding of people's heuristic judgment in fields in which it has not yet been studied one should realize that '*inevitably, each extension requires auxiliary hypotheses, mapping the abstract terms of the theory to the concrete complexities of the real world*' (Fischhoff 2002: 731).

The '*cognitive ecologist*' school '*with its emphasis on the ability of evolutionary mechanisms to achieve an optimal ... tuning of the organism to the local environment*' (Stanovich and West 2000: 650) adopted a slightly different view on heuristic judgment. Gigerenzer and Todd (1999) and colleagues treat heuristics as deliberate System 2 actions for guiding search, stopping search and 'decision making'[45]. They took a firm stand[46] against the heuristics and biases research

[43] People often use self-generated anchors that come readily to mind and adjust these in a direction that seems appropriate (Epley and Gilovich 2002). This cognitive strategy does not meet the re-definition of heuristics by Kahneman and Frederick (2002). It might better be ranked as a deliberate System 2 judgment procedure.

[44] '*In the heuristics and biases literature, the term bias is reserved for systematic deviations from normative reasoning and does not refer to transitory processing errors*' (Stanovich and West 2000: 646).

[45] The decisions treated in their book mainly concern the rank-ordering of attributes, which might be better considered as judgments.

tradition, suggesting that Tversky and Kahneman (1974) had characterized heuristics as '*overused, mostly dispensable cognitive processes that people often misapply to situations where logic and probability theory* ***should*** *be applied instead*' (Gigerenzer and Todd 1999: 25, their emphasis).

Regarding the use and relevance of heuristics in everyday human judgment one might, however, find hardly significant differences between their views and those of Kahneman and Tversky. For example, Gilovich and Griffin (2002) as well as Kahneman and Frederick (2002) give convincing explanations that the recognition heuristic, described by Gigerenzer and Goldstein (1996) as a deliberate System 2 strategy, draws on familiarity that is close to availability and relies on cognitive fluency that, according to Kahneman and Frederick, is routinely evaluated by the intuitive System 1. Thus the recognition heuristic fits well into the formal definition of heuristics as described above. The '*minimalist heuristic*' and famous '*take-the-best heuristic*' (Gigerenzer and Goldstein 1996; Czerlinski *et al.* 1999), for the rank-ordering of target attributes of objects, bear upon a lexicographic ordering (e.g. Rieskamp and Hoffrage 1999) of '*prototype*' attributes (recognition, size etc.).

Although Gigerenzer and Todd (1999) accent the potential application of the knowledge of heuristics for modelling real-world behaviour, the articles in their book contain hardly if any evidence of the use of their heuristics by people in everyday choice behaviour. Martignon and Laskey (1999) compared the performance of the Take-the-Best algorithms in the fitting and generalization of twenty totally different data sets with that of a linear-additive ('equal weight') decision rule, a multiple regression model, a naïve Bayes model and a Bayesian network. It appeared that Take-the-Best performed better than the linear-additive decision rule and outperformed multiple regression in generalization, though multiple regression performed better than Take-the-Best in fitting. Both Bayesian models performed better than Take-the-Best in fitting as well as in generalization, but the differences were small. Chater *et al.* (2003) compared the generalization performance of Take-the-Best with some standard models used in cognitive psychology and found that Take-the-Best performed better for small training sets and slightly less well for relatively large training sets. Newell *et al.* (2003) report that only (or as much as?) one-third of the participants in two experiments behaved completely consistently with the take-the-best heuristic, and quite a lot of participants used more information than required according to this heuristic. As could be expected, just as the 'biased-inclined' heuristics the 'fast-and-frugal' ones are not a panacea for the description of human judgment.

In any case, the use of heuristics in human judgment, including their nasty spin-off biases, has to be taken for granted. Many studies show that attempts to stimulate people to de-bias choice behaviour by shifting from an intuitive-heuristic to a rational judgment strategy influences the actual choices of only some of the subjects. This holds for allowing more time for decision making (e.g. Svenson and Benson 3rd 1993a), the supply of '*rational*' information about the consequences of alternatives (Stanovich and West 1999) and providing motivational incentives (Johnson *et al.* 1993b; 1996); see also Payne *et al.* (1996), Schul and Mayo (2003) and Larrick (2004) for more evidence. Thus for a descriptive model of choice behaviour the UT assumption of exclusively rational and/or belief-based assessment of attribute levels has to be rejected.

[46] Reading through their article one gets the impression that Gigerenzer and Todd reason from some strong and untested beliefs about the efficacy of ecological rationality (in the sense of evolutionary and environmentally determined human judgment strategies) and about the inadequacy of classical rational reasoning. Gilovich and Griffin (2002) and Chater *et al.* (2003) gave elaborate and sophisticated responses to these presumptions.

4.3.2 Assessment of attribute levels and probabilities

If time and opportunity permits, levels of several types of attributes may be assessed by 'objective' measurement. Kahneman and Frederick (2002: 55) state that decision makers can also assess attribute levels immediately, by reading them from a stored memory (e.g. one's body length) or from current experience (e.g. the liking of a cake), while others '*are routinely evaluated as part of perception and comprehension, and therefore always accessible'*. These natural assessments include both physical and abstract properties. However, many attributes are accessible only if they were recently evoked or primed. When this is not the case the attribute can be substituted by an associatively related heuristic attribute. According to Kahneman and Frederick (2002:55) there may be more candidate heuristic attributes for one substitution, '*it is not always possible to determine a priori which heuristic governs the response to a particular problem*'.

Once assessed by the subject in one way or another, attribute levels become '*beliefs'* about the objects of choice in the psychological meaning, i.e. '*the probability of a relationship between the object of belief and any other object, concept or goal*' (Fishbein 1963: 233). Subjects are generally aware of these beliefs, though the intuitive mental processes by which they arrive at them may often remain covert for them. Several fields of psychology rely on this human ability to elicit such beliefs when the situation demands it. Ajzen and Fishbein (1980), for example, presumed that each individual has many behavioural beliefs about specific attributes of the outcomes[47] of a particular behaviour, and that only a small number of these beliefs are readily accessible at a given moment. It seems obvious that this and similar other models of reasoning and judgment will yield elicitations very similar to those presuming heuristic judgment. The beliefs can be elicited by self-reports of expectations on a qualitative scale; see Van Praag and Frijters (1999) for an application in economics.

In particular when an alternative regards a prospect with probabilistic outcomes the elicitation of the expected probabilities of these outcomes mostly heavily relies on heuristic judgment. Actually, Tversky and Kahneman (1974) originally introduced heuristics as tools to assess probabilities. Manski (2004) gives an overview of the elicitation of expectations concerning the probability of outcomes. For several contexts he demonstrates that individual people are able to express their expectations in a probabilistic form, and that mean expectations and realizations often match up closely. He suggests combining data about expectations and actual choices to estimate econometric decision models and remarks: '*the collection of other subjective data may be useful as well. The possibilities range from elicitation of preferences to verbal probes asking persons to describe how they make decisions*' (Manski 2004: 1331).

4.3.3 Values of attribute levels and their dimensions

In psychology the term value is closely akin to the cardinal utility concept of Bentham (1789) that was adopted by Frey and Stutzer (2000) and Ng (2003), amongst others. The values that a subject attaches to attribute levels are equivalent to the subjective evaluation of beliefs of Attitude theories (Fishbein 1963; Ajzen and Fishbein 1980; Ajzen 1991) and the attractiveness ratings of Dominance Search and Differentiation and Consolidation theories (Montgomery 1989; Svenson 1992).

[47] E.g. 'causes me to gain weight' and 'is convenient' for an alternative like 'using birth control pills'.

Values of expectations, experiences and remembrences

Kahneman and Tversky (1984: 348) discerned the decision value, '*the contribution of an anticipated outcome to the overall attractiveness or aversiveness of an option in a choice*' from the experience value, '*the degree of pleasure or pain, satisfaction or anguish in the actual experience of an outcome*'. The former is obviously the determinant for choice behaviour. Later Kahneman defined decision utility as '*the weight that is assigned to an outcome in the context of a decision*' (Kahneman 1999: 17); experienced utility as '*the measure of the hedonic experience of that outcome*' (Kahneman 2000a: 761); and remembered utility as '*the global evaluation that is retrospectively assigned to a particular past episode or to a situation in which similar experiences occur*' (Kahneman 1999: 4). There is a growing body of evidence in literature that these utilities systematically differ. For example, recently Bennett *et al.* (2004: 2) demonstrated that '*a significant and systematic "wedge" exists between ... valuations implicit in ... decisions and those implied by retrospective ... evaluations*'. Different impacts of the expected, experienced and remembered feelings on the valuation and too optimistic expectations about the duration of the positive affect of choice-induced changes contribute to these differences. Adaptation processes will often result in a lower remembered value[48] than the experienced value, let alone the corresponding *ex-ante* expected decision value.

For a descriptive model of choice behaviour the decision value should be considered as the relevant 'driving force'. A researcher should, however, be well aware of these differences in valuation, in particular when engaging in comparisons of *ex-ante* stated and *ex-post* revealed choice surveys.

Monetary valuation

PT, like UT, was originally developed for the choice between gambles with monetary outcomes (Kahneman and Tversky 1979; Tversky and Kahneman 1992). Thus it presumed commensurability of attribute values in money. For everyday consumables and services this seems the 'natural' dimension. Hsee *et al.* (2003) observed that people often maximize the medium rather than the good they could obtain with the medium, when they make choices where the immediate outcome is money, or another medium with an interval scale (points, grades), for which the experienced affect of the medium *per se* is neutral. Many attribute levels are valued affectively rather than in a 'cognitive-calculative' way, see e.g. the Subjective Expected Pleasure theory (Mellers 2000). Affective valuation may be intuitively or deliberately performed by the affect heuristic or one of its constituents (Kahneman *et al.* 1999b; Slovic *et al.* 2002; Slovic *et al.* 2004). An individual presumably maps these values on some natural qualitative affective scale. In surveys and experiments such values can be elicited by self-reports on an ordinal dimension like 'good-bad', 'beautiful-ugly' etcetera.

When a subject maps the values of all attributes on the same scale these are principally commensurable, even if the scale is a qualitative one. To allow for a proper evaluation-and-choice this requires that the subject assigns some measure of importance to the different attributes. UT, as well as most alternative choice behaviour theories, presumes that subjects ascribe a subjective, belief-based importance value to each attribute (e.g. Dawes 1988; Johnson *et al.* 1993b). Dijksterhuis (2004: 591) considered that '*to reach a sound decision people should give different attributes different, idiosyncratic weights*' and presented the results of choice experiments that support his notion that '*unconscious thought*' is able to assess these, even for alternatives with many highly relevant attributes. These attribute decision weights are

[48] One might note that subjective well-being, as elicited in different surveys, largely draws on remembered utilities of many instances, see e.g. Kahneman (1999).

near equivalents of '*belief strengths*' and '*motivation levels to comply*' according to the theory of Planned Behaviour (Ajzen 1991). Some non-compensatory, attribute-based decision rules like the Strong Lexicographic rule (see Section 4.4) need only an attribute importance ordering.

If at least one attribute characteristic is monetary, the monetary value for any attribute level (e.g. of travel time) then follows from the ratio of its psychological value and the psychological value of money.

Mixed affective-cognitive valuation

Often '*the attractiveness of a decision alternative is determined by both cognitively derived values and affective variables*' (Nickerson 2004: 203; see also the description of Dual-process theory in Chapter 2). Alternatives may then be characterized with a mixture of affectively and cognitively[49] derived values on different, non-commensurable scales (e.g. Ajzen 1991; Nickerson 2004). When one or several attributes have a high affective meaning to the subject it appears very problematic for her to express them in a monetary or another '*cognitive-rational*' medium, see Kahneman and Frederick (2002) and Kahneman (2002).

Some neurological theories suggest that affective and cognitive values may be integrated automatically by some brain functions (Hoebel *et al.* 1999; Wagar and Thagard 2004; Kalidindi *et al.* 2005). Dijksterhuis (2004) suggests that when assessments of attribute characteristics are available 'unconscious thinking' may give idiosyncratic decision weights to the attributes and may combine them in some commensurable measure. Several researchers found evidence that this measure is a qualitative rating on an affective or hedonic 'good-bad' or 'pleasure-displeasure' dimension (e.g. Cabanac *et al.* 2002: General discussion): '*The fact that behaviour is a final common pathway entails that the brain needs a common currency to compare all motivations in order to rank priorities. Thus we can assume that pleasure is the universal common currency*'. Concepts like Dominance Search Theory, the Theory of Planned Behaviour and Differentiation and Consolidation Theory (Montgomery and Svenson 1989b; Ajzen 1991; Svenson 1992) presume that people anyhow confine their attribute valuation to some broad qualitative characterizations. Thus where an individual may have problems in the mapping of affective attribute values on a monetary or other interval medium scale she might easily map money on a subjective qualitative rating scale. The '*Leyden approach*' in welfare economics follows this principle to arrive at a monetary value of attributes (Van Praag and Frijters 1999). But subjects may just as well circumvent this cross-dimensional mapping problem by the use of non-compensatory decision rules. Thus, particularly when some attributes have an affective overtone, the commensurability assumption is too restrictive for a descriptive-functional theory of choice behaviour.

There is an important distinction between the affective and cognitive valuation of the scope of attributes: '*Value is nearly a step function of scope when feeling predominates and is closer to a linear function when calculation predominates*' (Hsee and Rottenstreich 2004: 23). Kahneman and Frederick (2002) found that people have problems with the mapping of affectively salient attributes on a scale that has no upper limit, like money. In surveys, respondents will mostly choose a scale that is internally consistent but that may result in large individual differences in the valuation. These consequences of mixed affective-monetary valuation are particularly annoying in studies aimed at assessing the value of public goods or attributes (like the value

[49] Cognitive valuation is interpreted here as 'judgment based on rational-utilitarian appraisals' as opposed to 'feelings' or 'emotional appraisals'.

of a particular number of traffic casualties) that have an ethical overtone (e.g. Kahneman and Knetsch 1992; Kahneman *et al.* 1999; McFadden 2001b; Kahneman and Frederick 2002; Slovic *et al.* 2002; 2004; Venkatachalam 2004). Subjects may however circumvent this cross-dimensional mapping problem by employing non-compensatory decision rules. Anyhow, when some attributes have an affective overtone UT's commensurability assumption is too restrictive for a functional-descriptive theory of choice.

Time discounting

When faced with a choice between different desirable or unwanted events the temporal sequence appears to be an important attribute. Research in the last decade of the 20th century showed that '*people typically favour sequences that improve over time*' (Loewenstein and Prelec 2000: 567). The experimental evidence that they provide shows that, depending on the temporal frame and type of event provided, some 10 to almost 50% of the respondents to different questions preferred a sequence where the best event occurred first. Nevertheless, these and many more published findings challenge the discounted utility model of Samuelson (1937) that is the standard for economic analyses of inter-temporal choice to date (Loewenstein and Prelec 1992). Their finding that losses are discounted at a lower rate than gains might be explained by a combination of loss aversion and a preference of the subjects for steadily improving prospects in their future life. The higher value attributed by most people to sequences of events with increasingly positive and/or decreasingly negative affect should result in a higher remembered utility and thus will contribute to their subjective well-being (Kahneman 2000a) at the cost of immediate satisfaction. It is also an indication that many people may frame their alternatives rather wide (Read *et al.* 1999), though generally only if they are aware of the long-term effects. Frederick *et al.* (2002) gave an extensive review of time discounting and time preference. They concluded that the discounted utility model has little empirical support and advocated a multiple-motive approach, for the understanding of both interpersonal and intrapersonal differences in inter-temporal choice behaviour across different domains. Their final statement '*since different motives may be evoked to different degrees by different situations (and by different descriptions of the* ***same*** *situation), developing descriptively adequate models of inter-temporal choice will not be easy*' underlines the relevance of framing and the context dependency of valuation for descriptive models of choice behaviour.

Mental accounting

Kahneman and Tversky (1984) propose that for the valuation of an attribute or alternative people set up a mental account that specifies the disadvantages, and advantages, of the alternative relative to the reference state. An alternative is acceptable if the value of its advantages exceeds that of its disadvantages. They discern three approaches for this assessment: a minimal, topical and comprehensive account. They illustrate this by the following choice problem: '*Imagine that you are about to purchase a jacket for $125 and a calculator for $15. The calculator salesman informs you that the calculator you wish to buy is on sale for $10 at the other branch of the store, located 20 minutes drive away. Would you make a trip to the other store?*' The minimal account disregards shared features, the remaining difference between the alternative and the reference state is the gain or loss, and thus is independent of the value of the attributes in the reference state: '*The advantage associated with driving to the other store is framed as a gain of $5*'. The topical account also disregards shared features but relates the consequences of possible choices to the chosen reference level: '*The willingness to travel to the other store for a saving of $5 on a calculator should be inversely related to the price of the calculator and should be independent of the price of the jacket*'. A comprehensive account takes all relevant features into account (in the example e.g. the price of the jacket plus other

expenses) and may be related to a broader definition of the reference state. Based on the responses of a panel on a few versions of the choice problem cited above they state: '*This finding supports the notion of topical organization of accounts*' (Kahneman and Tversky: 347). The topical approach is presumed in the models developed by Sugden (2003) and Köszegi and Rabin (2004). Utility maximizing theories generally presume that each individual makes decisions using the comprehensive account (Thaler 1999).

4.3.4 Valuation of gains and losses

PT presumes that alternatives are framed in terms of gains and losses on different attributes and that losses are valued higher than gains of equivalent size. Initially loss aversion was assessed as a decisive driving force in the choice between monetary and other gambles (e.g. Kahneman and Tversky 1979; 1984; Tversky and Fox 1995). Later on it was extensively encountered in the choice between certain outcomes. Tversky and Kahneman (1991) demonstrated the effect of constant loss aversion factors with respect to a reference state on the shape of a set of linear indifference curves. Figure 5 compares the customary indifference map of Figure 3 (page 26), conceived as indicating the average value attributed to gains and losses of equal size, with a transformation of it that results after constant loss aversion factors are applied to losses of these goods. It clearly shows the impact that loss aversion might have on valuation.

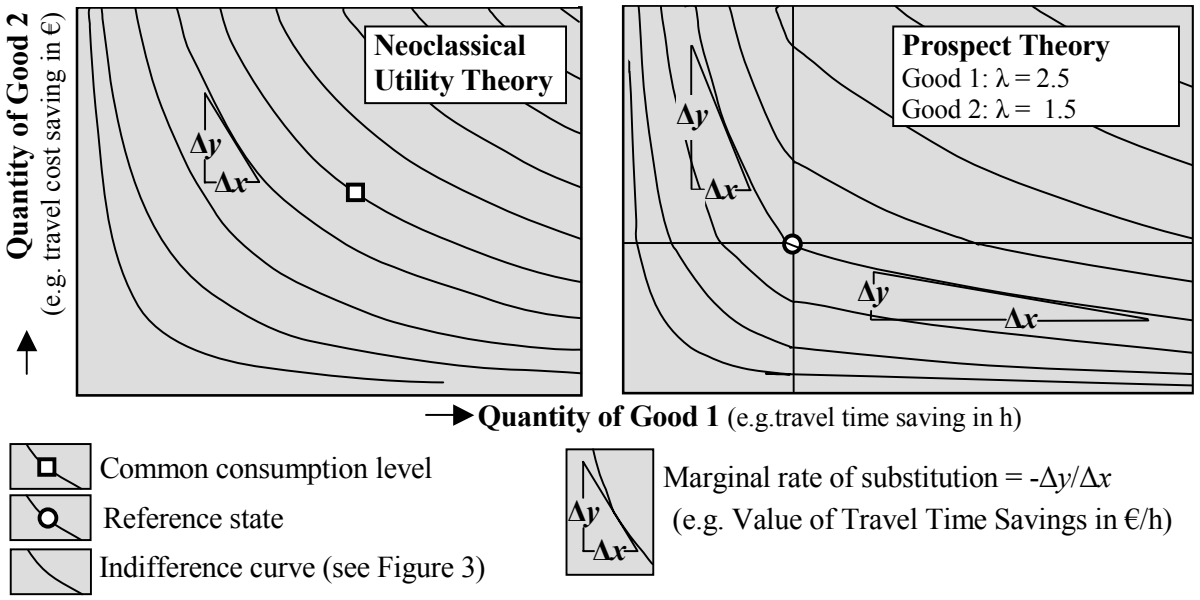


Figure 5: Indifference curves with averaged and sign dependent valuations

The significance of endowment

Loss aversion was demonstrated in a host of trading and swapping experiments with coffee mugs, cola tins, chocolate bars and the like. In such experiments it is assessed as the disparity between the selling price, or Willingness-to-Accept compensation for alienation of an object, and the bidding price or Willingness-to-Pay[50] for it. In many experiments the subjects were endowed with such goods and could trade them for money, in others they could swap them

[50] Willingness-to-Pay is defined as the amount of money that an individual is prepared to pay for the acquisition of a good (posited here). Willingness-to-Accept is defined as the amount of money that an individual is prepared to accept for the renunciation of a good that she owns.

for similar objects. In the re-examined swapping experiments very few participants were willing to swap an endowed object (e.g. Knetsch 1989; List 2004). In trading contexts the selling prices were on average much higher than the bidding prices. From twenty different experiments average loss aversion factors[51] can be calculated from selling and bidding prices ase reported in Knetsch (1989), Kahneman *et al.* (1991), Tversky and Kahneman (1991), Shogren *et al.* (1994), Loewenstein and Adler (1995), Camerer (2000), Arlen *et al.* (2002) and (Brown 2005). These yielded an average loss aversion factor $\lambda = 2.0$ (standard deviation $\sigma_n = 0.4$), at the lower end of the range from 2.0 to 2.5 reported in Kahneman (2002: 462). One should realize that this concerns an average of the mean values for all experimental subjects per experiment. In some publications the reference dependency of loss aversion was rigorously tested and confirmed with trading experiments (e.g. Bateman *et al.* 1997; Herne 1998). All experiments showed several individuals (say, 10 to 40% of the panel) who were inclined to sell the endowed object for much lower prices than the mean Willingness-to-Accept value.

In addition to loss aversion Venkatachalam (2004) mentions income constraints and transaction costs as possible explanations for the difference between selling and bidding prices, but it is hard to imagine how these could play a role in the '*instant endowment*' experiments discussed here. Brown (2005) used the verbal-protocol ('think-aloud') technique in the context of a real cash experiment in which he found a mean Willingness-to-Accept / Willingness-to-Pay ratio of 2 for inexpensive market goods. The interviewees' verbal explanations for their decisions on selling and buying prices revealed that transaction costs, income constraints and ownership *per se* were hardly ever mentioned, but '*the most commonly indicated reason for the disparity was that subjects based Willingness-to-Pay on what the good was worth to them personally and Willingness-to-Accept on what the good was worth in a sale situation … Although the endowment effect does not appear to explain the disparity, for most persons there was a reluctance to lose the value represented by the good*' (Brown: 377). Though Brown's findings might be severely biased by cognitive dissonance (see e.g. Nisbett and Wilson (1977) for extensive examples of such biases in similar contexts), they corroborate that the actual or envisaged transfers of ownership of objects, either by endowment *per se* or by the utility associated with it, largely determine the framing of choice decisions and in particular of the reference state. Either explanation fits well in the framework of PT and does not make a difference for the observed Willingness-to-Accept – Willingness-to-Pay disparity caused by instant or established endowment.

Venkatachalam (2004: 93) also mentioned the substitution effect. According to Hanemann (1991) this would result in a higher Willingness-to-Accept compared to Willingness-to-Pay when a public good is valued that has few substitutes. Most evidence for the Willingness-to-Accept – Willingness-to-Pay disparity is found in experiments where the choice objects are normal consumption goods. Venkatachalam cited authors who, even for public goods, found that '*though the substitution factor reduces the disparity it does not eliminate the disparity entirely.*'

[51] In trading contexts the loss aversion factor is the ratio between the selling price (after endowment) and the bidding price (before acquisition) for the traded good (posited here). The experiments were designed such that the acquisition might be considered as a common buying experience, like in real-life transactions in which '*money held for spending*' appears hardly susceptible to loss aversion (Kahneman and Tversky 2000b: 483). The loss aversion factors as elicited in trading contexts can thus be considered to reflect the ratios between the marginal psychological values of the decrease of one's assets with the concerned object and the increase in assets by adding of the same object to it, which connects the definitions of loss aversion as posited here for trading contexts and in Section 3.3 for choice contexts.

Loss aversion in routine transactions

Plott and Zeiler (2005) investigated the Willingness-to-Pay and Willingness-to-Accept for mugs by students, having given them very detailed explanations of how they should rationally assess a selling or buying price. They found no difference in mean Willingness-to-Accept and Willingness-to-Pay values. However, one should realize that before the bidding started they 'endowed' the mugs physically to all participants: '*all subjects were handed a mug before the start of the round*' (Plott and Zeiler: 539), with the alternative to sell for members of a Willingness-to-Accept group, and with the alternative to keep it by buying it formally for members of the Willingness-to-Pay group. Thus both Willingness-to-Accept and Willingness-to-Pay might be considered to express the strength of the inclination to continue the endowment. They also reviewed nineteen publications about Willingness-to-Accept and Willingness-to-Pay, of which eleven concerned trading behaviour with respect to physically endowed objects. They found an endowment effect in ten publications. Two of these showed that with extensive information, proper instruction or experience the initially observed effect diminishes or even disappears (Shogren *et al.* 1994; 2001). Eight more studies concerned environmental goods, road safety, securities, lottery tickets and credits versus books. For five of these latter publications the authors report an endowment effect. Plott and Zeiler (2005) indicated the findings of Arlen *et al.* (2002) as '*not reporting a Willingness-to-Accept – Willingness-to-Pay gap*'. But these latter authors definitely confirmed the endowment effect for mugs in the standard experimental setting, though they found that it almost disappeared in a within-firm simulation where the mug was considered as a production factor, which made the subjects focus on the exchange value of the mugs for trade. List (2004) also found that dealers as well as very experienced consumers (more than 6 trades monthly) of sports memorabilia demonstrated 'normal' (loss-neutral) swapping behaviour.

These findings are in line with the repeatedly expressed caveat of Kahneman and Tversky (2000b: 483) that loss aversion does not apply to '*Three categories of exchange goods (:) money held for spending, goods held specifically for sale, and "bargaining chips", goods that are valued only because they can be traded*' (see also Kahneman and Tversky 1984; Tversky and Kahneman 1991). Loss aversion in trading experiments should thus disappear after extensive instruction and/or when transfer of ownership becomes a routine, as was demonstrated several times (Shogren *et al.* 1994; 2001; Arlen *et al.* 2002; List 2004).

The 'Status Quo bias'

In view of the observed importance of endowment, subjects will often choose the status quo of their assets as the reference state. Then the choice set may comprise this reference state and one or more alternatives. In such contexts loss aversion explains a status quo bias if one or more attributes of the alternatives are framed as gains and others are framed as losses: '*Because losses loom larger than gains, the decision maker is biased in favour of retaining the status quo*' (Kahneman and Tversky 1984: 348). Samuelson and Zeckhauser (1988: 36; 41) found extensive status quo preferences for participants in several choice experiments and two large field studies of health coverage and pension fund choice decisions. They found that the '*status quo bias…is consistent with, but not solely promoted by, loss aversion; it is a natural consequence of many well-known psychologically based deviations from the rational choice model. As a result the canonical* (i.e. utility maximizing) *choice model is unlikely to provide a reliable explanation for a substantial range of behavior*'.

Samuelson and Zeckhauser considered that transition costs (including transaction costs) and search costs played an insignificant role in their surveys but mentioned some psychological

commitments like sunk costs and regret avoidance[52] as additional explanations. However, though these commitments are not losses in a monetary sense they can definitely be framed as expected losses with respect to some affectively valued attribute. The authors apparently conceived gains and losses in a rather strict, cognitive if not monetary sense. When we presume that an individual perceives and values gains and losses at least partly affectively their description of psychological commitment effects on choice behaviour may by and large be attributed to loss aversion.

Another psychological factor that is sometimes put forward to explain a status quo bias is mental inertia[53] (e.g. Meyer *et al.* 1997; Hirschleifer and Welch 2001). It was proposed as an explanation for different values for decreases and increases of travel time in the 1994 UK value of travel time survey (Bates 1999; Mackie *et al.* 2001a) but Van de Kaa (2005) showed that this explanation did not hold and that the differences should be attributed to loss aversion. Also the findings from the endowment experiments summarized above suggest that inertia is not a plausible generic explanation for the status quo bias.

More empirical support

Thus, both the endowment effect and the status quo bias can, at least to a large extent, be explained by the notion of loss aversion, as stated by Kahneman *et al.* (1991). Loss aversion has since been demonstrated in many disciplines. For example, Bateman *et al.* (1997) tested the validity of Neo-classical Utility Theory and PT formally in a stated preference survey where they controlled for income and substitution effects. They concluded that they had to reject the null hypothesis predicted by Neo-classical Utility Theory that there was no association between implicit preferences and reference state. Johnson *et al.* (1993a) investigated differences in valuation of deductibles of insurance premiums (framed as losses) versus rebates of equivalent size (framed as gains). They found that most participants chose the, effectively, more expensive rebate alternatives. Many more choice experiments and stated preference surveys supported the soundness of loss aversion. Several are documented in the references to this book.

Evidence for loss aversion in real-life choices is less extensively studied. In addition to the field studies about the choice of health coverage insurances and pension funds by Samuelson and Zeckhauser (1988), Johnson *et al.* (1993a) demonstrated the effect of the status quo-dependent assessment of the reference state on the preferences of drivers for automobile liability insurance alternatives. MacNair and Holmes (1998) evaluated the bureaucratic decision making of the USDA Forest Service concerning 57 environmental impact statements and found that it followed the principles of loss aversion much better than those of random utility maximization, though a slightly better fit was found for an ideal points model (decreasing utility beyond some optimum level). Camerer (2000) reports some more publications that demonstrated loss aversion in everyday life, concerning: the equity premium of stocks and bonds on the stock market, assuming an annual mental account; the continuation of a reference consumption level while the income decreases, based on a single year mental account; the early quitting on busy days by cab drivers, resulting from a daily income target frame; the popularity of long shots at the end of the day in racetrack betting; and larger price elasticity after price increases than after decreases when the subject brackets purchases of one

[52] See Loomes and Sugden (1982), Mellers (2000) and Brandstätter *et al*. (2002) for further explanations of regret avoidance and similar phenomena. For the inclusion of sunk costs and regret avoidance in decision framing see Thaler (1980).

[53] i.e. a '*disinclination to act or exert oneself*' (SOED 2002).

specific good[54]. Genesove and Mayer (2001: 1255) demonstrated the role of loss aversion during the 1990-1994 collapse in the Boston residential real estate market. They found that '*sellers subject to losses set higher asking prices of 25-35% of the difference between the expected selling price of a property and their original purchase price*'. These loss-aversive sellers either withdrew from the market or attained a selling price that was 3-18% higher than this difference, at the cost of a relatively long time on the market. Rizzo and Zeckhauser (2003) showed that the income growth of young American physicians can be explained when the subjective judgment of an adequate income level in their career stage is taken as the reference state: the income growth of those with an original actual income level below the reference state moved much more than of the physicians with an income above the self-assessed reference. However, in almost all these references as well as in the instant endowment experiments some 10 to 40% of the panel members might have valued the attributes loss neutral.

Valuation of public goods

For the elicitation of the value of public goods, like nature conservation, environmental pollution or transport safety, most often the contingent valuation method is followed. As people do not buy these goods normally, it may be assumed that they have neither easily accessible beliefs about the monetary value nor heuristic rules to derive them from accessible or perspective information. This makes the valuation highly sensitive to anchoring effects as mentioned in the preceding subsection.

In contingent valuation of Willingness-to-Pay for public goods it is often observed that many participants are prepared to pay a relatively high sum for the separate alternatives of the choice set compared to that for the choice set as a whole. This is called the embedding effect or the part-whole bias (Kahneman and Knetsch 1992: 58): it occurs if '*the same good is assigned a lower value if Willingness-to-Pay for it is inferred from Willingness-to-Pay for a more inclusive good rather than if the particular good is evaluated on its own*'. This may be attributed to 'reframing' of the survey questions by interviewees who conceive the elements to fulfill a broader goal than the researcher meant. In particular, in contingent valuation of environmental goods or other 'good causes' an individual may value the 'moral satisfaction' she will gain when contributing to any of the elements of the choice set or the choice set as a whole. Thus, a person may have the intention to allocate a certain budget for e.g. nature conservation. Responding to a stated preference survey she may sincerely state her Willingness-to-Pay a certain amount for any of the alternatives in the questionnaire. The underlying motive for this particular choice behaviour is sometimes termed the warm-glow or feel-good bias.

In a later article, Kahneman *et al.* (1999b) suggested that the stated Willingness-to-Pay for this type of public goods could be conceived as attitude expressions. They presumed that just one 'prototype' often equals the attitude to a set of similar public goods and thus the size of the set is neglected. The affect heuristic (Slovic *et al.* 2002) can be used to arrive at a valuation on a 'good-bad scale' of feelings with a purely hedonic as well as with a social-normative, ethical and/or deontological origin. However, affective valuation by humans is largely scope-independent (Kahneman *et al.* 1999b). For example, for species protection the affective appeal of the individual animals or plants rather than the number of individuals that are saved determines differences in value. When the relevance of scope for the valuation is pointed out to respondents, for example by varying it systematically from one choice to

[54] He cites a study that found for orange juice a ratio of around 2.4 of loss and gain respective to a reference price, based on observed purchases (Camerer 2000).

another, the valuation of different scopes is strictly additive to the global judgment: '*both the dollar measure and the rating of importance exhibit nearly perfect additivity of the effects of species popularity and size of population decline*' (Kahneman *et al.*: 654). The same subadditive valuation of scope was also found for the aversiveness of sounds as a function of loudness and duration (Kahneman and Frederick 2002).

The contingent valuation method requires that their values be mapped to a monetary scale. As discussed above, people have problems with cross-dimensional mapping when the scale of the target attribute has no upper limit, as is the case with the monetary value. When the experimenter provides no anchor, respondents will choose one that is internally consistent but results in large individual differences in the valuation (Kahneman *et al.* 1999b; Kahneman and Frederick 2002). This phenomenon may also explain the enormous differences in Willingness-to-Accept and Willingness-to-Pay that are once in a while reported for public goods like safety and nature protection: an individual might value a suggested further decline as 'this is the bloody limit!' and state very high Willingness-to-Accept levels, without caring too much for an improvement of the status quo. No need to say that the stated values are not a guarantee that the respondents will 'buy' those public goods in the real world. For an extensive overview of embedding effects and the warm-glow bias in contingent valuation studies, see Venkatachalam (2004).

Diminishing sensitivity

PT presumes a diminishing sensitivity for increases in both gains and losses. Tversky and Kahneman (1992) proposed it to describe the decreasing per unit values of monetary attributes at increasing attribute levels. They suggested a value 0.88 for the exponent, based on observed choices between prospects with monetary outcomes in which the extension of the gains and losses amounted to a few hundred dollars. Compared to loss aversion, empirical evidence for this premise is less commonly reported. Some exceptions are the results of experiments in Hong Kong (Wong and Kwong 2005) and Finland (Herne 1998: 191). The latter author claimed: '*the results give support to…the loss aversion and diminishing sensitivity hypotheses. Evidence of the influence of diminishing sensitivity is of particular importance because it has not been tested in previous studies*'.

Hedonic adaptation

Diminishing sensitivity is generally attributed to hedonic adaptation. It may be caused by shifting adaptation levels and/or by desensitization with increasing intensity or duration of a stimulus. Frederick and Loewenstein (1999: 307) found some evidence that '*hedonic adaptation to improvements is faster than hedonic adaptation to deteriorations*'. They reviewed the literature on hedonic adaptation with respect to four types of undesirable and four types of desirable experiences. This showed that the pace of the adaptation process strongly differs between these domains. For the 'undesirable' domain of noise they even found convincing evidence of a sensitization effect at increasing exposure duration. Earlier, Dawes (1988: 185-186, his emphasize) mentioned that '*Coombs enunciated a very simple principle that implies moderation:* ***good things satiate and bad things escalate****. This principle has reference to choosing between alternatives that vary in* ***amount***'. Dawes reconciled this with PT by suggesting that the 'bad things escalate' principle concerns a generalization from past experience, whilst the framing and valuation of the corresponding loss in PT refers to the imagination of future consequences, and alternatively '*it's not true in many contexts that "bad things escalate"*'(Dawes: 189). Many findings in literature support the alternative explanation, and his first suggestion might be in line with the observed gap between decision utility and remembered utility (Kahneman 1999; Bennett *et al.* 2004). Anyway, no evidence was found that the values of

losses as expected after an experience in a choice situation systematically decrease faster than those of the expected gains. From this perspective one might wonder if loss aversion should not be incorporated in normative models of choice behaviour!

4.3.5 Valuation of probabilities

A basic principle of Expected Utility Theory in choice contexts with probabilistic or uncertain outcomes is the assumption of a linear-additive composition of the utility of outcomes and the corresponding probabilities of their occurrence into an expected utility. Following Allais (1953) many studies showed that participants commonly violate this linearity principle of Expected Utility Theory both in experiments and in their real-world behaviour. In their introduction of PT Kahneman and Tversky (1979) gave an early overview of such findings and explained the popularity of lotteries and insurances by, for example, the overweighing of small probabilities and attributed the observed risk seeking in choices involving sure losses to the under-weighting of high probabilities. Machina (1987) gave an overview from an economist's perspective and listed five different previously published non-linear transformations of probabilities, including PT. Viscusi (1989) proposed a linear weighted probability function under what he called Prospective Reference Theory. Tversky and Kahneman (1992) referred to this and other reviews and recognized Quiggin (1982) as the inventor of the cumulative functional, another transformation listed by Machina, that they integrated in their Cumulative Prospect Theory.

In Cumulative Prospect Theory, the findings from Tversky and Kahneman's choice experiments concerning gambles with given probabilities fit nicely into an inversely S-shaped weighted probability function of expected probability, in which the weighted probability is equal to the expected probability for certain outcomes, i.e. $p = 0$ and $p = 1$, as well as for $p \approx 0.35$ (Tversky and Kahneman 1992). They also found small differences in the weighted probabilities between positive and negative prospects with the same expected probability, but in seven studies, involving activities including sports games, climate and stock option trades, Tversky and Fox (1995) and Fox and Tversky (1998) did not find significant differences. Gonzalez and Wu (1999) assessed the shape of the probability weighting function with a nonparametric estimation method. Their experiments concerned choices between certain outcomes and gambles with outcomes in the gain domain. All subjects exhibited an inversely S-shaped weighted probability function. They found, however, large interpersonal variations in the curvature and elevation of that function.

Prelec (1998; 2000) evaluated several empirical estimates and found that they fitted well to a two-parameter function and to a single parameter function with inflexion point at $p = e^{-1} = 0.368$ (see Figure 6). Stott (2006) investigated seven formulations of value functions, seven weighted probability functions and four stochastic models of interpersonal heterogeneity. He compared the explanatory performance of 256 models of different combinations of these formulae with stated choice outcomes. It appeared that a power value function combined with Prelec's one-parameter weighted probability function and a Logit model offered the best match.

Bleichrodt *et al.* (2001) developed a method, based on PT, to resolve discrepancies in 'normative' utilities caused by different elicitation methods. They tested it in an experiment in which, instead of prospects with monetary outcomes, they used assumed medical treatments as alternatives, with expected survival in terms of remaining years of healthy life. It appeared that the discrepancies could be attributed to loss aversion and the probability weighting by

respondents. The values for the loss aversion factor and probability weighting function were of the same order as suggested by Tversky and Kahneman (1992).

Several real-world applications of PT under risk and uncertainty concern gambling and insurance decisions. Camerer (2000) enumerates studies in which betting on long shots in horse races corroborates the assumptions of PT, and shows that in particular the shift to relatively more long shot betting at the end of the day can be explained by loss aversion in combination with a daily account. Wang and Fischbeck (2004) report a study in which they presented decision frames with different reference states for the same health insurance choice decision to panels of Chinese and American citizens. Consistent with PT most Chinese and Americans chose the sure alternative in the gain frame. In the loss frame only the Chinese were risk seeking while all Americans bought the health insurance[55]. The latter result supports the theory that in the loss domain the risk attitude is less stable than PT suggests (see references in Wang and Fischbeck 2004). Starting from the assumption that different individuals/groups use different reference states the authors present an interesting model of PT that allows for the elicitation of different reference states. Also experiments and real world surveys by Brandstätter *et al.* (2002) support the weighted probability-concept.

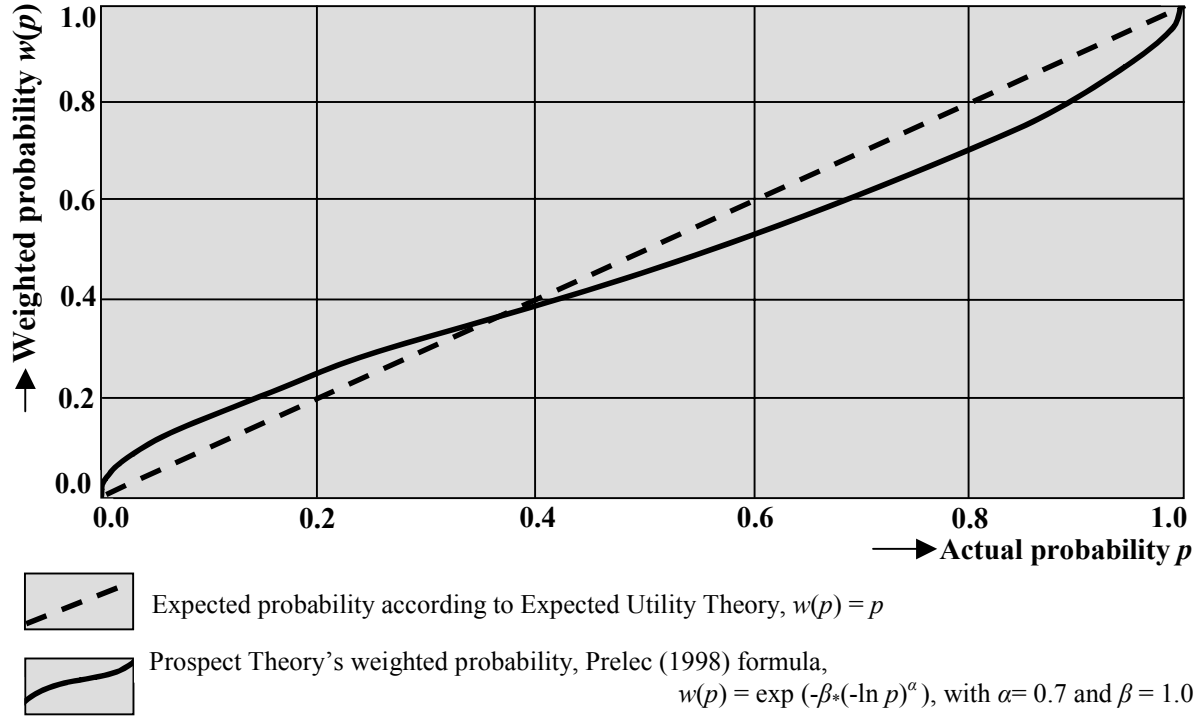


Figure 6: Example of a Weighted Probability function

Unsuspected support for the weighted probability concept comes from Levy and Levy (2002) who analysed three choice experiments and concluded that the outcomes were inconsistent with PT. Wakker (2003) showed that their results would have fitted well with PT, had they not disregarded the probability weighting function.

However, the empirical evidence supporting the weighting functions above is constrained to $p > 0.01$. Slovic *et al.* (2004) referred to a study in which the feelings of subjects towards

[55] The cultural differences remain puzzling, even though one cannot exclude the possibility that the Americans 'reframed' the loss frame, offered to them into a 'status quo' frame.

lotteries with probabilities of 10^{-4} and 10^{-6} to win were virtually the same. In a traffic safety context De Blaeij and Van Vuuren (2003: 174) also observed that for '*bad outcomes*' and $p<0.01$ subjects '*base their decision on the possible outcomes rather than on the probabilities involved*'. In view of their findings one might wonder if many individuals value differences in very small probabilities at all.

Several other theories were proposed that explain the violations of Expected Utility Theory. Regret theory (e.g. Loomes and Sugden 1982) disregards probability weighting and offers an alternative explanation for the violations of Expected Utility Theory by assuming that subjects expect to experience regret or rejoice, depending on whether the outcome of the chosen alternative is as desired or that the rejected alternative would have yielded a better result. Kahneman and Tversky (1991) showed that Cumulative PT explains several probabilistic choices that are inconsistent with Regret Theory and another alternative, the '*Skew Symmetric Additive model*' (Fishburn 1988).

Tversky and Kahneman (1992) attributed the non-linear weighting of probabilities to diminishing sensitivity to gains and losses at increasing distances from the '*certain*' ($p = 1$) and '*certainly not*' ($p = 0$) references. Gonzalez and Wu (1999) interpreted the inverse S-shape as a consequence of the psychophysical near-synonym of discriminability of probabilities. They considered that differences in the height of the function, i.e. the degree of underweighing and overweighing, might be attributed to interpersonal and intrapersonal differences in the attractiveness of gambling/risk seeking between different domains. Subjective Expected Pleasure Theory (Mellers 2000) attributes values for the anticipated rejoice and disappointment to the different possible outcomes of the chosen alternatives. Brandstätter *et al.* (2002) also explained it as a consequence of expected elation and disappointment with respect to the outcomes of the chosen alternative. The probability weighting function, as assessed in Tversky and Kahneman (1992), was closely matched by adding the expected elations and expected disappointments to each corresponding objective probability. Their empirical data and those of Mellers (2000) supported these findings. Brandstätter *et al.* (2002: 95) concluded that over and under weighting refer to a normative standard, but that in view of their findings '*there is nothing non-normative about accounting for emotions that are expected to be experienced*'. Thus, where even in a normative model of choice behaviour one might consider to incorporate probability weights they seem indispensable in a descriptive model.

4.3.6 Summary of findings about judgment

In addition to accessible knowledge and natural assessments of perceived information, heuristic judgment plays a crucial role in the assessment of the probabilities, contingencies and outcomes of alternatives. It may result in sub-optimal assessments and even in completely overlooking of the scope in the valuation of public goods, though in most instances it yields at least satisficing results. For a descriptive model of choice behaviour the UT assumption of exclusively rational and/or belief-based assessment of attribute levels has to be rejected. This also holds for the assumption that all attribute levels can be valued in a commensurable medium. Subjects often frame alternatives as a mixture of cognitive and affective attributes that are valued on non-commensurable dimensions. These may either be intuitively integrated into some qualitative affect scale or be evaluated with a non-compensatory decision rule. Depending on which strategy a subject follows she assesses a complete set of subjective attribute decision weights or confines herself to an importance ordering of attributes. Likewise a descriptive theory should include loss aversion (with $\lambda \approx 2.0$ as a first shot), diminishing sensitivity and weighted probabilities. However, in many studies some 10 to 40% of the panel

members either framed all attribute levels in the gain domain or valued them loss neutral, so this possibility should be included in a descriptive model as well.

4.4 Evaluation-and-choice

Once the values for the attributes of alternatives are assessed, sufficient information is available for their evaluation against the subject's aspiration level. This section explores the scientific literature, particularly of Decision Theory, on theoretical and empirical findings about the evaluation-and-choice function. This is treated here as a functional description of the largely covert mental processes that do the same job. It is common practice to assume that individuals evaluate and choose by applying '*decision rules*'. To clarify the meaning of that term, this section starts with the definition and categorization of decision rules in connection with the evaluation-and-choice function. Successively it gives an overview of manifestations and evidence of the use of decision rules that account for the evaluation-and-choice function. It is concluded with a short summary of findings with respect to the descriptive performance of the assumptions of UT, PT and other concepts from Decision Theory.

4.4.1 Interpretation and categorization of decision rules

In scientific literature, decision rules may be called decision heuristics (e.g. Huber 1989; Payne *et al.* 1999) or decision strategies (e.g. Dawes 1988; Rieskamp and Hoffrage 1999), even in the same article (e.g. Payne *et al.* 1996; Gigerenzer and Todd 1999). This book follows the interpretation for heuristics as given by Kahneman and Frederick (2002), see previous section, and thus refrains from its use as a synonym in this context. Likewise, the term '*decision strategy*' will be avoided as a synonym of decision rule, as several authors use this also in a wider meaning, in which sense it might more appropriately be considered as the '*choice behaviour strategy function*' (e.g. Karlsson 1989; Payne *et al.* 1993).

Thus far no concise definition of decision rule has been found in the scientific literature on decision making. Combining the semantic meanings of the constituent words in common English it is '*a principle, regulation, or maxim governing individual conduct concerning the action of coming to a determination with regard to any point or course of action*.' It may be more appropriate to define it in terms like 'a series of routines that a subject applies to select one alternative from a choice set'. Decision rules should at least comprise two of these routines: an 'evaluation algorithm' for the assessment of the relevant value(s) of the alternatives and a 'choice decision algorithm' in terms of rejection or selection of alternatives as a consequence of the comparison of these with the criterion that suits the subject's aspiration level. Conceived in this way it is an operational tool employed by subjects to execute the mental function of 'evaluation-and-choice'. However, in the scientific literature on human decision making it appears to be employed mostly as a functional description of the largely covert mental processes that do the same job. In this book it will be used in the latter sense. Refraining from the discussion as to whether or not such rules might be isomorphic representations of these mental processes, this interpretation might include very complex procedures like subjective expected utility calculations or complete compensatory assessments of overall utilities of many multi-attribute alternatives.

Focussing on evaluation, the most commonly employed categorization is in compensatory and non-compensatory rules (e.g. Foerster 1979; Edland and Svenson 1993; Payne *et al.* 1993). According to Edland and Svenson (1993: 32) '*in compensatory rules, a poor evaluation on one attribute may be compensated by a positive evaluation on another attribute (e.g., high rent may be*

compensated by a nice location of a flat). In non-compensatory rules, this is not possible (e.g., a poor location of a flat makes it an impossible choice)'. This distinction is similar to that between an alternative-wise comparison, in which one overall value per alternative is evaluated against some criterion, and an attribute-wise comparison, where the alternatives are evaluated with respect to the values of one or more attributes (e.g. Payne *et al.* 1996). Compensatory rules are often based on some kind of linear-additive compounding of attribute values. Most non-compensatory comparisons are based on either lexicographic or elimination principles or combinations of them. Lexicographic rules presuppose that subjects rank the attributes in order of importance and evaluate the alternatives in that order, commonly by choosing the alternative with the highest value on the most important attribute. Attribute-Based Elimination rules assume that alternatives are rejected if the value of any important attribute does not surpass a certain threshold. However, several well-known non-compensatory rules do not fit into these two subcategories. In this section the individual decision rules are classified into four groups: compensatory, lexicographic, elimination and other non-compensatory decision rules.

With respect to choice proper, and leaving random choice out of consideration, decision rules may select an alternative that complies with either a maximizing or satisficing aspiration level (e.g. Simon 1955; Gigerenzer and Todd 1999). Most commonly, the maximizing principle is presumed. When an individual follows a lexicographic rule this implies that after valuation of the only relevant (or most important) attribute of each alternative the one with the highest value is chosen. The same holds for a compensatory evaluation of a set of multi-attribute alternatives. Attribute-Based Elimination rules are principally of the satisficing type. The application of a satisficing criterion is, however, less straightforward. Of course, subjects may select the first alternative that meets the 'numerical' aspiration level if they have set one (Simon 1955). But often other procedures are followed. The higher the number of alternatives in the choice set the more often this might be the case. Dawes (1988: 53-54) illustrates three alternative choice behaviour strategies to implement a satisficing decision rule for the selection of a secretary out of a hundred applicants: (i) When the decision maker knows how to judge the qualifications of the secretaries she can go on interviewing until she finds one in the top-five, which requires an average of seventeen interviews. (ii) When she has no pre-set aspiration level she may just interview, say 20, randomly chosen subjects and take the best one, resulting in a 68% chance to select one of the top-five. (iii) Alternatively she may first interview a pre-set number of say fifteen randomly chosen applicants and successively select the next candidate that is better than any of the previously evaluated ones. For the latter case, Dawes found a probability of 83% to pick one of the top-five candidates, with an expected search length of 29 interviews. Later on, Todd and Miller (1999) presented the latter approach as their take-the-next-best rule: the subject first evaluates (and rejects) about a dozen candidate-alternatives, next takes the best of these rejected alternatives as aspiration level and next selects the first alternative that meets this level.

4.4.2 A review of decision rules

There are many different specific decision rules reported in the scientific literature. Those most commonly encountered in marketing science and in the literature on judgment and decision making are interpreted below under the headings compensatory, lexicographic, elimination and other non-compensatory rules.

Compensatory decision rules

Compensatory decision rules are most often concluded by the selection of the alternative with the highest value or utility. However, those same compensatory procedures can be used to evaluate alternatives in any sequence and choose the first one that meets a satisficing value (Simon 1955). Moreover, compensatory routines may be applied in two-stage decision rules following a first-stage non-compensatory elimination rule.

The Weighted Additive decision rule

The most commonly reported compensatory rule in quantitative research is the Weighted Additive decision rule (Payne *et al.* 1993). It goes under several other names as well, like Weighted Additive Value rule (Johnson *et al.* 1993b) and Additive-Linear rule (Sundström 1989). Dawes (1979) traced the origin of this concept back to Benjamin Franklin (see Annex A) and later on Gigerenzer and Goldstein (1999) called it '*Franklin's rule*'. There are several, slightly different formal definitions (Sundström 1989; Payne *et al.* 1993) that all fall inside the scope of the following circumscription: The Weighted Additive decision rule assumes that the importance or relevance for the decision maker of each attribute is expressed in a subjective attribute decision weight independent of the attribute values. Mostly it is assumed that the characteristics of different attributes are valued in the same measure, for example, money. When attributes are valued in different measures, e.g. for time and money, the weight factor may also take the conversion into account. The subject multiplies the attribute values of all alternatives with the relevant attribute decision weights, and next adds these products for each alternative. The alternative with the highest Weighted Additive value is chosen.

Attitude Theory and Theory of Planned Behaviour assume the same procedure to convert beliefs and belief strengths into one over-all behavioural intention (Fishbein 1963; Ajzen and Fishbein 1980; Ajzen 1991). Also most Logit-type Random Utility Maximization models presume this decision rule (e.g. Foerster 1979). For uncertain outcomes of choice processes, the equivalent rule is the Subjective Expected Utility rule and its synonyms like '*Highest Expected Utility rule*' (Hanna and Sun 1999), '*Expected Value rule*' for the choice between probabilistic prospects valued in money and '*Expected Utility rule*' when the utility of each outcome is substituted for its monetary value (e.g. Montgomery 1989). It draws on subjective probability expectations (Manski 2004). The attribute decision weights are multiplied by the corresponding probabilities of occurrence (e.g. Johnson *et al.* 1993b). A PT-consistent alternative, of which no reference could be found thus far, might use a weighted instead of an expected probability.

The Linear-additive compensatory rule

When the assessment of subjective attribute decision weights is considered as part of the judgment function of a functional-descriptive theory of choice behaviour, the preceding decision rule is reduced to a Linear-Additive Value rule. This is equivalent to the linear-additive multiple regression model (e.g. Tversky 1969; Foerster 1979) that is often used to assess the mean values (and variance) of the weight factors that survey populations are supposed to apply. However, in these evaluations each individual is commonly supposed to follow this rule after a loss-neutral valuation of attribute characteristics following the assumptions of UT. From the preceding chapter, one might expect that compensatory models drawing on a loss-neutral valuation of attributes may simulate a descriptively effective choice behaviour strategy for a minority of the population only. However, such models may just as well be applied to alternatives valued according to the principles of PT.

Other weighted linear-additive rules

Several computationally less demanding versions of the Weighted Additive rule are encountered in the literature on decision making. The Equal Weight rule (Payne *et al.* 1993) arises when an individual sets the attribute decision weights at unity. This is also called the Sum-rule (e.g. Edland 1993) or Equal Weight Additive Value rule (Johnson *et al.* 1993b: 105): '*like weighted additive value, it examines all alternatives and attributes values but ignores the weights (probabilities). It sums the attribute values for an alternative to get an overall score for that alternative and then selects the alternative with the highest evaluation*'. It evidently requires that attribute characteristics are valued in the same measure. Maybe the most well known is '*Dawes' rule*', as Gigerenzer and Goldstein (1999) coined it. It follows from the work of Dawes (1979), recapitulated above, and '*simply adds up the number of positive cue factors and subtracts the number of negative cue values*' (Dawes 1979: 84). Once more, the alternative with the highest value should be chosen. As mentioned above, this simple rule performed remarkably well in many judgment contexts reported in Gigerenzer *et al.* (1999). Similar is the Frequency of Good and Bad Features decision rule (Alba and Marmorstein 1987, as referred to in Payne *et al.* 1993). Rieskamp and Hoffrage (1999) called a slightly modified version the Good Features rule. A good feature of an alternative is an attribute value that surpasses a specified cut-off value. For each alternative the number of good features is assessed and the alternative with the highest number is chosen. It is easy to see that when the cut-off value is set at zero this rule does the same job as Dawes' rule. Very close to the Equal Weight rule is the Majority of Confirming Dimensions decision rule (Russo and Dosher, 1983, as referred to in Payne *et al.* 1993). It evaluates pairs of alternatives on each attribute and selects the alternative that has higher scores or values on the majority of attributes than any other alternative. The Weighted Pros decision rule (Huber, 1979, as referred to in Rieskamp and Hoffrage 1999) follows the same pair-wise evaluation process. Any attribute of an alternative that has a higher value than that of the 'other' alternative is called a 'Pro' for the alternative. These Pros are multiplied with the attribute decision weight before they are summed for each alternative. The alternative with a higher sum of weighted pros than any other alternative is chosen.

These latter five simple compensatory rules all share the common feature that the nature of the evaluations is relatively simple compared to the Linear Additive rule and, more importantly, that they do not require commensurability of attribute values. They are predominantly based on comparison, which is a cognitively less demanding task than e.g. multiplication and summation, and also circumvent the problem of cross-dimensional mapping. Nevertheless, all the individual attribute characteristics of all alternatives have to be evaluated and 'bad' values can be compensated. The rules are of little value in the choice between alternatives with less than three attributes as all these rules then either select the dominant alternative or they do not result in a choice. Behaviourally such rules may be plausible for the choice from multi-attribute alternatives of which a part is valued affectively. The evidence found about their use by subjects in experimental and real-life choice contexts was, however, both scarce and largely circumstantial.

Non-linear compensatory rules

In the search for a fair description of human choice based on Random Utility Maximization principles several non-linear models have been developed. Clearly, both the diminishing marginal utility function of UT and the diminishing sensitivity principle of PT presume non-linear utility or value functions. Several non-linear models consider power functions of attributes as well as interaction between attributes (e.g. Foerster 1979). What these models share with the linear ones is that they might describe averages and variance in the choice

behaviour of populations but, when applied as one deterministic expression in an econometric model in which stochastic terms catch interpersonal heterogeneity, they are less suited to account for non-stochastic differences in choice behaviour strategies. Such non-linear decision rules are also less credibly applied in human decision making than the Weighted Additive rule. Moreover, as the variations in attribute levels around the reference are generally small compared to the 'absolute' reference level, these functions can most often be approached well with a linear and kinked-linear relationship, respectively. Therefore they will be further disregarded here.

Tversky (1969) developed the more generic additive difference model for the attribute-wise comparison of alternatives. For each attribute the difference in subjective attribute values between pairs of alternatives is assessed, and to this difference a 'difference function' is applied that determines the contribution to the overall evaluation of these two alternatives. After summation over all the attributes the best alternative can be chosen. Tversky showed that the Linear Additive rule, in which the difference value functions are linear, is a special case of his rule. He stated: '*the vertical* (i.e. intra-attribute) *processing strategy is, thus, compatible with the additive model if and only if the difference functions are linear*' (Tversky 1969: 42). Several authors inferred the use of this Additive Difference rule when decision makers consider an equal number of attributes for each alternative and predominantly follow an intra-attribute evaluation (e.g. Sundström 1989), but such inferences might be considered as circumstantial evidence for its application as several other choice behaviour strategies might draw on a similar information search. Anyhow, for a functional-descriptive model this rule seems to add little to the Linear-Additive Value decision rule.

Comparison of the performance of compensatory rules

Dawes (1988) compared the goodness-of-fit of judgment by experts with that of a multiple regression model with different estimates of attribute decision weights in a linear-additive model. The judgments concerned were: the diagnosis by eminent clinical psychologists of neurosis versus psychosis from scores on a psychological test; the prediction by graduate students of the first-year performance of students from earlier assessed aptitude variables and personality characteristics; and the prediction by graduate students of the performance of senior students based on their undergraduate results. Multiple regression models with random decision weights outperformed the expert judgments and so did the Weighted Additive rule. An even better fit was found by '*unit weighting (in which) each variable is standardized and weighted +1 or –1 depending on direction*', which was considered as trivial '*because random and unit linear models will yield predictions highly correlated with those of linear models with optimal weights, and it had already been shown that optimal linear models outperform global judgments*' (Dawes: 209). In view of these results Dawes advocated deliberate choice behaviour by use of the Weighted Additive decision rule. Several empirical findings corroborated his findings: Czerlinski *et al.* (1999) demonstrated that the unit-weighted linear rule performed equivalent to multiple regression in some twenty judgment tasks; Rieskamp and Hoffrage (1999) found almost the same predictive power of both this rule and the Weighted Additive rule in a choice experiment concerning the selection of a company with the highest profit. In view of Dawes' findings, when only the 'objective' choice context and the final choices of the participants are known, it will often be impossible to figure out whether they used the Weighted Additive or the Equal Weight decision rule.

These observations underline the importance of 'rational-normative' linear-additive models as decision support tools. In the context of this book a more relevant inference may be that, as several implementations of the Linear-Additive Value rule outperform human judgment in

several contexts and presumably in real-life choice behaviour as well, this decision rule in connection with loss-neutral utility maximization is not the best functional-descriptive model for the choice behaviour of all those individuals.

Lexicographic decision rules

Lexicographic rules presuppose that subjects rank the attributes in order of importance and successively evaluate the alternatives attribute-wise in that order, commonly by choosing the alternative with the highest value on the most important attribute. Attribute-wise evaluations following a lexicographic attribute importance order may also be carried out by elimination of alternatives based on attribute cut-off levels. These latter will be treated under the Attribute-Based Elimination rules. Lexicographic rules may be employed as the first or second stage of a two-stage decision rule, together with a compensatory or elimination rule.

The Strong Lexicographic decision rule

Presumably the lexicographic rule is the most often-cited non-compensatory decision rule. Within cognitive psychology it is considered in the study of decision making from the mid-twentieth century onwards (see references in Tversky 1969; 1972). Authors often use the term '*lexicographic decision rule*' when they actually mean its Strong Lexicographic version. This rule implies that the alternative with the highest value on the most important attribute is chosen, unless two or more alternatives have the same 'highest' value on that attribute. Then the second most important attribute is evaluated in the same manner.

Compared to other answering patterns it is quite easy to establish if a respondent systematically chooses the alternative with the highest value on one attribute. Such response patterns are mostly explained as 'non-trading' choice behaviour according to the Strong Lexicographic decision rule. However, the same sequence of answers might as well be a consequence of the application of a compensatory or another non-compensatory rule. This will be the case, for example, if all values of the presumed 'non-decisive' attributes proposed by the researcher are in the 'satisficing' range. Cairns and Van der Pol (2004) found that seemingly lexicographic non-trading behaviour in a discrete choice experiment with respect to future states of illness (*x* number of days ill in year *y* from now) decreased from 45% of the respondents in an earlier study to below 1% when the interviewees were offered progressively more extreme trade-offs.

This might reduce the application of the genuine Strong Lexicographic rule to individuals with lexicographic preferences. In mainstream economics strong lexicographic preferences for consumption goods were considered and rejected as not confirmed by observed behaviour and behaviourally implausible (e.g. Houthakker 1961). Recent findings suggest that only small segments of a population may exhibit such preferences, and only with respect to alternatives or their attributes that concern public goods with a high affective appeal, based on ethical convictions regarding life-threatening eventualities, human rights, species conservation etc. Spash (2000), for instance, reports some convincing examples with respect to lexicographic preferences for environmental goods. He reports a study in which approximately 700 UK citizens were asked about their Willingness-to-Pay for the re-creation of a wetland as well as about their ethical positions regarding endangered bird species versus social interests. Spash concluded that quite a percentage of the trading respondents actually had lexicographic preferences for the re-creation, and 11% of the respondents showed this by their non-trading behaviour. Rosenberger *et al.* (2003: 64) conducted two '*paired comparison*' discrete choice experiments amongst 250 university students to assess their valuation of different private and public goods. All attributes of alternatives were in the gain

domain, thus loss aversion could not influence the results. Five private goods concerned tickets or vouchers for a meal, books, concerts or sporting events, clothing and a round-trip flight. Three public goods served the interests of the interviewees directly: a no-fee library service, extra parking garages and expansion of the eating area at the campus. Two goods, an improvement in local air-water quality and the purchase of a wildlife habitat, can be considered as pure public environmental goods. In the first experiment the presented dollar values of the goods ranged from US$10 to US$700. The proportion of potential lexicographic choosers for the five private goods ranged from 0-3%, for the three '*personal interest*' public goods from 1-9%, for the pure public goods '*clean air and water*' and '*wildlife protection*' 18 and 26%, respectively. In the second experiment the range of dollar values for the goods was extended, now ranging between US$10 and US$9,000. Extension of the dollar scale reduced the proportion of potential lexicographic choosers to 0-2%; 0-3%; 9% and 16%, respectively. Apparently only the lexicographic choices for the '*pure public goods*' were a consequence of strong lexicographic preferences. The environmental disposition of the respondents was also elicited, and evaluated as attitudes as defined in the Theory of Planned Behaviour. High valuation of the pure public goods by respondents was strongly correlated with positive disposition towards nature preservation and even more with an ethical disposition towards the natural environment.

One might therefore conclude that observations of so-called Strong Lexicographic decision rules might commonly be founded on a misinterpretation of the outcomes of another compensatory or non-compensatory decision rule, caused by a research design that does not cover the range of acceptable reservation prices. For 'pure' public goods a small but significant part of the public may have strong lexicographic preferences and thus may express this by lexicographic choice behaviour.

It is obvious that the application of the Strong Lexicographic rule demands much less mental effort than a valuation and successively a compensatory compounding of all attributes of all alternatives. However, one might observe that the Weighted Additive rule often results in the same chosen alternative, for example if the attribute decision weight of the most important attribute is higher than the sum of the weights of all other attributes. Thus this Strong Lexicographic rule is superfluous in a functional-descriptive choice behaviour theory if it contains the Weighted Additive Value rule.

Other lexicographic decision rules

The Lexicographic Semi-order decision rule (Tversky 1969; Payne *et al.* 1993) and the related '*Just Noticeable Difference lexicographic model*' (Russ 1972 as referred to by Foerster 1979) and '*Just Effective Difference lexicographic model*' (Foerster 1979) are similar to the Strong Lexicographic rule. These rules are reported for choice sets derived from Lexicographic Semi-orders '*where a semiorder or a just noticeable difference structure is imposed on a lexicographic ordering*' (Tversky 1969: 32). The just noticeable difference principle dates back to 19th century psychology (see Annex A). The rules also evaluate attributes in order of importance, but only accept the alternative with the highest value on an attribute when the difference between the highest attribute of the best and second-best alternative surpasses a just noticeable difference. As soon as this happens, the alternative with the highest value on that attribute is chosen. If this procedure does not result in a choice a second stage compensatory evaluation should do the job. Tversky (1969) designed two experiments where subjects had to make a series of choices from two alternatives at a time. The alternatives were characterized by two or three attributes, and ordered in increasing size of the first attribute that at least in the second experiment clearly was the most important. The increase in size of this first attribute

was apparently small, whilst at the same time the size of the other attributes diminished noticeably. In each of the two experiments approximately 40% of the participants preferred the alternative where the third and/or second attribute had a greater size when they had to choose from a pair of 'adjacent' alternatives (i.e. with small differences in the first attribute characteristic) but preferred the alternative with the higher value on the first attribute from pairs of 'remote' alternatives. These subjects participated in the experiments, from which indeed a 'just noticeable difference' could be inferred. The results of these experiments furthermore clearly demonstrated the occurrence of intrapersonal intransitivity of preferences in successive choice decisions.

Tversky showed that the Lexicographic Semi-order rule is a special case of his additive difference model (see previous section). He also stated that a common approximation procedure for the additive difference model is reducing the number of attributes by cancelling out those with (nearly) equal differences. He refrained, however, from the formal definition of a behavioural plausible decision rule that accounts for such a procedure. One might observe that the Lexicographic Semi-order rule just as the Strong Lexicographic one orders all attributes according to their subjective importance and selects the alternative with the highest value on the most important attribute. Thus their character is rather maximizing than satisficing as meant by Simon (1955).

Lexicographic rules from a microeconomic perspective

Supporting Houthakker's (1961) rejection of strong lexicographic preferences, Encarnación (1964) suggested what he called L*-ordering to explain some consumer behaviours that do not comply with mainstream economic theory. This is based on a rejection of the non-satiation principle of mainstream economics, by assuming that there exist upper limits of the utility derived from an increasing quantity of goods, which '*assures that any want or need is satiable with finite quantities of goods*' (Encarnación: 215). Referring to Georgescu-Roegen (1954) as the originator of this approach to consumer choice and its '*butter-margarine*' illustration, Encarnación explains that according to L*-ordering a consumer might buy an increasing quantity of margarine when her income increases within a range of low incomes. When her income surpasses a certain level the same individual might start to trade-off margarine and butter, and consume increasing quantities of butter and decreasing quantities of margarine until her income once more surpasses a certain level, above which she might only consume butter. Though mainstream economics adhered to the non-satiation principle it is easy to see that the Lexicographic Semi-order rule and several other non-compensatory decision rules can be conceived as particularizations of L*-lexicographic orders.

Attribute-Based Elimination rules

Attribute-Based Elimination rules can be conceived as satisficing decision rules. Simon (1955) suggested that people would select the first alternative in a choice set of which the over-all utility measure attains or surpasses a satisficing aspiration level, or alternatively the first alternative of which the values of all relevant attributes attain or surpass attribute-specific aspiration levels. The latter procedure apparently describes an Attribute-Based Elimination rule as meant in this book. Several rules that are called Attribute-Based Elimination rules here have been proposed in the past, differing in the sequence in which attributes are evaluated and in the criterion for the rejection or acceptance of alternatives. Most Attribute-Based Elimination rules presume that, contrary to Simon's satisficing concept, all alternatives are evaluated. This implies that often several – or no – alternatives may remain in the end.

The Conjunctive rule

The Conjunctive decision rule presumes that '*the chosen alternative must meet requirements for all attributes*' (Dawes 1964, as cited in Swait 2001: 906). This definition complies with the attribute-based interpretation of aspiration levels according to Simon (1955). Not surprisingly, Payne *et al.* (1993) coined it the Satisficing decision rule. Foerster (1979) referred to one publication reporting the use of satisficing threshold values and another article with evidence that clinical diagnoses are often based on the Conjunctive rule. One should observe that the Conjunctive rule with satisficing cut-off levels definitely falls within the satisficing concept as cited above but that several other rules do as well. Foerster (1979: 21) remarks that conjunctive rules cannot be used to make unique choices but '*conjunctive processes can be used to sort out acceptable and unacceptable alternatives, and a second process (perhaps additive or lexicographic) can be used to make a selection from the set of acceptable alternatives.*'

Elimination-by-Aspects

This decision rule was proposed by Tversky (1972) and may be the most well known Attribute-Based Elimination rule. It makes Simon's attribute-wise aspiration levels work in a choice process that is considered probabilistic. Tversky views each alternative as a set of aspects that may or may not be present in the alternative. Quite implicitly, Tversky (1972: 284, 285) defined aspects[56] as dichotomies indicating whether or not features or ranges of attribute values are acceptable for the decision maker: '*each alternative consists of a set of aspects of characteristics…In contemplating the purchase of a new car, the first aspect selected may be automatic transmission: this will eliminate cars that do not have this feature…(next) another aspect, say a $3000 price limit, is selected and all cars whose price exceed this limit are excluded*'. The sequence in which attributes are evaluated is chosen with a probability that is equivalent to the relative weight (importance) of the aspect with respect to the sum of the weights of all possible aspects. An alternative that does not contain the aspect is eliminated from the choice set as soon as the relevant attribute is evaluated. As soon as only one alternative remains this is chosen and the remaining attributes are not evaluated. Note that, contrary to Simon's proposal, all alternatives in the choice set are evaluated.

From the preceding it seems clear that, like the conjunctive rule, Elimination-by-Aspects may result in several remaining alternatives (for low threshold values of attributes and/or few attributes). To arrive at one chosen alternative it is commonly presumed that an individual evaluates the remaining alternatives (or re-evaluate the rejected alternatives) with a second-stage compensatory or lexicographic rule. Another approach might be to adjust the cut-off level of one or more attribute until only one alternative is chosen (Manrai and Sinha 1989). In an experimental setting one might take precautionary measures to ensure that only one alternative is chosen. Ouwersloot (1994) did so in an empirical analysis of communication media choice by university personnel in different European countries. He compared the goodness-of-fit of predicted and observed choices of an Elimination-by-Aspects model and a Logit-type model and concluded: '*in a statistical sense Logit performs unequivocally better. Yet … the much richer possibilities of interpreting the results make the Elimination-by-Aspects model an interesting and serious alternative to the Logit model*' (Ouwersloot: 163-164).

[56] This book follows Tversky's (1972) definition of aspect, just as e.g. Manrai and Sinha (1989) did in their Elimination-by-Cutoff model. Also Payne *et al.* (1993), to mention another example, followed this interpretation when stating '*The "aspect" is defined as having a value on the selected attribute that is greater than or equal to the cutoff level*'. Other authors define aspects as '*the values of each attribute*' such as '*a certain rent or a certain size (of an apartment)*' (Montgomery 1989: 24), but these are called 'attribute levels' here, to avoid confusion with the interpretation of attribute value as used in this book.

Other Attribute-Based Elimination rule
Many authors refer to Elimination-by-Aspects when they actually mean a lexicographic sequence of evaluations in attribute importance order (e.g. Sundström 1989; Johnson *et al.* 1993b). Others, like Payne *et al.* (1993) and Rieskamp and Hoffrage (1999), mention the right probabilistic definition of Elimination-by-Aspects but indicate that they use it in the non-probabilistic way. The Take-The-Best heuristic (Rieskamp and Hoffrage 1999) is a lexicographic decision rule for two-alternative ordering, but as the attribute levels are transformed into binary numbers (or dichotomous aspects) this might better be considered as a particularization of the Elimination-by-Aspects rule, with a fixed lexicographic instead of probabilistic sequence of attribute evaluations, see Berretty *et al.* (1999) for a similar opinion. Berretty *et al*.'s categorization-by-elimination judgment heuristic follows a similar procedure. This quite common inclusion of non-stochastic variants under the Elimination-by-Aspects rule will be followed here.

Comparison of Attribute-Based Elimination rules
One might observe that the Conjunctive and Elimination-by-Aspects rules differ drastically in the character of the evaluation process. Where the Conjunctive rule presumes a predominantly alternative-wise evaluation, the Elimination-by-Aspects rule may be conceived as attribute-wise. However, from a functional perspective the differences between these rules are subtle. When there are few attributes and/or the satisficing thresholds of attribute values are low, generally all attributes will be considered and the stochastic or weighted sequence of aspect elimination has no added value: a functional-descriptive Elimination-by-Aspects decision rule becomes indiscriminate from the Conjunctive decision rule then.

Tversky (1972) did not suggest a method for the assessment in real-life decision making of thresholds of attribute values, whether or not associated with satisficing aspects. In view of the observed importance of loss aversion it seems tempting to presume that many individuals might consider the reference state as a set of minimum acceptable thresholds for a '*Reference-Based Elimination rule*.' A careful consideration of the choice context and the (interpersonal differences in) framing and associated attribute valuation is required then to arrive at sensible interpretations of observed choices that might be a consequence of such a rule. So far, no suggestions were encountered to investigate such a contextualisation of decision rules.

Nowadays, Elimination-by-Aspects and/or conjunctive rules are occasionally used in studies of consumer behaviour: '*when consumers are faced with the task of choosing from many different brands having different features, they tend to use a non-compensatory decision rule, most likely conjunctive or elimination-by-aspects to reduce the number of brands…before using a compensatory decision rule to make a final choice*' (Andrews and Manrai 1998: 248). In an overview of such two-stage consumer choice models Manrai and Andrews (1998: 213-214) conclude that '*there is no doubt that … consumers use simplifying heuristics prior to making choices*' but '*despite the theoretical and empirical attractiveness of two-stage models, some factors limit their widespread applicability at present*'.

Applicability of Attribute-Based Elimination rules
Attribute-Based Elimination rules, just as Strong Lexicographic rules, do not necessitate the evaluation of all alternatives against all attributes. But a far more relevant advantage of Lexicographic and Attribute-Based Elimination rules relative to most other non-compensatory and compensatory decision rules is that they do not require commensurability of the values of different attributes to a common scale, and thus circumvent the problematic mapping of the affective values of one attribute on the monetary scale of another.

Other non-compensatory decision rules

Several other decision rules have been proposed in the past, often as variations or combinations of the preceding principles, and only incidentally used by either one or a small group of researchers. However, some rules mentioned by many different researchers cannot be attributed to one of the categories above. These are listed below.

The Random decision rule

This rule '*simply selects one alternative at random with no search of the available information; it provides a baseline for measuring both accuracy and effort*' (Johnson *et al.* 1993b: 105). In addition to the possibility that a small but significant part of subjects might apply this rule in several domains and contexts it is often conceived as a reference for the relative occurrence of different rules within survey populations.

The Disjunctive rule

The Disjunctive rule results in '*the acceptance of any alternative with an attribute which exceeds a certain criterion*' (Foerster 1979: 21). It is the counterpart of the conjunctive rule and as such it is often mentioned in scientific literature.

The dominance rule

In a particular choice context one alternative may be dominant, i.e. it is valued higher than all other alternatives on all relevant attributes. Decision makers might follow a Dominance rule then. However, it is clear that all compensatory, lexicographic and Attribute-Based Elimination rules will select this alternative as well, thus such a rule cannot be elicited indisputably in practice and has no added value in a functional-descriptive model of choice behaviour. One should not confuse this rule with the Dominance Search concept (Montgomery 1989) that describes a particular choice behaviour strategy (see next section).

The Maximax and Maximin decision rules

These rules are the most well known non-compensatory alternatives for the Subjective Expected Utility rule for the evaluation of probabilistic outcomes, as proposed in Game Theory (Von Neumann and Morgenstern 1944). According to the Maximin or Pessimist decision rule, the subject identifies for each alternative the worst outcome of all possible states of the world, and successively chooses the alternative with the best worst outcome. The Maximax or Optimist decision rule first determines all the best outcomes and successively chooses the alternative with the best of all the best outcomes. Edland (1993) and colleagues call the Pessimist and Optimist rules the Minimum and Maximum rules, respectively. The same rules may be applied to choice under certainty by using attributes instead of states-of-the-world (Foerster 1979). To make sense, the attribute values should be expressed in the same dimension. The resulting rules become very similar to the conjunctive and disjunctive rules, though the Maximin and Maximax rules will generally select just one alternative.

Occurrence of the 'other' non-compensatory rules

All these 'other' decision rules may select alternatives with much lower over-all utilities or considerable losses relative to the reference state. Except for rather exceptional circumstances, like oligopolies (Katz and Rosen 1998) or gambles and insurances that stimulate risk seeking or risk-averse behaviour, there is little empirical evidence that many individuals employ such rules in real-world decision making.

Recapitulation of decision rules

Refraining from different names for the same decision rule, almost 30 different decision rules are discussed above. The differences between many of them are quite subtle and leave few rules that are indispensable in a descriptive theory of human choice.

Most compensatory rules submerge under a Linear-Additive Value rule if the attribute importance weight is considered as a constituent of the judgment function. This holds also for the Strong Lexicographic Rule. Several simple compensatory rules (Dawes' rule, Frequency of Good and Bad Features, Majority of Confirming Dimensions, Weighted Pros) require no commensurability of attribute characteristics and might be interesting for the evaluation of multi-attribute alternatives. They have little value in the choice between alternatives with few attributes, rely on attribute values in terms of 'aspects' rather than 'figures' and may approach aspect-based elimination rules closely, both in the choice task and their outcomes, though they principally do a different job.

The Lexicographic Semi-order rule evaluates attributes in order of importance until the difference between the highest attribute value and the second highest one of an alternative meets or surpasses a just noticeable difference. As soon as this happens, the alternative with the highest value on that attribute is chosen. If this procedure does not result in a choice a second stage compensatory evaluation might do the job.

Though the Conjunctive rule presumes a predominantly alternative-wise and the Elimination-by-Aspects rule an attribute-wise evaluation, from a functional perspective the differences between these rules are small. In many choice contexts such Attribute-Based Elimination rules are followed by a second-stage compensatory or lexicographic rule to arrive at a unique choice. No references were found in which the reference state was proposed as a satisficing cut-off criterion. A decision rule drawing on that criterion might be called a Reference-Based Elimination rule and seems plausible as a first-stage screening rule. Such a screening rule will do a similar job as the Status Quo bias might do in UT and as loss aversion combined with the weighted-additive value rule does in PT.

Most other decision rules might be used by a small minority of people in specific domains and contexts while at least one is superfluous in a descriptive model.

This adds up to the conclusion that in a functional-descriptive concept an idiosyncratic valuation of attributes might be followed by different combinations of three rules – the Linear-Additive Value rule, Conjunctive Attribute-Based Elimination rule and the Lexicographic Semi-order rule – that together might cover the evaluation-and-choice function of almost all individuals in almost all contexts. These rules offer ample opportunities to describe satisficing as well as maximizing choice behaviour. Before arriving at more definite conclusions the empirical evidence for their occurrence will be reviewed in the next subsection.

4.4.3 Use of decision rules in experiments and real-life choices

This subsection first discusses the scientific approaches used to elicit the use of decision rules. Successively empirical findings on the frequency of application of different decision rules by subjects are reviewed. After an overview of concrete applications, some elicitation studies are discussed in more detail, to give an idea about the confidence one might have about the inferences following from different research approaches. Successively, examples of studies

based on the observed outcomes of choice behaviour, on observed information acquisition and on self-reports will be treated. The section is concluded with a short summary.

Elicitation approaches

Two approaches can be followed to assess what decision rules an individual uses in decision making: the structural or outcome-oriented approach and the process or process-tracing approach (e.g. Maule and Svenson 1993; Rieskamp and Hoffrage 1999). Studies following the process approach can, in turn, be discerned in the information acquisition analysis method and in the subjective self-report method. All three methods actually elicit the choice behaviour strategy of individuals rather than the applied decision rule. To allow for inferences about the application of decision rules the reviewed articles rely strongly on assumptions made about other elements of the choice behaviour strategy.

The structural approach

The structural approach can be applied to outcomes of real-life choice behaviour but is more commonly followed in an experimental choice context. To elicit decision rules, the researcher defines several decision rules that she conceives as feasible in the experimental context at hand, applies them to a series of choice sets in that context and uses a statistical tool to compare the choices following from each rule with those of the experimental subjects. In structural approach studies the subjects are forwarded with a limited number of alternatives that are each described with attributes characterised by concrete, mostly numerical levels and, in the case of uncertainty, explicit probabilities. This means that if some assumptions with respect to other elements of the choice behaviour functions hold, the inferences as elicited from these studies should predominantly concern attribute level valuation and the evaluation-and-choice function. An important assumption is that the choice subjects do not reframe the experimental context. However, in reality they may, for example, value some 'hidden attributes' that interfere with the decision process. And when the researcher presents a series of choice sets where the alternatives are only characterized by attribute levels in terms of money or a similar medium, the subject may intuitively use the affect heuristic (Slovic *et al*. 2002) to value such a hidden attribute and thus might show apparently intransitive and/or inconsistent behaviour in successive choices. The assumptions of the researcher with respect to the choice behaviour strategy that the choice subject follows might thus be crucial in the reports of observed behaviour.

The information acquisition analysis method

This method within the process approach concentrates on the identification of the acquisition and processing by an individual of information regarding the attribute characteristics of the alternatives. This method is only used in experimental settings. Early researchers used eye fixation patterns of experimental subjects who were observing a panel with overt information to infer information acquisition activities. Most common is the use of an '*information board*', nowadays mostly on a computer screen, from which (hidden) values of attribute characteristics can be opened, typically one value at a time (e.g. Payne *et al.* 1993). The guiding principle in both techniques is that the information acquisition behaviour (quantity of information, inter-attribute and intra-attribute search, shifts during the decision process etc.) is indicative of the type of choice behaviour strategy and/or decision rule.

The information-acquisition method is subject to the same limitations as the structural approach. An additional drawback of the information acquisition analysis method is that '*by definition, information-board techniques do not give information about processes that cannot be externalised in terms of some kind of interaction between the decision maker and his/her environment*'

(Montgomery and Svenson 1989b: 130). As information-acquisition is essentially a supporting process for all mental functions and as these and other supporting processes are largely covert (see Section 2.3) the inferences that most scientists make from studies focusing on information acquisition may be strongly influenced by their own idiosyncratic 'logical' concept of the choice behaviour process.

The verbal protocol analysis method

This method within the process approach relies on verbal protocols, most often in terms of recordings of '*think aloud*' choice experiments. This method is also exclusively used in experimental settings. It is subject to the same limitations as the structural approach. Moreover, the mostly limited information in subjective reports about how the mental process works is notably unreliable (Nisbett and Wilson 1977). According to Svenson (1989a), who wrote an extensive article about the use of verbal protocols for the elicitation of choice behaviour processes, '*Most verbal protocols actually contain a lot of information about the information processed and very little or nothing about how it is processed. Therefore it is important to have a good theory or model which makes it possible to understand the data*'. Thus, just like the inferences based on studies focusing on information acquisition those made from verbal protocols may be influenced by the researcher's concept of the choice behaviour process. More importantly, obviously '*think aloud reports mainly mirror deliberate, conscious mental processes*' (Ericsson and Simon 1980, as referred to in Montgomery and Svenson 1989b: 130). Of course, some subjects might commonly decide after a predominantly conscious reasoning concerning the alternatives and may think aloud in a similar manner in the experiment at hand. But the experimental assignment to 'think aloud' might incite conscious 'System 2' mental processes of individuals who generally base their choices on unconscious 'System 1' processes (see Chapter 2), or the reported 'reasoning' might be an *ex post* rational explanation of the outcome of covert processes.

Review of findings about the application of different decision rules

There is rather general agreement and much empirical support for the claim that many individuals use the compensatory Weighted Additive rule when the choice task is simple and that a large group (though not all) shift to non-compensatory evaluations with increasing complexity of the choice task. Similar shifts from predominantly compensatory to non-compensatory rules as the numbers of alternatives and/or attributes increase were found in many experiments (e.g. Maule and Svenson 1993; Payne *et al.* 1993; Payne *et al.* 1996; Rieskamp and Hoffrage 1999). Some references report explicitly that a part of the survey population shifts to a lexicographic rule under increasing time pressure (e.g. Stern 1999).

Many choice behaviour theories state that individuals organize multi-alternative choices as sequences of two or three alternative evaluations (Montgomery 1989; Svenson 1992; Klein 1993), mostly implicitly or explicitly including the reference state (Beach 1990; Ajzen 1991). This may explain the extensive use of the Weighted Additive rule in situations where a simultaneous evaluation of all relevant alternatives would be cognitively very demanding. Another explanation for its use in such circumstances might be the high processing power of unconscious thought (Dijksterhuis 2004). The use of the Weighted-additive rule is also most commonly presumed in the second stage of non-compensatory two-stage rules, where the complexity of the 'remaining' choice task is reduced.

Though the use of simple compensatory rules that circumvent the problem of cross-dimensional mapping seems plausible, particularly for multi-attribute choice sets, no clear evidence was found that individuals use these extensively in real-life choice contexts.

Application of non-linear models in everyday choice behaviour seems even less plausible. Also the descriptive performance of the Subjective Expected Utility rule is disputable (Maule and Svenson 1993).

Foerster (1979) states that strong lexicographic choices are reported in: trust investment decisions, the purchase of women's clothing and the evaluation of sales personnel, while weak processes should occur in the acquisition of small home appliances. Also supporting this rule are the findings of Haines and Ratchford (1987: 291) that '*only 15.6% of the respondents reported using all fourteen attributes listed. These data reinforce the idea that not all attributes of a product are necessarily used by all consumers in making a choice*'. The use of the Strong Lexicographic rule is frequently reported from stated choice surveys, such as in travel behaviour research (Sælensminde 2001; Rizzi and Ortúzar 2003; Iragüen and Ortúzar 2004; Rouwendal and De Blaeij 2004). As discussed above it is descriptively indiscriminate from the Weighted-additive rule.

There is some evidence that a sizeable number of individuals may use the truly non-compensatory Lexicographic Semi-order rule (Tversky 1969). Yamamoto *et al.* (2002) applied it partially in a travel mode choice context, and the '*arrival time indifference band*' of Mahmassani (1990) might be conceived as another implementation of this rule.

With respect to Attribute-Based Elimination rules, Foerster (1979) refers to one publication reporting the use of satisficing threshold values and another article with evidence that clinical diagnoses are often based on the Conjunctive rule. Some elimination rules (like Elimination-by-Aspects and/or Conjunctive rules) are frequently reported as the first stage part of a two-stage elimination-weighted additive rule. It is commonly reported in consumer behaviour when consumers are faced with products that go under many guises (Simonson 1990; Andrews and Manrai 1998; Manrai and Andrews 1998; Swait 2001; Gilbride and Allenby 2004). Manrai and Andrews (1998: 213-214) conclude that '*there is no doubt that ... consumers use simplifying heuristics prior to making choices*'. Andrews and Manrai (1998: 248) state: '*when consumers are faced with the task of choosing from many different brands having different features, they tend to use a non-compensatory decision rule, most likely conjunctive or elimination-by-aspects to reduce the number of brands…before using a compensatory decision rule to make a final choice*'. This use of Attribute-Based Elimination rules in two-stage choice processes is also found by Gilbride and Allenby (2004) and Simonson (1990), though the latter observed a lexicographic rather than compensatory second stage. For travel behaviour research a similar succession of elimination and compensatory evaluations was proposed by Bovy and Stern (1990) in their conceptual route choice process framework.

In view of its similarity to the conjunctive rule, evidence for the use of the Maximin rule by subjects is scarce and ambiguous, except for contexts with explicitly known probabilities of the outcomes of alternatives. The Maximax and related Disjunctive rule are hardly if ever used in practice (e.g. Edland 1993; Swait 2001; Gilbride and Allenby 2004; Annex B).

Examples of structural approach analyses of the use of decision rules

This subsection does not aim to discuss all the empirical evidence for the use of the different decision rules that are described above. It rather aims to indicate by examples approximately what degree of irrefutability of conclusions one might expect in a particular context and as a consequence of a particular elicitation method. To that aim several studies that differ in the approach followed are described and re-analysed in some detail.

Choice between alternatives with 'certain' outcomes

Svenson and Benson 3rd (1993b) and Edland (1993) investigated the selection of the more likely candidate, from two psychology students at a time, for a university education in psychology. The candidates were characterized by three attributes: their secondary school grades in psychology and two more disciplines. The choices were compared with the predictions according to several decision rules, with the Random rule as reference. The Linear-Additive Value rule (both in the Strong Lexicographic and Equal Weight version) and the Maximin[57] rule predicted observed choices better than the Random rule. The Maximax rule performed less than chance in both experiments. Edland found that under time pressure the frequency of choices that could be explained by the Strong Lexicographic rule increased by almost 10% at the expense of the frequency explained by the Maximin and/or Equal Weight rules. These results were in concordance with earlier findings of Svenson and others in the same experimental setting. However, the research design was insufficiently discriminating to arrive at clear conclusions with respect to the frequency of use of the different decision rules in the conditions without time pressure. Averaged over four conditions with or without time pressure, about 75% of the choices could be explained by any of these three rules.

Rieskamp and Hoffrage (1999) designed an experiment in which interviewees had to decide which company out of four, all characterized by six attributes (share price, dividend etc.) was considered to have the highest profit. Here, all eight rules examined could predict the observed choices of a representative series of choice sets equally well (79 to 83%). To reduce this overlap they selected a series of choice sets where Dawes' rule and the Strong Lexicographic rule selected different alternatives. Now the Strong Lexicographic and the Weighted Pros rule yielded the best prediction of the observed choices (both 66%), followed by the Lexicographic Semi-order rule and the Weighted Additive rule (59-57%). The four other rules, including Dawes' rule and Elimination-By-Aspects (cut-off value unrecorded) had a predictive power below 44%. As all rules had almost the same predictive power in the representative series one might wonder, however, why another criterion for the composition of a selected series might not result in a better performance of these latter rules.

Gilbride and Allenby (2004) compared the choices predicted by an ordinary Random Utility Maximization model with those following from four models in which different screening rules eliminate part of the alternatives before, in a second phase, the Random Utility Maximization model assesses the probability of each alternative being chosen. The screening models concerned: the Weighted Additive,[58] Conjunctive and Disjunctive rule, and a fourth model in which individuals exclusively use a Conjunctive or Disjunctive rule. They were tested on the results of a stated choice survey amongst 300 potential buyers that had to make a decision on fourteen choice sets of cameras (six alternatives and a no-buy alternative, eight attributes per alternative). Twelve choice sets were used to calibrate the five models. All threshold values were allowed to vary between individuals and between attributes at this stage. With these calibrated models the decisions concerning the remaining two choice sets were predicted and compared with the observed choices. The goodness-of-fit of the two-stage Disjunctive – Random Utility Maximization model was the lowest (39.0%), but the one-stage Random Utility Maximization model (39.1%) and the two-stage Weighted Additive – Random Utility Maximization model (39.3%) predicted almost equally poorly. The two-stage

[57] In this study the closest match for the conjunctive rule.

[58] Actually, they used the deterministic part of the Random Utility Maximization model to assess one utility measure for each alternative, and eliminated the alternatives where this measure did not surpass an individually calibrated threshold.

conjunctive – Random Utility Maximization model yielded the best prediction (41.8%), with almost the same result for the model with the mixed Conjunctive-Disjunctive first phase (41.7%). In the latter case the model assigned 99% of the respondents to the Conjunctive rule. The authors found that some attributes are only used in the screening stage while others are used in both screening and final product choice. Their claim that 92% of the respondents used a Conjunctive rule is not convincing, as many decision rules were not tested.

Choice between alternatives with probabilistic outcomes

With respect to choice behaviour under uncertainty the Subjective Expected Utility decision rule is often considered as a descriptive rule that might predict how individuals make decisions. However, Maule and Svenson (1993: 10-11) refer to four research reviews to conclude: '*the descriptive validity has been tested by evaluating the extent to which peoples' choices in simple decision making situations can be predicted by Subjective Expected Utility and by evaluating whether people accept the axioms ... and behave consistently with them. Both approaches have found only limited support for the theory*'. This suggests that at most a minority of people use this rule.

Busemeyer (1993) re-examined his 1985 investigation in which six subjects attended fifteen sessions, in each of which they made 360 successive choices between monetary prospects with small certain outcomes (either –US$0.03; US$0.00; or US$0.03) and probabilistic outcomes (mean US$0.00, standard deviation either US$0.05 or US$0.50). Evidently, the expected utility of the certain gain alternative is dominant whenever offered, as well as that of the uncertain one when the certain prospect is negative. Busemeyer called this the 'correct decision'. The subjects got feedback after each choice by showing them the amount they would have won or lost when choosing the uncertain alternative. This 'correct decision' was made successively in 94% (the low standard deviation, no time pressure context); 89% (low standard deviation, high time pressure); 68% (high standard deviation, high time pressure); and 59% (high standard deviation, no time pressure) of the decisions, averaged over subjects and choice sets. Busemeyer explained this apparently counter-intuitive result from Decision Field Theory (see next subsection). One might also consider that, if more time is available, individuals might pay more attention to feedback-induced experienced loss aversion, maybe drawing on the peak-end heuristic. It is easy to see that the allegedly correct decision could lead to significant (say > US$0.03) or even large (say US$0.30) experienced losses relative to the outcome of the rejected alternative. The frequency of this negative feedback will have been much higher for the high standard deviation choice sets than for the low standard deviation sets: 47% against 17% (> US$0.03) and 30% against 0% (> US$0.30) respectively. This might have made a difference to the extent of loss-aversive risk- seeking behaviour. Thus, maybe a comparison with predictions based on PT with interpersonal different decision frames and feedback-based updating of the reference state could have resulted in a better fit. Anyway, the experimental results demonstrate large interpersonal differences, as two out of the six subjects improved the percentage of correct decisions from the high standard deviation sets with decreasing time pressure.

A deterministic interpretation of the structural approach

The studies above all used statistical methods to compare the performance of a stochastic model simulating one particular decision rule with the outcomes of choice experiments. One might, however, consider a more deterministic elicitation process in which the successive choices of each individual decision maker are compared with the choice predictions of different decision rules. Of course, one needs a guiding principle for the evaluation of successive intra-personal within-context choice behaviour. For individuals who choose in agreement with the UT assumptions, this might be the transitivity principle. One of the

consequences of the use of non-compensatory decision rules is that it may cause intransitive choice behaviour in successive paired comparisons (Haines and Ratchford[59] 1987; Rosenberger *et al.* 2003). Thus, responses of one individual to a series of bi-optional choice sets that show significant intransitivity are indicators of non-compensatory decision rules.

Haines and Ratchford (1987) compared the predicted and observed preferences for alternative home heating systems from large surveys in Canada and the US. They found that in both surveys only about 35% of the respondents showed transitive choice behaviour. As explanations for the observed high rate of intransitive behaviour they suggested missing information on different attributes in different paired comparisons, and differences in the attribute decision weights in different choice sets. As an example of the latter they suggested that 'reliability' might be a very salient attribute in a comparison between 'oil' and 'gas', while for the comparison between 'oil' and 'electricity' the 'use of space' attribute may be the decisive one and reliability is not really important.

Haines and Ratchford also reported the number of attributes that American respondents would use when actually buying a central heating system. Only about 15% would use all the fourteen attributes listed, 50% would use eight to nine attributes and about 15% would evaluate only four out of the fourteen attributes. In view of the relative importance of such a 'once-in-a-decade' decision this demonstrates the frugality of most consumers with respect to information search. It seems obvious that the presumption of a compensatory decision rule that takes all attributes into account will generally reveal a lot of intransitive behaviour. On the other hand, from this finding one might expect that quite some individuals use lexicographic or Attribute-Based Elimination rules.

Assessment of interpersonal differences in choice behaviour with the structural approach

No publications were found that examined the possibility of interpersonal non-stochastic differences in attribute valuation in conjunction with decision rules. However, when one allows for the co-existence of loss-aversive individuals and others who value loss-neutral, these differences have to be taken into account when one wants to elicit the frequency of different decision rules from observed choices. Annex B demonstrates what type of inferences about possible decision rules one might make, based on aggregated recorded decisions from successive bi-optional choice sets, taking non-stochastic interpersonal differences in valuation and choice behaviour into account and assuming that most individuals will demonstrate intrapersonal within-context consistency. It draws on a 'yesterday's newspaper' report on the stated propensity of a representative sample of the Dutch grown-up population to switch one's health insurance company (Van Eijk 2004).

From the analysis of the aggregated results in Annex B it was found that as much as 82% of the responses could be explained from loss-aversive attribute valuation followed by a compensatory decision rule. Most of these (74%) might also be explained from the use of the

[59] Like many authors, Haines and Ratchford (1987) treated transitivity in terms of adherence to a reference-independent idiosyncratic preference order, as presumed in utility maximizing theories. In its mathematical sense, a subject's choice behaviour is also transitive as long as she uses the same logic algorithms to value all attributes, composes them compensatorily into one value per alternative, and chooses the alternative with the highest value from successive choice sets. When this strategy is followed according to PT, the resulting choice sequence may, however, violate a reference-independent preference order according to UT. To avoid confusion, 'consistent' is used to denote when a subject uses the same choice behaviour strategy during a succession of choices in the same context.

conjunctive Reference-Based Elimination rule, where required followed by a compensatory evaluation. This coincidence is not surprising as both strategies largely rely on loss-aversive valuation. At most 42% of the responses might also be explained by loss-neutral valuation followed by a compensatory decision rule, of which only 21% plausibly so. At most 4% of the responses might be explained from the use of either the Maximax or the Disjunctive rule. Finally, about 15% of the responses did not comply with a consistent use of any of the tested decision rules.
The abundant occurrence of loss aversion might be plausible in view of the prominence of the incumbent provider and the small number of attributes (three to four) in this particular research design. One might object that this experimental context arranged for a high accessibility of the status quo or reference state by confronting individuals with it in all successive choice sets. But one might wonder as well if this is not what real-life decision making generally is all about…

Examples of information acquisition analyses of the use of decision rules

Most authors using such techniques presume that the decision rules encountered are based on a cost-benefit trade-off (e.g. Maule and Svenson 1993 for a listing of early publications). As Payne *et al.* (1993: 13) stated: '*the fundamental assumption of our framework is that individuals decide how to decide by considering both the cognitive effort and the accuracy of various strategies*'.

There is ample experimental evidence supporting the rather general agreement within behavioural decision theory that when the complexity of the choice task increases there is a shift from compensatory to non-compensatory decision rules, the latter often by means of a two-stage process in which the second stage may be compensatory (Maule and Svenson 1993; Payne *et al.* 1993; Payne *et al.* 1996). Referring to a long list of publications, Payne *et al.* (1993) conclude that people use compensatory decision rules for choices between two alternatives and prefer non-compensatory rules when faced with multi-alternative decision tasks. Evidence of a shift from compensatory to non-compensatory rules with increasing numbers of attributes is less unanimous, though most scientists presume a similar effect. Increasing time pressure first causes speeding-up of processing. As time pressure becomes severe '*people accelerated their processing, were even more selective and changed strategy from a more depth-first (alternative-based) to a more breadth-first (attribute-based) pattern of processing*' (Payne *et al.* 1996: 132).

The latter statement is from an article that describes experiments where about 150 students chose from a series of choice sets consisting of four alternatives (gambles) with different outcomes for four probabilities, in which the payoff decreased with increasing duration of the decision. Under conditions with no time pressure, the average proportion of the choices that might be explained by the Weighted Additive rule was 47% while 53% might be the result of the Strong Lexicographic rule[60]. Under severe time pressure these percentages shifted to 44% and 57%, respectively. In accordance with this observed shift, the observed pattern of information acquisition shifted towards attribute-based comparison.

[60] The percentages presented here are averages of the values mentioned in Tables 2 and 3 in their article and do not add up to 100% but may show considerable overlap. The authors conceived the Strong Lexicographic rule as representative for the other non-compensatory rules. The proportion of choices that might be explained by other rules as well was not reported. It goes without saying that these might have shown considerable overlap with each other and with the proportions that could be explained from the use of the Strong Lexicographic and/or Weighted Additive rules.

Rieskamp and Hoffrage (1999) observed a similar shift in information acquisition pattern in their four companies-six attributes choice sets. However, though these shifts are statistically significant they are typically small compared to the extension of their scales. Thus, the discriminatory power is rather low.

Examples of verbal protocol analyses of the use of decision rules

An extensive think aloud experiment was reported by Timmermans (1993). She carried out a study in which 24 subjects each had to decide about the appointment of an associate professor and 24 more subjects about a project manager. The complexity of the choice situation varied between subjects: three, six or nine candidates characterized by five or twelve attributes (education, age, experience etc.), thus from fifteen to 108 cues.

The recorded think aloud statements were coded under three categories: selection of information; use of information; and decision rules used. Depending on the character of the statements in the latter category each subject was assigned to one of a series of well-known decision rules. This yielded:

- Additive compensatory rule, employed by 20 interviewees;
- two-stage Conjunctive – Additive compensatory rule, 13 interviewees;
- two-stage Conjunctive – Lexicographic rule, 3 interviewees;
- two-stage Conjunctive – Conjunctive rule, 1 interviewee;
- Lexicographic rule, 3 interviewees;
- Undetermined, 8 interviewees.

While for the choice sets with up to and including 36 cues fifteen out of 24 subjects used the compensatory rule, this number dropped to only five out of 24 for the choice sets with 45 and more cues. At the same time the number of subjects following a two-stage process starting with a Conjunctive rule increased from four to 13. The information collected about the selection and use of information was in concordance with this shift as well as with earlier findings of Svenson, Payne and their colleagues. The author illustrates the character of the statements in the verbal protocols from which the Conjunctive rule was inferred as '*An alternative is eliminated when one or more relevant aspects are negatively evaluated*' (Timmermans 1993: 109). This posits the Conjunctive rule as conceived by her very close to the Reference-Based Elimination rule. The experimental setting and related instructions in this study might have stimulated a 'cool' deliberate-rational rather than a 'warmer' intuitive-affective decision process, thus the observed high use of the 'rational' compensatory strategy might be higher than in similar real-life contexts. A further overestimation of the use of the additive compensatory rule might have occurred because her alternatives hardly affected the self-interests of the decision makers and her alternatives were not 'humans of flesh and blood' but descriptions on paper. However, her research corroborates the findings from other process-oriented approaches in which these marginal comments were less relevant (e.g. Svenson 1989a; 1989b).

In a simpler think-aloud experiment conducted by Simonson (1990), about the sequential consumption of different snacks, the snacks were physically placed in front of the test subjects. Here, the majority (70 to 90%) of the subjects started the decision process with an elimination of less attractive alternatives, most often followed by a second choice based on: the current state of mind; earlier consumption; being in the mood for sweet or salty; etc. Thus,

essentially a two-stage conjunctive-lexicographic rule was followed, drawing on an affect attribute. Simonson (1990) also found a common strategy, where feasible, of an initial elimination stage followed by the selection of smaller quantities of *all* non-eliminated alternatives at the cost of larger quantities of one 'most preferred' alternative.

Once more the content and context of the choice situation largely seem to influence the frequency of the use of different decision rules. The '*subjective self-report*' verbal protocol approach shows a much higher discriminatory strength regarding the application of choice behaviour strategies than either the stochastic structural approach or the 'objective' information acquisition mode within the process approach. In addition to the objection that it stimulates 'System 2' reasoning at the expense of unconscious 'System 1' processes, and that it may only reveal conscious reasoning processes anyhow, its main drawback seems that it is very laborious. For example, the average number of think-aloud statements per subject per choice was 53 in the study of Timmermans (1993). All of these over 2500 statements had to be transcribed, interpreted and coded by two high-skilled observers to arrive at a database for the analysis of just 48 individual decisions. Thus such an approach is very costly if one wants to arrive at a statistically reliable assessment of the use of decision rules in a certain setting. This may be the reason that it is only reported incidentally in the literature. Nevertheless, in several circumstances it still may be the best research tool there is.

4.4.4 Summary of findings about evaluation-and-choice

According to the Meta Theory of Choice Behaviour, the judgment function is presumed to arrange for the (loss-aversive or loss-neutral) valuation of attributes, the assessment of attribute decision weights and, under uncertainty, possibly weighted expected probabilities. In light of the observed use of decision rules, the compensatory Linear Additive rule with a maximizing choice criterion (which includes the Strong Lexicographic rule) might be appropriate for a functional description of the evaluation-and-choice function of by far the most people. When, in addition to this, the elicitation process allows for a two-stage Conjunctive-Linear Additive decision rule, with cut-offs of the different attributes that allow for varying degrees of loss avoidance, such a model might describe almost all observed choices functionally. Extension of the elicitation process with the Lexicographic Semi-order rule might explain some more choices, but in view of the evidence as presented in Annex B one should not be surprised if all these latter choices are already explained by the Conjunctive and/or Linear Additive decision rules.

It appears that in many choice contexts most subjects may compound the characteristics of alternatives compensatory in one overall value and successively select the alternative with the highest value. However, other individuals may evaluate the alternatives attribute-wise and/or select any alternative that meets a satisficing aspiration level in another choice context. She may use combinations of non-compensatory and compensatory evaluations and of satisficing and maximizing criteria in one and the same context as well. Thus, the assumptions of UT and PT concerning evaluation-and-choice should be relaxed in a descriptive model of choice behaviour. Evaluation and comparison of multi-attribute alternatives might be either alternative-wise, based on one compensatory compounded value or else attribute-wise, based on a sequential evaluation of attributes in importance order against a maximizing or elimination (threshold) criterion. Likewise, the choice criterion might be either maximizing, by the selection of an alternative with the highest overall value or the highest value on the most important attributes, or satisficing, by selecting the first alternative that meets an acceptable overall value and/or successively rejecting alternatives that do not meet threshold values on separate attributes.

4.5 Choice behaviour strategy

The choice behaviour strategy function arranges for the coordination of framing, judgment and evaluation-and-choice. From a normative-rational perspective on choice behaviour individuals might be expected to complete those functions sequentially, because they should have complete knowledge of the future states of the world and the needs of their body as well as unlimited and unfailing information processing power. In doing so their successive behaviour would be consistent with their values, attitudes and beliefs with respect to the choice context. Even without extensive reasoning (e.g. Simon 1955; Gigerenzer and Todd 1999) common sense says that lay people are aware of their shortcomings in complete knowledge and unlimited and unfailing information processing and thus will follow a less ambitious choice behaviour strategy that might at least approximate the desired cognitive consistency. The previous sections provide ample evidence that most individuals generally follow such less 'rational' strategies.

This section first reviews some hypotheses and findings about choice behaviour strategies from studies in Behavioural Decision Theory. These are subsequently aggregated and related to the cognitive consistency principle from Social Psychology to arrive at a functional description of the choice behaviour strategy that covers the observations thus far. The section concludes with a short summary.

4.5.1 Pocess-tracing approaches for elicitation of choice behaviour strategies

The elicitation of the use of decision rules in the previous section appeared to be based on the assessment of a part of the choice behaviour function, controlled by a research design that accounted for the framing function and most of the judgment function. All of these studies assume a process theory in terms of some *a priori* template for the human decision process, which suits well in a concept of pre-determined stable idiosyncratic preferences that can be revealed from experiments. As far as could be retrieved, the conclusions with respect to the validity of these theories relied on their ability to explain the observed choices. From the preceding section one might further infer that neither a structural nor a process-oriented approach allows for a straightforward elicitation of mutually exclusive choice behaviour strategies. Within the experimental context a structural approach using statistical methods will often reveal many different choice behaviour strategies that explain the same choices. The information acquisition analysis method does not generally add discriminating strength to the diagnosis of the use of choice behaviour strategies. Only the very costly think aloud technique does so, but it might reveal a more 'conscious-rational' choice process compared to real-life choices and is also sensitive to biases induced by cognitive dissonance avoidance. Thus, the following process theories that were inferred from the elicitation of choice behaviour strategies might be better considered as overlapping potential explanatory theories than as descriptive theories.

The cognitive effort-accuracy model

This concept may also be encountered as the cost-benefit model. It explains the shifts in choice behaviour strategies during a decision process or between different processes (e.g. Payne *et al.* 1993) by a deliberate trade-off. This presumes a logic, conscious adaptation (or an unconscious intuitive equivalent) by subjects to environmental situations in relation to their motives. It is the most commonly accepted explanation for these shifts in behaviour that are observed in many studies see previous section. However, no studies were recovered in which this assumption was tested.

The Dominance Search model
This model assumes that in a pre-editing phase alternatives are eliminated that have a small chance of becoming dominant on all relevant attributes (Montgomery 1989). Next, an alternative is selected that is more attractive than the others on an important attribute. In a dominance-testing phase, the subject looks to see if this alternative is dominant and, if not, she tries to restructure the information in such a way that a dominance structure is obtained, by adjusting attribute decision weights, combining attributes and so on. If she succeeds, the now dominant alternative is chosen. If this is not possible, as happens occasionally, the search starts again. In all stages of this model different decision rules may be applied iteratively. The process described by this theory can hardly if at all be falsified. Its empirical support is mainly based on interpretations from statements in verbal protocols. The think-aloud studies that were adduced to support it definitely showed an intense evaluation process after a preliminary choice was made (Dahlstrand and Montgomery 1989; Montgomery 1989; Montgomery and Svenson 1989b). However, this dominance-structuring phase might be highly stimulated by the experimental think aloud assignment and several observations suggest that reasoning to avoid cognitive dissonance might have played an important role in the observed utterances. Nevertheless such a 'second thought' validation of preliminary choice testing is reported from several other experiments and contexts as well.

Dynamic sequential comparison models
These models try to embody the dynamics of the individual choice processes. They assume that, as soon as a decision process with uncertain outcomes starts, people retrieve an initial preference from memory. The starting point of one of these models, Decision Field Theory, fits well in PT: '*Subjects start out biased against the uncertain alternative when the certain value is positive, and they are initially biased in favor of the uncertain alternative when the certain value is negative*' (Busemeyer 1993: 187). If the available time for the decision is very short the initial preference yields the chosen alternative. Given sufficient time the decision may be changed during a sequential adjustment process in which more attributes are taken into consideration or more information is retrieved from memory. In view of the relatively small changes observed in the use of decision rules under increasing time pressure one might infer from the findings of Decision Field Theory a high frequency of non-compensatory decision rules drawing on loss aversion.

The 'unconscious thought concept'
This concept was developed to explain the observed behaviour during the choice of an apartment and a roommate by subjects, after the observation of apartment and roommate-attribute information (Dijksterhuis 2004). One group of interviewees had to state their choices directly after the observation stopped, one group directly after a consecutive three minutes in which they were assigned to think their choice over ('conscious thought condition'), and a third group directly after a consecutive three minutes in which they were charged with another, conscious-cognitive demanding task ('unconscious thought condition'). It appeared that the subjects in the 'unconscious thought' condition approached a normative optimal choice better than those in the other conditions, while those in the conscious thought conditions performed not or just slightly better than those in the immediate condition. As the subjects had to retrieve all information from memory only and had no paper-and-pencil aids, the poor performance of conscious thought in these experiments might be attributed to the limited capacity of working memory.

Overview of process-tracing approaches of the choice behaviour strategy
All these process theories as well as several other ones that were reviewed but not summarized here agree to some extent with the hypothesis of a deliberate monitoring, given sufficient time, by the slow, conscious System 2 (Kahneman 2002) and/or by unconscious thought (Dijksterhuis 2004) of a fast, unconscious, intuitive System 1 choice. One might note, however, that the presumed specific mental processes and their sequences strongly differ from one explanatory theory to the other. Also, the validity of one at the expense of another was not demonstrated anywhere. Thus, the evidence for a last 'second thought' stage in the choice behaviour process that may be limited or cancelled by cognitive capacity or time pressure seems rather strong but should be considered circumstantial.

4.5.2 Cognitive consistency

The human striving for what is called cognitive consistency was an important topic in social psychology (e.g. Atkinson *et al.* 1983). It is a main determinant of Cognitive Dissonance Theory (Festinger 1957) and Self-perception Theory (Bem 1967) and evidently lingers in the background of Attribution Theory (Kelley 1973), Attitude Theory (Fishbein 1963) and its extensions Theory of Reasoned Action (Ajzen and Fishbein 1980) and Planned Behaviour (Ajzen 1991), though the focus of attention has shifted in the latter theories to causal explanations of behaviour. It means that an individual tries to avoid or discontinue contradicting cognitions, in choice behaviour mostly related to causal relationships of context, motives, values, choices, behaviour and consequences. This may be attained by mental activities like adapting existing beliefs and changing judgments or conclusions. The social psychology literature that relates to '*cognitive consistency*' shows that people are more concerned with consistency in their affective appraisals and feelings with respect to the different elements of the choice process than with the consistency of their '*cold cognitions*'. As Zajonc (1980: 155) aptly remarked, '*at least three social-psychological conceptions labelled "cognitive" consistency focus not on consistency of content but on the consistency of affect*'.

On second thoughts…

The suggestion of a final, second thought stage in the choice behaviour process might be interpreted as an expression of the 'control function' of System 2 (Kahneman 2002; Lieberman *et al.* 2002). It might, however, more often be interpreted as a search for a rational ex-post explanation of the largely covert choice process, as excellently demonstrated by Nisbett and Wilson (1977). The following draws on the assumption that most individuals follow a choice behaviour strategy in which their choice is consistent with their appraisal of the expected outcomes of the alternatives even though, in retrospect, they may conceive causal explanations that do not match their previous assessments and valuations. If a choice behaviour strategy is elicited by a researcher that reveals within-context cognitive consistency in this sense, this will yield a functionally effective description that fits into the Meta Theory of Choice Behaviour, though it does not necessarily describe the actual choice process followed accurately.

The choice of a choice behaviour strategy

To arrive at such a cognitively consistent choice, an individual may select a strategy from her '*adaptive toolbox*' (Gigerenzer and Todd 1999) that has proved itself before in a similar context (e.g. Klein 1993). This adaptive toolbox concept was proposed much earlier in social psychology by Kelley (1973:118) in his seminal article on Attribute Theory: '*it (is) plausible to assume that the layman has a repertoire of thought models for dealing with causal problems…these models are reflected in the person's thinking – each at specific (and specifiable) times, and all, over a*

variety of occasions'. In a particular context, the differences between the (*ex-ante*) expected and actually experienced outcomes of previous choices at the same level of the 'strategic-operational choice hierarchy' might act as attributes for the presumably intuitive choice between alternative strategies from this toolbox. The rejection of strategies that in a similar context yielded substantially worse outcomes than expected and adoption of strategies that proved satisficing might dominate this learning process, that for recurrent operational choices coincides with the tactical choice process as conceived in this book. When this yields no satisficing choice behaviour strategy for the context in question, the individual has to develop some alternative strategy.

According to Payne *et al.* (1993: 171, their emphasis), who attribute this finding to a 1979 publication by Bettman, people might in novel situations '***construct*** *choice strategies on the spot during the course of making a decision*'. They showed excerpts from verbal protocols and referred to experimental results that make it very plausible that during choice processes individuals may re-frame their choice sets, re-adjust their valuations and adapt their previously intended decision rules while under-way, dependent on the available data and causal results of information processing. The authors suggested that such a constructive approach might be particularly followed in decision contexts in which individuals are under stress or have little previous experience. Later on, they suggested a '*building code*' for experiments aimed at arriving at plausible '*constructed preferences*' for such choice contexts (Payne *et al.* 1999).

Slovic (1995: 369), among other decision theorists, adopted this constructed preference idea and stated that '*This new conception applies to judgments and choices among options that are important, complex, and perhaps unfamiliar, such as gambles, jobs, careers, homes, automobiles, surgical treatments, and environments*', while the '*mental gymnastics*' of such processes include '*anchoring and adjustment, relying on the prominent dimension, eliminating common elements, discarding nonessential differences, adding new attributes into the problem frame in order to bolster one alternative, or otherwise restructuring the decision problem to create dominance and thus reduce conflict and indecision*'. In this and the successive vivid descriptions by Slovic the significance of the mental functions of framing, judgment and evaluation-and-choice are easily recognizable but it shows that they may be completed, in crumbled pieces, in any order and partly iteratively. As the 'proven' strategies mentioned above were once developed in a novel situation these may reflect a similar 'creative' and thus seemingly chaotic process.

Sequence of function completion

From the preceding one might infer that the followed choice behaviour strategy might be emerging afterwards rather than chosen beforehand. It is generally opportunistic, strongly dependent on the context and on the perception of the environment and as such violates the UT assumption of a temporally stable, context and reference-independent choice behaviour strategy. One might easily attribute the elements of Slovic's non-exhaustive listing to the functions of the choice behaviour process and find that the sequence in which these are completed may differ strongly between contexts and individuals. It unites several earlier but narrower concepts and process theories of choice behaviour, including essential elements of the heuristics-and-biases school (overview in Gilovich *et al.* 2002), Image Theory (Beach 1990), Dominance Search Theory (Montgomery 1989) and Differentiation and Consolidation Theory (Svenson 1992). In particular both latter theories seem strongly occupied with the attainment of *ex-post* cognitive consonance between the relevant beliefs, values and outcome of the choice context at hand.

Combining the 'random' sequence of function completion and the striving for *ex-post* within-context cognitive consistency means that from a functional-descriptive perspective the choice behaviour strategy can be approximated by a causal sequence of 'final states' of the framing, judgment and evaluation-and-choice functions of the Meta Theory of Choice Behaviour. Another consequence is that during repetitive choices in similar contexts an individual might consistently use one particular choice behaviour strategy from her 'toolbox'. This may be considered as a weak substitute for the concept of a complete, transitive and context-independent idiosyncratic preference order. It implies that interpersonal heterogeneity in the use of choice behaviour strategies might be systematic rather than random, while remaining observed inconsistencies in successive choices might be attributed to random errors.

Within-context consistency and transitivity

In transport literature the wording '*consistent*' is often used for the consequent application of the assumptions of UT in a sequence of choices (e.g. Sælensminde 2001; Rouwendal and De Blaeij 2004). It means that an individual always chooses A over C when she chooses A over B and B over C, a condition that is called transitivity here (e.g. Tversky and Kahneman 1986; Haines and Ratchford 1987), as there is ample evidence for choice conditions where '*consistent and predictive intransitivities can be demonstrated*' (Tversky 1969: 31).

To illustrate the different meanings of consistency, just imagine that a person's present condominium (market price €300,000) is in danger of being expropriated. The city council offers her reimbursement of all relocation costs plus either ownership of apartment A with 5 m^2 more floor space, or €50,000 cash plus apartment B, which is 15 m^2 smaller than her present condo. Being an experienced utility maximizer she compares the selling prices and floor sizes of apartments in her market segment and after thorough calculation assesses the average price at €2,000/m^2. She now values offer A at €310,000 and B at €320,000 and, proud of her consistent adherence to the UT assumptions but maybe with some indefinable feeling of doubt, she proposes to her partner to accept apartment B who answers: 'You are right that we shouldn't care for a few square metres of additional space, but can you really imagine us to be happy with a loss of 15 m^2 living space, even if we got €60,000, dear'? After sleeping on it she concludes to accept apartment A and to renounce B and the associated sum. She might feel that this latter decision is cognitively consistent with her aspiration level regarding her living space as well as with her valuation of the attribute levels.

This concept of a person's 'within context' consistency is one out of three types of information that in conjunction determine the validity of judgments according to Attribution Theory (Kelley 1967). It is of vital importance in communication and understanding in everyday life as well as indispensable for the elicitation by scientists of context-dependent choice behaviour of individuals. In the condominium-choice example above, an analyst who observes the offers to the subject and her final decision may infer several choice behaviour strategies from it, including PT with loss aversion, UT with a high value of floor space, a 'reference-based' conjunctive decision rule or even random choice. But when the analyst observes a number of different occasions where similar choice situations are at stake and in which the subject chose consistently, i.e. '*constantly adhering to the same principles of thought or action*' (SOED 2002), she would probably be able to reduce the range of possibly employed choice behaviour strategies considerably. One should realize that the use of this outcome-based principle to elicit choice behaviour strategies requires a deterministic approach, aimed at describing the idiosyncratic behaviour of individuals (see Annex B for an example). As such it differs strongly from the predominantly probabilistic assessment of decision rules and

strategies as generally followed in disciplines like cognitive psychology, microeconomics, consumer theory and transport sciences.

Stated choice surveys might offer the easiest contexts to elicit idiosyncratic domain-specific choice behaviour strategies. A caveat regarding the use of stated preference results for making inferences about real-life decision making may be that the interviewees are supposed to choose one alternative from each choice set, even when they experience a loss on at least one of all the presented attribute alternatives. When confronted with such choices in real life many individuals might use a conjunctive Reference-Based Elimination rule to reject all the alternatives, choose to stay with the reference state and to keep on searching for more alternatives. In stated choice surveys they have to select an alternative, maybe by using a lexicographic or compensatory rule. This may bias the inferences from stated preference results about the decision rules applied in real-life choice behaviour. The addition of a '*null good*' to the choice sets might overcome this problem (e.g. Swait 2001; Gilbride and Allenby 2004). For operational choice with a repetitive character simulator technology nowadays offers much better opportunities to simulate real-life choice contexts in many domains.

4.5.3 Recapitulation of findings about choice behaviour strategy

From the considerations given above it is clear that choice behaviour strategy is neither stable nor context-independent, that the order and sequence of function completion is not sequential and that intrapersonal choices, even in the same context, may be intransitive. Consequently, successive choices by the same individual may often violate the assumptions of UT. Nevertheless, following the assumption that most individuals strive after an *ex-post* cognitively consistent choice behaviour strategy in a particular context this may be described as a sequence of 'final states' of the framing, judgment and evaluation-and-choice functions. Another consequence is that during repetitive choices in similar contexts these individuals might consistently use one particular choice behaviour strategy from their 'toolbox' (see e.g. Van de Kaa 2006). This may be considered as a weak substitute for the concept of UT's complete, transitive and context-independent idiosyncratic preference order. It implies that within-context interpersonal heterogeneity in the use of choice behaviour strategies might be systematic rather than random as presumed in Random Utility Maximization Theory, while remaining inconsistencies in successive choices might be attributed to random errors.

4.6 Summary

This chapter has convincingly demonstrated that the majority of people appear to follow several assumptions of PT with respect to the framing, judgment and evaluation-and-choice functions in almost any considered research domain and context. Deliberate or intuitive framing of choices in terms of changes relative to some reference point might even be a universal rule for human choice, though there are definitely important interpersonal and even intercultural differences in the way individuals flesh out their choice frames in particular domains and contexts. Consequently, several corresponding assumptions of UT were often violated by majorities of research populations. However, several of these UT assumptions were not violated by the observed choices of significant minorities of populations. Moreover, some findings, like the mapping of affective and rational values on different, incommensurable dimensions and the use of non-compensatory decision rules by at least significant segments of populations in several contexts ask for a relaxation of the assumptions of both UT and PT. In the next chapter the consequences of these findings are synthesized into a functional-descriptive theory of human choice behaviour.

Chapter 5
Foundation of Extended Prospect Theory

*What varies with wealth in Bernoulli's theory is the response to a given **change** in wealth. This variation is represented by the curvature of the utility function for wealth. Such a function cannot be drawn if the utility of wealth is reference-dependent, because utility then depends not only on current wealth but also on the reference level of wealth.*

Daniel Kahneman (2002: 460)

Context: Footnote in Kahneman's Nobel Prize Lecture in which he underlines aptly what might be the most fundamental difference between Utility Theory and Prospect Theory. However, he did not propose any assumptions, either here or elsewhere, for how to cope with this context dependency of preference orders when Prospect Theory is applied for choice prediction.

5.1 Introduction

An extensive review of the literature on human choice behaviour from the social and the behavioural sciences shows that it is a largely unconscious, intuitive process that is often at most only superficially monitored and controlled by conscious, deliberate reasoning. Rather than reflecting stable, context-independent preferences it can be conceived as an iterative, adaptive, highly contingent process of 'preference construction'. This applies to all types of choice processes, including strategic decision making that may linger on intermittently for months, tactical choice behaviour that results in scripts, habits or simple rules for concrete actions, and operational choice behaviour that is conceived here as a mental process that accompanies concrete, often recurrent, script-based, habitual and/or impulsive behaviour that may last for split-seconds. The diversity of feasible processes also implies that large interpersonal differences in the way in which they operate may abound, even in similar contexts.

This seemingly chaotic and largely covert character makes any isomorphic description of the choice process disputable. However, according to the Meta Theory of Choice Behaviour that was developed in Chapter 2, the overall function of human choice behaviour is the same,

however different the processes that carry them out may be, and there is no *a priori* reason to believe that the actual transformations that are carried out to perform that function differ widely between similar contexts. In Chapter 2 and 3 it was found that the theoretical concepts and empirical observations of choice behaviour reviewed thus far can be attributed to the four interrelated subsystems of the Meta Theory. By adding the assumption that each individual strives for a cognitively consistent conclusion of her choice processes, this systems-theoretical concept may be transformed into a causal sequence of 'final states' of decision framing, judgments of probabilities and attributes, and decision rules for the evaluation-and-choice of alternatives. This causal sequence by no means pretends to describe the choice process but offers a functional description of what a person may choose, intuitively and/or deliberately, when she perceives several alternative courses of action. As the core of this choice behaviour concept draws on assumptions of Prospect Theory (PT), it is called Extended Prospect Theory (EPT), in recognition of the impressive work of Kahneman and Tversky.

After a recapitulation of the assumptions of EPT, this chapter will compare this choice behaviour concept with other theories, discuss how it can be used to elicit context-dependent travel choice behaviour and provide some thoughts on its modelling.

5.2 Assumptions of Extended Prospect Theory

The review of the assumptions of Utility Theory (UT) and PT in Table 1 (page 34) showed that, after extension with some obvious behavioural assumptions, both constitute complete and non-redundant implementations of the overall choice behaviour function. The review in the previous chapter of the adherence to these assumptions, observed in experiments as well as in everyday life, showed that the assumptions of UT are violated more often than not by a majority of the subjects. The corresponding PT assumptions were followed by a majority of subjects in those contexts. However, almost all articles that provided information on the distributions of feasible choice decisions over survey populations showed that a segment of some 10 to 40% might have applied the UT assumptions. Some of these assumptions, particularly the loss-neutral valuation of attributes, can be accommodated by assuming idiosyncratic differences in the framing of alternatives in relation to the reference state, as PT values alternatives the same as UT if all their attribute levels are in the gain domain.

The reviews in the previous chapter also revealed that most often at least a minority of research populations had satisficing rather than maximizing aspiration levels, encountered commensurability problems in mapping affective values on 'rational' scales, and/or applied non-compensatory decision rules. Moreover, the available information about the choice behaviour strategy function strongly suggests that the search for cognitive consistency is a major driving force and guiding principle for within-context choice behaviour[61]. All these findings about the completion of choice behaviour functions are not covered by the assumptions of PT or by those of UT.

Compared to those of UT, the PT assumptions provided a better descriptive performance and were thus taken as a starting point for the foundation of EPT. To take the empirical findings and corresponding theoretical inferences from the behavioural sciences into account these are, where appropriate, extended into more general assumptions that allow for the inclusion of the

[61] Note that '*cognitive consistency*' does not refer to '*deliberate, conscious reasoning*' but to a covert process that yields ex-post coherence in affective appraisals and feelings with respect to the objects of choice.

population segments that adhere to the UT assumptions. They are summarized and presented in Table 2.

These extended assumptions were synthesized with the assumptions that are required to cope with the deviations of both UT and PT, as observed in the previous chapter. It resulted in further relaxations of some PT assumptions and the complete replacement of one UT assumption and corresponding PT assumption by a new assumption about the order of function completion. In interrelationship these assumptions constitute the functional-descriptive model of choice behaviour that is called Extended Prospect Theory (EPT).

EPT is presumed to describe all types of choice processes, including strategic decision making, tactical choice behaviour, and operational choice behaviour, made by individuals and households. It was developed as a paradigm rather than as a conceptual model. Though its assumptions as listed in Table 2 might be sufficient for the description and understanding of individual human behaviour in particular contexts, additional assumptions are required to allow its use for generalization and prediction to other contexts. The context-independent, complete preference order concept of UT principally asks for a complete evaluation of all the feasible alternatives and outcomes in every choice situation, but this implies that, once the relevant part of an individual's preference order is elicited in one context, it can be generalized for description and prediction in all other contexts. As a weak substitute for UT's context-independent preference order EPT adopts three more assumptions.

The first additional assumption draws on the cognitive consistency principles of Social Psychology and states that most individuals use consistently the same choice behaviour strategy in recurrent choice processes if these deal with the same or similar contexts. The second assumption exploits the instant endowment observation of Behavioural Decision Theory: individuals adjust their reference state almost immediately when they experience changes in their circumstances. The third is related to the recognition-primed decision principle of Naturalistic Decision Theory as proposed by Klein (1993). It assumes that in a particular context previous choices on the same or a higher level of the strategic-operational choice hierarchy act as constituent elements of the actual reference state, reduce the range of feasible alternatives and yield thresholds for acceptable attribute levels. This latter principle allows the intuitive selection of an earlier, successfully applied, choice behaviour strategy in a similar choice context as the one actually considered. A consequence of this is that the alternatives considered will commonly contain the reference state or the 'going concern', if possible supplemented by alternatives that consist of adjustments of it with respect to one or a few relevant attribute levels (see e.g. Beach 1990). EPT thus considers successive choices of an individual as an ongoing process, with reference updating after each concrete choice. Together these additional assumptions, which offer a weak substitute for UT's context-independent preference order, extend EPT from an explanatory theory to one that can be used for predictions as well.

This interpretation of an intrapersonal consistent, efficient assessment of context-dependent reference states, subjective consideration choice sets and choice behaviour strategies evidently reduces the cognitive load of choice behaviour. An obvious consequence is that in fast changing environments the strong impact of previously established reference states might result in sub-optimal choices compared to UT. On the other hand, this incremental-adaptive character of choice behaviour, leading to the adjustment of previously successful choices to suit a changed context, keeps the subject from seemingly optimal but unconventional choices that with handsight may appear 'a bridge too far' in the new context.

Table 2: Assumptions of Extended Prospect Theory

Assumptions	Extended Prospect Theory
Perception	
Subject's environment	Dependent on subject's concurrent needs, recall, experience, attention, etc.
Subject's state	Dependent on subject's concurrent moods, ease and content of recall, etc.
Framing	
Reference state	Expected 'no change' state of assets; if valued: subject to diminishing marginal utility
Alternatives, outcomes, attributes	Context-dependent expected changes (gains and losses) in assets relative to reference state
Subject's needs	Preference order dependent on the context and the way in which alternatives are presented and perceived
Aspiration level for needs gratification	Satisficing search for alternatives, maximal or satisficing decision value, or satisficing attribute values, within budget constraints
Judgment	
Attribute levels and probabilities	Subjective belief-based expectations, partly drawing on heuristic judgment
Valuation of attribute characteristics	May be in different non-commensurable dimensions; Diminishing sensitivity: concave for gains, convex for losses; Independent of size, predominantly loss aversive
Valuation of attribute importance	Belief-based subjective attribute decision weights
Valuation of expected probabilities	Belief-based variable weight factor, dependent on probability
Evaluation-and-choice	
Comparison of multi-attribute alternatives	Alternative-wise, based on a single compensatory compounded overall value, or attribute-wise, sequential evaluation in attribute importance order
Choice criterion for alternative selection	Highest overall value, first alternative with acceptable overall value, and/or rejection of alternatives with unacceptable attribute values
Choice behaviour strategy	
Choice of strategy	Aimed at ex-post cognitive consistency; dependent on the context and the way in which alternatives are perceived
Order of function completion	Can be described by a causal sequence of 'final states' of the assumptions regarding framing, judgment and evaluation-and-choice
Successive choices in the same context	Interpersonal heterogeneity in intrapersonal consistent (may be intransitive) choice behaviour

5.3 Comparison with other theories of choice behaviour

The familiarity of different choice behaviour theories within the scientific community strongly differs. In a 2005 internet search 'Prospect Theory', 'heuristics and biases' and 'Theory of Planned Behaviour' yielded about a thousand journal articles each on scientific search engines and 'Utility Theory' twice as much, whereas a dozen or so alternative theories of choice behaviour together yielded far below a thousand hits. Obviously, a proper assessment of the applicability of EPT requires a comparison of its functional-descriptive character with that of UT, PT as well as the Theory of Planned Behaviour and other versions of Attitude Theory. As the potential application of EPT focuses on the understanding of travellers' choice behaviour, some less commonly encountered process theories that are occasionally mentioned or may be of interest for particular domains in transport sciences are also shortly reviewed.

5.3.1 Choice paradigms, UT, PT and non-compensatory decision rules

In Annex A the historical development of the scientific views on human choice and behaviour is analysed from a systems-theoretical perspective. It is illustrated in diagrams depicting an early 20th Century Rationalist's, a Mid-20th Century Behaviorist's and an actual Cognitivist's paradigm (Figures A.2 to A.4). Comparing the assumptions of EPT, UT and PT on the one hand and the Cognitivists paradigm on the other shows that EPT is fully consistent with that latter paradigm, whereas several UT assumptions and some PT assumptions might be considered as manifestations of the Behaviorist's paradigm. However, the way in which EPT was synthesized ensures that it is an implementation of the Meta Theory of Choice Behaviour, just as UT and PT can, to a large extent, be conceived as particularizations of EPT. Even a normative interpretation of UT can be considered as such. This also ensures that reductions in the range of application of the EPT assumptions allow for the description of choice behaviour according to UT as well as PT, maybe by different individuals in the same context. There is one exception to this rule: UT's decreasing marginal utility assumption and/or its concave utility function cannot be reconciled with PT's and EPT's diminishing sensitivity assumption and partly concave, partly convex value function[62]. A comparison of Tables 1 (page 36) and 2 should verify this.

To a large extent, both UT and PT consider the concrete choice processes of a person in isolation from her other choice processes. UT explicitly presumes an all-inclusive assessment of all relevant alternatives in each individual choice process, PT suggests some intuitive choice set formation and alternative elimination process in the framing stage. EPT considers that the individual choices of a person fit within a strategic-operational choice hierarchy. This means that people are regarded as using their recognition of previous strategic decisions, tactical and operational choices in similar contexts to generate a subjective consideration set that only contains those alternatives that may cope with the challenges posed by the actual choice process.

EPT, PT and UT all describe self-interested subjects that employ a deterministic and static[63] choice behaviour strategy. As such, they can all be simulated with an appropriate actual discrete choice model.

[62] This difference is only relevant if a linear approximation of the utility and/or value function is not justified.
[63] i.e.: once a particular choice process has started there are no stochastic or time-dependent changes.

Both PT and UT assume that all individuals are insatiable utility or value maximizers. Both theories are commonly applied as if all individuals follow just one choice behaviour strategy[64]. This then reduces the main difference between the two to a distinction between UT's context-independent framing and valuation of alternatives in terms of final states of assets and PT's context-dependent framing and valuation of alternatives in terms of changes relative to a reference state. Consequently, UT attributes all interpersonal differences in choice behaviour to differences in idiosyncratic preference orders or 'taste templates' while PT commonly explains these from similar differences in the context-dependent valuation of alternatives. Contrary to both UT and PT, EPT explains within-context interpersonal differences in choice behaviour as a combination of the application of different choice behaviour strategies and of differences in the idiosyncratic valuation of attributes. Choice behaviour strategies describe the use of framing, attribute valuation and evaluation-and-choice principles by each individual such that these are consistent with her interests in the context at hand. As EPT allows for the context-dependent framing of either satisficing or maximizing aspiration levels and evaluation with compensatory and/or non-compensatory rules it obviously covers the use of non-compensatory rules by population segments in any choice context.

In Table 1 and 2 (page 34 and page 96) seventeen different assumptions are listed for UT, PT and EPT. Some differences are, under most circumstances, less important. Disregarding the less prominent differences and combining some others leaves five sets of assumptions that may characterize the most important differences and agreements between EPT, UT and PT. These are juxtaposed in Table 3. Obviously, the differences between the assumptions are not discriminating in all choice contexts. For example, for choices between alternatives with 'certain' outcomes, expected probabilities do not play a role, thus whether these are weighted or not is irrelevant. And the diminishing sensitivity and diminishing marginal utility principles will only have a significant impact on the valuation of attribute levels when the changes in levels relative to the level of the reference state are high[65], which may only be the case in a minority of real-life choice contexts.

To illustrate the descriptive suitability of EPT on the one hand and of UT, PT and non-compensatory decision rules on the other, they are depicted in a Venn diagram (Figure 7). Obviously, all these theories can be regarded as implementations of the functions discerned in the generic Meta Theory of Choice Behaviour. More interesting may be that the concrete assumptions of EPT allow the functional description of choice behaviour by different individuals in the same context according to PT as well as to most implementations of UT (as far as a linear-additive utility specification satisfies) and to the behaviourally relevant non-compensatory decision rules. It also shows that under particular circumstances UT, PT and/or the non-compensatory Strong Lexicographic decision rule explain and predict the same choices for an individual.

[64] PT allows for context-dependent interpersonal differences in the framing of alternatives but with very few exceptions (e.g. Levin *et al.* 2002) these are hardly if ever considered in published observations of human choice behaviour.

[65] If the considered changes in, say, a person's wealth are small compared to her 'reference wealth' the logarithmic cardinal utility function can be approximated by its tangent. For similar small changes the convex indifference curves that depict the neoclassical 'diminishing marginal rate of substitution' principle can then be approximated by a linear function. As the exponent 0.88 of the power function, as proposed by Tversky and Kahneman (1992), is close to one a linear approximation might also be used for small deviations from the reference state, though it should be kinked at that reference to account for loss-aversive valuation.

Table 3: Discriminating assumptions of EPT, UT and PT

Extended Prospect Theory	Utility Theory	Prospect Theory
Reference-dependent framing and loss aversion		
Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to an updated reference state, and most individuals value losses higher than gains of equivalent size	Alternatives and attributes are framed context-independent, as post-decisional states, independent of the sign of the change	Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to a reference state, and each individual values losses higher than gains of equivalent size
Size-dependent valuation of attributes		
Diminishing sensitivity: the value function is concave for gains and convex for losses	Diminishing marginal utility: the utility function is concave	Diminishing sensitivity: the value function is concave for gains and convex for losses
Valuation of probabilities		
Most individuals weigh expected probabilities of uncertain outcomes with a subjective non-linear probability weight	An individual does not weight expected probabilities	Each individual weights expected probabilities of uncertain outcomes with a subjective non-linear probability weight
Compounding of attributes		
Affectively salient attributes may be valued in a qualitative affect dimension, other attributes on a monetary or medium scale	All attributes are valued in a commensurable medium	All attributes are valued in a commensurable medium
Heterogeneity in choice behaviour strategies		
Within-context interpersonal differences in choice behaviour strategies occur (framing of attributes, satisficing and maximizing, compensatory and non-compensatory rules, etc.)	Each individual chooses the alternative with the highest (compensatory compounded) overall ordinal utility	Within-context interpersonal differences in framing occur, but each individual chooses the alternative with the highest (compensatory compounded) overall value

5.3.2 Attitude Theories

Attitude Theory (Fishbein 1963) from social psychology, and its extensions Theory of Reasoned Action (Ajzen and Fishbein 1980) and Theory of Planned Behaviour (Ajzen 1991), presume that individuals process the norms, beliefs and appraisals of alternative courses of action in a cognitive, rational, systematic way to arrive at a '*behavioural intention*' with respect to one alternative. As such they can be regarded as choice behaviour theories. More specifically, these theories describe a linear-additive, loss-neutral compounding of belief strengths multiplied with their corresponding subjective evaluation into overall attitudes and, in later versions, subjective norms and perceived behavioural control. The subjective evaluations of beliefs as conceived in these theories are similar to cognitive and/or affective attribute values expressed in a qualitative 'good-bad' dimension; the belief strengths are equivalent to attribute decision weights. Attitudes, subjective norms and controls are once more considered to be transformed linear-additively into one behavioural intention that is considered to be the best predictor of the actual behaviour. The process needed to arrive at a behavioural intention is thus functionally identical to that which results in a choice according

to the assumptions of UT. However, Attitude Theories describe how people adjust their attitudes, which are a close match to preferences as conceived in UT. Thus, similarly like EPT, attitude theories reject the temporal stability of idiosyncratic preferences. Like EPT, it also underlines the importance of considering the affective as well as the utilitarian valuation of attributes but like UT, it presumes the loss-neutral, compensatory compounding of 'attribute levels' into one behavioural intention, whereas EPT allows for other strategies as well.

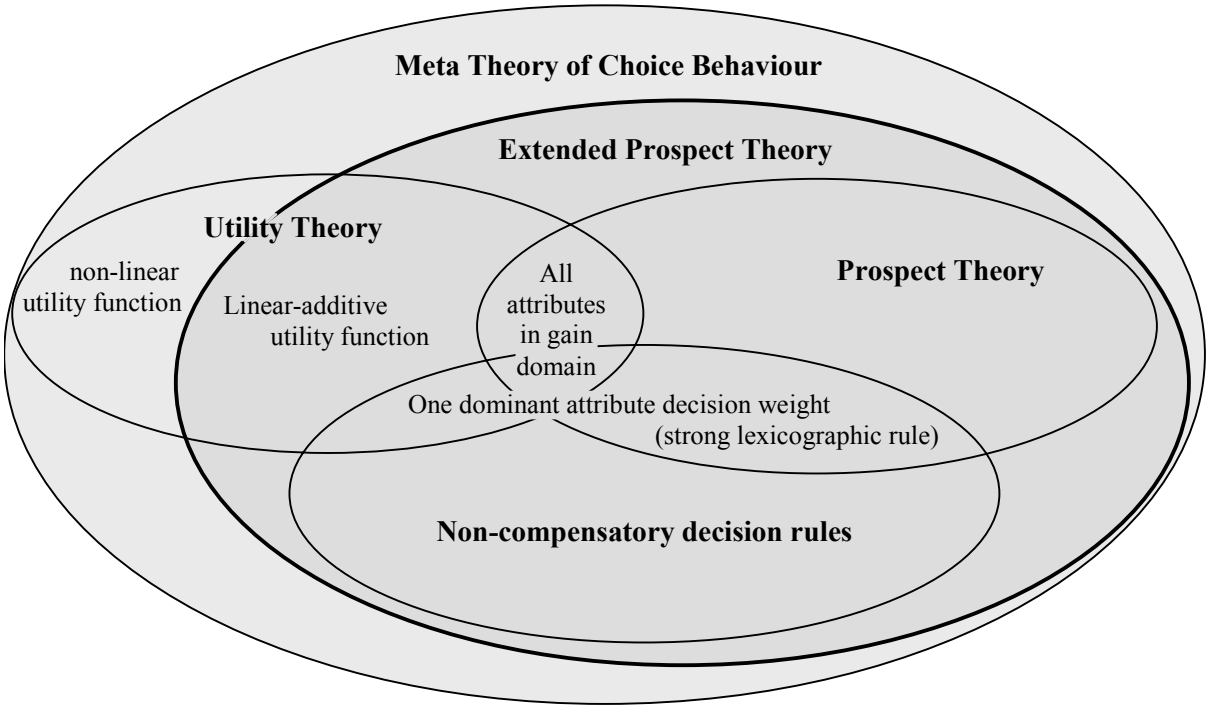


Figure 7: Venn diagram[66] of choice behaviour theories

The applications of Attitude Theory to travel behaviour research deal mainly with the consistency between a behavioural intention and the observed actual behaviour, where errors of commission (i.e. insufficient intention strength) and errors of omission are held responsible for inconsistencies (Gärling *et al.* 1998; Fujii and Gärling 2003). Without calling this approach into question a caveat may be that the emphasis on the causal intention-behaviour relationship might promote a dispositional bias, i.e. attributing the behaviour too much to the subject's stable internal motives at the expense of external or situational attribution (e.g. Bem 1967; Kelley 1967; 1973; Atkinson *et al.* 1983). In EPT behavioural intentions can be conceived as the outputs of strategic decision making, which allows, for example, taking loss-aversive valuation into account, and also as inputs into tactical and/or operational choice behaviour processes, considering that these generally take place in a very different context. Compared to Attitude theories this may promote a more balanced causal attribution of dispositional and situational factors. To summarise, Attitude Theory can therefore be interpreted as two interrelated choice behaviours, which fit into the wider assumptions of EPT, and their output-input relation.

[66] Note that the sizes of the different elements and overlaps in the diagram do not indicate ranges of applicability or other measures, like importance or extent.

5.3.3 Process Theories

Process theories aim to describe the observed choices by assumptions about the mental processes that arrange for the choice behaviour functions. As the way in which these processes work is highly covert, not only for the analyst but also for the choice subject, most of these theories are based on postulates that draw on introspection and/or verbal protocols of choice experiments.

Cognitive Dissonance Theory (Festinger 1957) offered an explanation for several experimental observations in which persons were persuaded to perform a task even though they had stated beforehand that they did not like it. Most subjects had adjusted their attitude towards these tasks when they were questioned about them afterwards.. Festinger posited that the contradicting cognitions in such experiments caused an unpleasant state of cognitive dissonance that stimulated the subjects to modify their previous beliefs in order to solve or mitigate the dissonance. He conceived cognitions as knowledge about appraisals, attitudes, beliefs, etcetera, thus as feelings rather than facts. Tertoolen *et al.* (1998) showed that mental activities to dispose of cognitive dissonance (or to adjust self-perceptions, see hereafter) could at least partly explain the observed change in attitude of car drivers subjected to campaigns that promoted the use of alternative modes. This observation fits well within the assumptions of EPT.

Self-Perception Theory (Bem 1967) presumed that people infer cognitions from observation of their own previous behaviour. According to this theory, during the cognitive dissonance experiments the subjects should have inferred that their pre-experimental cognitions apparently were not appropriate and thus updated them, requiring no aversive feeling of dissonance. Greenwald (1975) made clear that experiments could not disconfirm either theoretical explanation. This is a consequence of the postulation of mutually exclusive explanations that largely rely on predominantly covert mental 'System 1' processes (see Section 2.3). Support for either of these theories has to rely on self-reports of such processes by experimental subjects, of which Nisbett and Wilson (1977) convincingly showed that these are notoriously unreliable for such purposes. It is worth noting that the 'final states' cognitive consistency principle of EPT is in agreement with both theories, while the functional-descriptive character of EPT does not require either process to be explained.

Regret Theory was developed for probabilistic choices as an alternative for PT, and is incidentally mentioned in the contemporary travel behaviour literature (e.g. Chorus *et al.* 2006). Loomes and Sugden (1983: 428) postulated that '*people tend to compare their actual situations with the ones they would have been in, had they made different choices*'. The psychological basis for this theory and its elaboration relies predominantly on introspection (Loomes and Sugden 1982). Essentially, it adds a regret-rejoice utility to the utility of each outcome of a probabilistic alternative. This added utility is a function of the difference between the considered outcome and the outcome that would result if an alternative prospect was chosen. Successively, the principles of Expected Utility Theory are applied to the resulting utilities of each outcome to arrive at a choice. Regret Theory could explain the same violations of Expected Utility Theory on which Kahneman and Tversky (1979) founded PT, although it appeared slightly inferior to PT (Tversky and Kahneman 1992). As with EPT in a more general sense, Subjective Expected Pleasure Theory (Mellers 2000) and the expected elation/disappointment concept of Brandstätter *et al.* (2002) propose emotional phenomena similar to regret and rejoice as explanations for loss-aversive valuation and for the shaping of the weighted probability function.

Dominance Search Theory (Montgomery 1989) and the closely related Differentiation and Consolidation Theory (Svenson 1992) draw on the same cognitive consistency principle as Cognitive Dissonance Theory, if one considers the post-decisional phase of the latter as part of the choice process. These theories describe a postulated choice process and are apparently largely based on observations from think aloud choice experiments. They presume an alternative-elimination process in an early stage, leaving only two or three alternatives. Of these, a promising one is chosen if the difference in attractiveness (equal to the value concept of PT) with its closest competitor surpasses a threshold criterion. The latter reflects aspiration levels and standards that may change during this iterative process. Though Svenson (1992) illustrated elements of his theory with examples from the car acquisition process, he offered no outline there of how it could be applied to travel mode choice as suggested in Stern and Richardson (2005), and no other applications of this theory to travel behaviour could be found. These theories evidently influenced the constructed preference concept and are as such functionally covered by EPT. It is equally clear that EPT does not claim to be able to describe the conceived progress of the choice process.

Image Theory (Beach 1990) might be applied to concrete operational choice behaviour but it seems more tailored to the strategic decision making of individuals and organizations. Alternatives (plans) are evaluated against the subject's '*images*' (i.e. her values: beliefs, ideals, morals; her goals; and her plans). Image Theory describes choice behaviour as comparisons of the forecasted elements of the alternatives (plans), mostly with respect to the status quo in terms of the concurrent images. The adaptive character of the choice process as conceived in Image Theory, leading to the adjustment of previous choices where feasible rather than the recurrent drastic reconsideration of all options, is covered by EPT's 'framing' of particular choices in the strategic-operational choice hierarchy.

Decision Field Theory (e.g. Busemeyer and Townsend 1993), which was extensively discussed in Stern (1999), is both a dynamic and a probabilistic process theory of choice between alternatives with uncertain outcomes. Just as with other theories that draw on the description of the progess of the individual choice process[67], EPT does not pretend to cover it in an isomorphic way as the required assumptions about the covert choice process cannot be falsified. It describes a dynamic choice process in which '*subjects start out biased against the uncertain alternative when the certain value is positive, and they are initially biased in favour of the uncertain alternative when the certain value is negative*' (Busemeyer 1993: 187). This theory apparently presumes loss aversion, as a consequence of approach and avoidance inclinations towards outcomes. It offers an elaborate and elegant model that draws on several assumptions of how the human choice process works. Consequently many different parameters have to be estimated to cover the whole range of choice situations it might describe. A re-examination of the substantiating observations in a choice experiment in this reference showed that these could just as well be caused by myopic reference-updating and loss aversion in a feedback-based choice setting, such as e.g. examined by Barron and Erev (2003) and by Avineri and Prashker (2005), the latter in a route choice experiment. The observed shift of some respondents under increasing time pressure towards non-compensatory strategies was found in many more choice experiments and is more often attributed to a cost-benefit trade-off between decision rules, such as the cognitive effort-accuracy model (Payne *et al.* 1993). Stern

[67] According to Busemeyer and Townsend (1993: 432) '*dynamic (choice) theories specify how the preference relation or probability function changes as a function of deliberation time*'. Decision Field Theory is one of the very few concepts that claims to model these dynamics appropriately. Dynamic theories in this sense are sometimes confounded with theories that are able to model the dynamics of recurrent choice settings. This ability is well covered by the reference-state updating assumption of the 'static' EPT.

(1999) hypothesized and confirmed such a shift in the choice behaviour of car drivers and attributed it to Decision Field Theory, but his hypotheses follow just as well from these other theories.

The Recognition Primed Decision model may also be of interest for particular travel behaviour domains and contexts. Klein (1993) assumes that subjects start with a recognition phase, i.e. an assessment of the situation by comparing it to previous experiences, and an evaluation phase in which alternatives are evaluated one by one with respect to their effectiveness. The presumed outcomes of the recognition phase (relevance of contextual factors, goals, expected development of status quo, and context-dependent promising alternatives) are close to those of the framing function of EPT, those of the evaluation phase to those of EPT's judgment function concluded with a satisficing choice criterion. Lipshitz (1993) compared this model with Dominance Search Theory and Image Theory, amongst others, and classed them together under 'Naturalistic Decision Theory' (Lipshitz and Strauss 1997), the concept of which should typically apply to the choice behaviour of experienced decision makers like fire or army officers in field settings.

The overview of process theories above yields no hard evidence that any of them should be either rejected or adopted at the expense of others. This could have been expected in view of the largely covert characteristic of the mental processes under consideration and the connected ambiguity of inferences from the process-tracing studies that support them (see Section 4.4), Thus several of their assumptions, though conflicting, might be employed unnoticed by different individuals in the same context and by the same individual in different contexts. All the processes hypothesized in these theories performed functions that are either represented in individual choice behaviour systems as conceived in EPT or in their interrelations. Thus EPT seems able to cover the range of processes described in these theories in a functional-descriptive way, though it definitely offers no clues on how human minds are doing this. Examination of these process theories by transport scientists might remain very helpful in conceptualising the range of different decision frameworks and choice behaviour strategies that might simulate human choice behaviour in a particular context.

5.3.4 Decision making in organizations

Though EPT was developed as a descriptive model for the choice behaviour of individuals and households it might also be useful as a descriptive model for the choice behaviour of firms and other organizations. Like PT it can be considered as an implementation of the Bounded Rational Decision-Making model (Simon 1960). More supporting considerations are: the apparently predominantly holistic, intuition-based decision making by managers[68] of large organizations (Mintzberg 1989); the loss-aversive choice behaviour that managers often demonstrate within the narrow decision frame of their own department/interest, and the overestimation of their own skills and judgment (Kahneman and Lovallo 1993); and the resemblance of the sequence of phase/function completion in the decision making of firms (e.g. Pen 2000; 2002) with that of individuals (e.g. Slovic 1995). Though it is beyond the scope of this book, the performance of EPT as a functional-descriptive model for strategic decision making and the tactical and operational choice behaviour of transport authorities, shippers, transporters etc might be an interesting topic for future research.

[68] As experienced and observed by the author during his own career in higher management.

5.4 Elicitation of choice behaviour characteristics

According to EPT, a choice behaviour strategy is a combination of: a reference state arising from several feasible expected states; a particular choice set composition (e.g. lumping alternatives together in one choice process or splitting them over a succession of choices) in terms of changes of outcomes relative to the reference state; a maximizing or satisficing aspiration level; loss-aversive or loss-neutral valuation; etc. One strategy generally covers many different choice processes that will mostly be more complicated than the straightforward causal sequence of the final states of EPT. Even then different individuals may apply several distinct choice behaviour strategies in any choice context. This complicates the elicitation of choice behaviour strategies and/or parameter estimation. However, the preceding sections offer several clues to the design of elicitation contexts and about the frequency of occurrence of the choice behaviour strategies to be encountered. For example, under a variety of circumstances most individuals:

- Demonstrate the loss-aversive valuation of attributes (e.g. Kahneman and Tversky 1979);
- Successively evaluate one alternative at a time against the reference state in strategic decision making (e.g. Ajzen 1991; Beach 1990; Lipshitz and Strauss 1997); and
- Evaluate such choice sets in a compensatory manner (e.g. Payne *et al.* 1993; Timmermans 1993).

In operational choice contexts that recur daily the number of alternatives considered is mostly small (e.g. Hoogendoorn-Lanser 2005). An individual may constrain the choice set size by adopting the outcomes of her previous strategic decisions and tactical choices (Section 4.2). For the design of stated preference surveys this implies that bi-optional or tri-optional choice sets, in which the alternatives are related to a recent real-life experience that might act as a reference state, might be the most appropriate, as is the current practice in value-of-travel time studies (Gunn 2001; Burge *et al.* 2004). Presumably explicit inclusion of the reference state in the choice sets, as practiced by e.g. Hensher (2001b), might further improve behavioural reliability and boost a compensatory evaluation. However, in contexts where subjects have little time to choose from many multi-attribute alternatives, a non-compensatory elimination strategy might be supposed for large population segments, with cut-offs drawing on the loss aversion principle. Nevertheless, the elicitation of choice behaviour strategies from both experimental or real-world observations of travel behaviour requires an expert in the field to conceive a plausible range of choice behaviour strategies, where required in interplay with observed choices. Paraphrasing an address of Frederick *et al.* (2002: 394) to economists one might recommend that transport researchers '*should proceed as they typically do. Economics* (and transport research) *has always been both an art and a science. Economists* (and transport researchers) *are forced to intuit, to the best of their abilities, which considerations are likely to be important in a particular domain, and which are likely to be largely irrelevant*'.

Once the researcher has conceived the plausible choice behaviour strategies, she might follow the structural approach to elicit the employed valuation and choice behaviour strategies. To date this is the most common practice to elicit decision rules (e.g. Maule and Svenson 1993; Payne *et al.* 1993; Rieskamp and Hoffrage 1999). This means that one analyses the coherence between the observed decisions, e.g. as found in choice experiments, and the information about alternatives and attributes available to the decision maker. To date, a statistical analysis of all individual choices is most commonly followed, resulting in a large overlap of inferred feasible choice behaviour strategies (e.g. Edland 1993; Gilbride and Allenby 2004; Stern 1999). When the choice sequences of individuals are recorded in the same context, like in a

stated choice survey, a 'deterministic' analysis of individual choice sequences may be followed (e.g. Haines and Ratchford 1987). Such an approach was recently chosen by Sælensminde (2001) and Rouwendal and De Blaeij (2004) to demonstrate violations of UT in the stated choices of travellers.

When information is available about the successive choices of an individual in a particular context, the 'intrapersonal' choice sequence can be considered as the basic entity of analysis for the assessment of the use of choice behaviour strategies according to EPT. The analysis may start with statistics for the identification of sequences that cannot be explained by random choice, followed by the exclusion of sequences that can be explained from errors or inconsistencies in one separate choice of the more frequently observed sequences. The remaining sequences might now be considered as determined by a limited number of choice behaviour strategies and their associated attribute valuations. The analyst should now assess the choice sequences that follow from the conceived plausible choice behaviour strategies, and identify the observed choice sequences that these explain. She might attribute sequences with overlapping explanatory strategies to the most plausible or frequently observed one in that context, or use another distribution that makes sense. An application of such a deterministic elicitation approach to a stated choice survey of the value-of-travel-time is published in Van de Kaa (2006).

Most tactical and operational choices in real-life contexts recur frequently, and the subject receives feedback in between them, at least in terms of experiences. The choice behaviour strategies that are considered for the elicitation process should then include behaviourally plausible routines for updating the elements of the subjects' choice frames. When choice behaviour strategies have to be inferred from non-recurrent real-world circumstances, the consistence of sequential choices cannot be employed for elicitation. In strategic decision making this might often be the case. Sometimes, like in residence location choice, information might be retrieved about the sequential evaluation of alternatives compared to a reference state. Otherwise the analyst has to rely on her understanding of the choice behaviour employed in the domain at hand to identify the observed choices. In novel contexts it might be sensible to precede this with a preliminary survey of how different individuals arrive at a choice set and organize their choices (e.g. Stanbridge 2006). Asking subjects to list alternatives and attributes, either by asking for unaided listing or by aided recall, may achieve this (Horowitz and Louviere 1995). *Ex-post* open interviews of *what* alternatives and attributes were considered and *what* choices were made, with avoidance by the interviewer where feasible of *why* and *how* questions, as these might provoke cognitive dissonance (Nisbett and Wilson 1977), might also be appropriate here; see Hoogendoorn-Lanser (2005) for a recent application of this approach in a multi-model route choice context.

5.5 Some preliminary thoughts on modelling

This book refrains from listing and discussing the many different mathematical formulae that were proposed to estimate the theoretically presumed real-life human choice behaviour approximately. This is to prevent a proper appraisal of the behavioural assumptions of the underlying theories being blurred by a discussion of the appropriateness of the applied simplifying assumptions needed to enable its mathematical simulation. There are also no attempts made to propose more or less 'general' mathematical formulae that might be used to estimate and predict actual choices. Experience shows that, once a mathematical formulation is proposed, the attention of authors and readers often shifts from the examination of observed

choices aimed at a better understanding of the underlying choice process towards the quality and possible improvement of the mathematical model with respect to a better simulation of the observations. Obviously, mathematical formulations to accommodate behaviour according to any paradigm might differ depending on the considered choice context and the aim and character of the model framework. With respect to the contexts, for example, a kinked-linear value function may be adequate when individuals consider small adjustments in their current behaviour while a power function might be more appropriate when relatively large changes in their income are at stake. An elaboration of such a specific model that allows the prediction of tactical travel choice behaviour in agreement with the EPT paradigm, tuned to the Singapore road-pricing context, will be presented in Chapter 7. In the literature referred to in the preceding chapters, including the original publications (Kahneman and Tversky 1979; Tversky and Kahneman 1991; 1992), there is an ample supply of more generic mathematical concepts and models that simulate choice behaviour. It has also been demonstrated that the Logit-model family of discrete choice models can accommodate several of its assumptions, such as loss aversion (Arentze and Timmermans 2005). The present section explores several of these concepts with respect to their appropriateness for models in agreement with the EPT paradigm from a more global perspective.

The few authors who have modelled applications of PT in travel behaviour research mostly framed intrapersonal as well as interpersonal choice heterogeneity in a Multinomial Logit model (Arentze and Timmermans 2005; Avineri and Prashker 2005) or applied a similar stochastic approximation (Katsikopoulos 2000). Thus they added implicitly the Random Utility Maximization assumption of stochastic intrapersonal variations in utility to the essentially deterministic decision rule of PT and used the same approach to model interpersonal variations. Hensher (2001a) demonstrated that this latter approach might underestimate the average value of travel time savings from stated choice surveys by over 50% compared to a more sophisticated treatment of intra- and interpersonal variations in tastes and preferences. Van de Kaa (2006) confirmed his findings, based on a deterministic assessment of an individual's values of travel time in conformity with EPT. One should thus check the different sources of intrapersonal and interpersonal variations in observed choices carefully to avoid major misjudgements of people's appraisals.

The Mixed Logit model concept in particular offers possibilities to accommodate interpersonal differences in valuation and choice behaviour strategies (Hensher and Greene 2003; Train 2003). Up to a certain extent it might accommodate non-compensatory decision rules (Swait 2001). However, compared to a Mixed Logit model that treats several types of variations in a stochastic manner, a discrete choice model in which the distribution of choice behaviour strategies in a population can be correlated to the characteristics of the individual and the actual choice conditions might have a better descriptive performance. For the elicitation and simulation of such distributions the discrete choice model framework as proposed by Williams and Ortúzar (1982a) might be most appropriate. It allows the accommodation of non-stochastic interpersonal differences in choice behaviour strategies. The probability that an individual selects a particular alternative might be nested here within the probability that she employs a particular choice behaviour strategy. Actually, Williams and Ortúzar spoke of 'decision rules' but their framework might accommodate the strategies that include them just as well. Their concept seems to accommodate EPT more appropriately than the one-stage Mixed Logit model with penalized attribute cut-offs of Swait (2001) and the two-stage conjunctive-compensatory discrete choice model of Cantillo and Ortúzar (2005). These latter might, however, be modelled as one of the choice behaviour strategies in an EPT-model structure following Williams and Ortúzar (1982a). For the domain and context

specific formulation and implementation of the formulae in such models it might be better to wait until specific surveys have resulted in at least a preliminary assessment of the corresponding variation in idiosyncratic travel choice behaviour strategies.

An important consideration for modelling is the conceived strong impact that the outcomes of previous strategic decision making and tactical choice behaviour may exert on the framing of choice contexts that come across an individual. By and large these may often determine the reference state, constrain the consideration choice set and influence the aspiration level. Likewise, recurrent operational choices, like the home departure time for the morning commute, cannot be described well by presuming an unchanging reference state over time (Avineri and Prashker 2005). A model which simulates many individuals reframing the choice situation from day to day, depending on the experienced outcome of their previous choices would be in agreement with EPT (e.g. Schul and Mayo 2003). To account for the interrelationship of the different choice categories, flexible model frameworks like Albatross (Arentze and Timmermans 2000) might be helpful.

Scant evidence suggests that the use of choice behaviour strategies might be correlated to relatively stable personality characteristics (Shiloh *et al.* 2001; McElroy and Seta 2003; Levin *et al.* 2002). This could imply that the distribution of choice behaviour strategies is approximately stable across large ranges of travel choice contexts. Long-term stability of the distribution of personality-choice behaviour strategy combinations over populations might also reduce the purely inductive context-dependent component of EPT implementations. To study this one might investigate the consistency between choice behaviour strategies and characteristics like gender, age and personality types.

Several segmentations of populations in relatively stable categories of personality characteristics are proposed in literature. One might consider the sixteen personality types following from the Myers-Briggs Type Indicator® (Briggs-Myers *et al.* 1998) or the team roles of Belbin (1993), that both can largely be retraced to the personality characteristics as defined by early 20th century psychologist Jung (1971, re-edition) and nowadays have a certain popularity in management circles. Particularly within organizational contexts there might be an interrelationship between a person's characteristics and her role. Another possibility is the more domain-specific segmentation of populations that draws on the work of one of Jung's contemporaries, Adler (1964, re-edition). Some examples are the different living-and-lifestyle groups that characterize consumers on the Dutch housing market (Hagen 2002) and the lifestyle groups with respect to the experience and perception of travel (Goal-oriented travellers, Environmentalists, Competitors, Pleasure-seekers and Passive travellers) as discerned in Need (2003). However, more appropriate than either of the previous segmentations might be one based on the Big Five personality trait scales, about the relevance of which most psychologists agree from the 1990s onwards. These trait dimensions, as originally proposed by Norman (1963), are: Neuroticism, Extraversion, Openness to experience, Agreeableness and Consciousness. It might be complemented with the scores on the Rational-Experiential Inventory (Pacini and Epstein 1999). Only one article was retrieved that considered the correlation of interpersonal differences in choice behaviour strategies and personality characteristics: Levin *et al.* (2002) found significant correlations between the scores on the Big Five scales and the Rational-Experiential inventory and the extent of framing effects, whereas they found no correlation with, for example, gender.

Obviously a hypothetical long-term stability of the distribution and relative context independency of personality-choice behaviour strategy combinations over populations would

be very desirable, as it would reduce the purely inductive context-dependent component of EPT implementations. However, the assessment of the extent to which choice behaviour strategies are correlated to personality types would be too ambitious within the framework of this book and thus is addressed here as a topic for future research.

The rapid development of agent-based micro-simulation may offer a modelling concept for the future that seems much more apt for a functional-descriptive reproduction of real-life choice behaviour. EPT might provide the answer to several questions regarding the simulation of choice processes in agent-based micro-simulation models as e.g. raised by Hunt (2002). This type of model might also introduce the opportunity to simulate changes in public opinion due to the mutual influencing of common choice behaviour strategies of population segments. Obviously, this asks for a functional-descriptive adequate simulation of the choice behaviour of different individuals and their interrelationships, which seems by no means an easy thing to develop. Once more, this research area is beyond the scope of this book but seems to offer very promising tools for a better understanding of travellers' choices.

Chapter 6
Evidence from Travel Behaviour for EPT's Assumptions

If persons change their attitudes or values leading to differences in choices (e.g. a different weighing of mode attributes), a correct forecast would no longer be possible.

Tommy Gärling and Satoshi Fujii (2006: 8-9)

Context: In their resource paper for the 2006 IATBR conference the authors observe the limitations of the utility-maximization framework for the modelling of travel behaviour modification. Their argument is essentially the same as that made in Kahneman's Nobel Prize lecture (see the heading of Chapter 5). Like him they do not refer to other theories or principles that overcome this limitation.

6.1 Introduction

6.1.1 Background and purpose

When browsing through the proceedings of recent conferences that deal with travel behaviour, like the CD-ROMs of the International Conferences on Travel Behaviour Research (IATBR, Lucerne 2003 and Kyoto 2006) and the European Transport Conferences (ETC, Strasbourg 2005 and 2006), it soon becomes evident that, to date, Utility Theory (UT) dominates travel behaviour modelling. Whenever choice concepts from other social sciences are considered in a transport context they are most often framed in a discrete choice model that adheres to Random Utility Maximization Theory. For practical applications, like elicitation of observed behaviour, parameter estimation from surveys and concrete demand predictions, Multinomial Logit models prevail, commonly applied in order to encompass both intrapersonal and interpersonal choice heterogeneity. Choice model innovation sessions in these conferences are mainly devoted to the improved description of choice heterogeneity, predominantly by considering improved specification of the stochastic parameters in Mixed Logit frameworks. In all kinds of model descriptions, linear-additive formulations for the deterministic part of the utility function abound. Only incidentally is an alternative specification proposed for the

deterministic part of the utility function, and no papers were found that modelled interpersonal different choice behaviour strategies within the same context.

In recent years several alternatives for UT have been developed in Behavioural Economics and Decision Theory, the most well known of which is Prospect Theory (PT). When the behavioural assumptions of UT and PT are assembled in a systems-theoretical framework it appears that some of these are similar but several others differ greatly (see Chapter 3). A review of the literature from the behavioural sciences revealed an extensive body of empirical observations, and of notions deduced from them that enabled a comparison of the descriptive performance of different behavioural assumptions. The comparison demonstrated that in almost all survey and naturalistic choice contexts only a minority of the subjects complied with the UT assumptions. Most subjects behaved according to the alternative PT assumptions, but there were important segments of the population who did not follow these either (see Chapter 4). Drawing on the hypothesis that subjects strive for *ex-post* cognitive consistency in successive choices, an assemblage of assumptions was developed that might be appropriate as a more generic functional-descriptive theory for human choice behaviour (see Chapter 5). In recognition of the impressive work of Kahneman and Tversky (e.g. 1979) this was denoted as Extended Prospect Theory (EPT). As the assumptions of this theory draw on observed choices in many experiments and real-life contexts one would also expect EPT to facilitate a better description and prediction of travellers' choices compared to UT and PT, without disputing the usefulness of UT as an acceptable descriptive model in many choice contexts.

The present chapter aims to assess the extent to which the five assumptions that most discriminate EPT from UT and PT might offer a better explanation for the observed choices in a variety of travel contexts. The resulting inferences are used to compare the three theories with respect to their overall descriptive ability of travel choice behaviour.

6.1.2 Considered assumptions of EPT

Choice behaviour is conceived as a mental process that precedes human behaviour. EPT as a generic functional-descriptive concept is considered to apply to all types of human choice processes, including strategic decision making, tactical and operational choice behaviour. Following a mental perception stage, it discerns four functions that together mimic human choice behaviour. The choice behaviour process is presumed to be largely covert (e.g. Kahneman 2002), complying with a context-dependent constructed preference concept (e.g. Payne *et al.* 1999), rather than satisfying UT's assumption of a stable, context-independent preference order. This is described as if it consisted of a sequence of final states of the framing, judgment and evaluation-and-choice functions, controlled by the choice behaviour strategy function. Choice behaviour strategies describe the use of framing, attribute valuation and evaluation-and-choice principles by each individual such that these are consistent with her interests in the particular context.

Where UT explicitly presumes an all-inclusive assessment of alternatives in each individual choice process, PT suggests some intuitive choice set formation process, but both treat the individual choices in isolation to other choice processes of the same subject. EPT considers that the individual choices of a person fit within a strategic-operational choice hierarchy. This means that individuals use their recognition of previous strategic decisions, tactical and operational choices in similar contexts to generate a subjective consideration set that only contains those alternatives that may cope with the challenges posed by the actual choice process. EPT assumes that within-context interpersonal differences in choice behaviour are caused by differences between the applied choice behaviour strategies in combination with

differences in the idiosyncratic valuation of alternatives. This distinguishes EPT the most from both UT and PT, where interpersonal choice heterogeneity is attributed to stochastic differences in idiosyncratic taste templates, preference orders or valuation[69].

In Chapter 5, EPT was founded on seventeen different assumptions that are mostly less restrictive than those of UT and, to a lesser extent, of PT. Five of these assumptions were selected for the present re-examination of findings from the travel behaviour literature, being the ones that discriminated EPT the most from UT and/or PT. These assumptions, which are listed in Table 3 (page 99) next to those of UT and PT, are:

- **Reference-dependent framing and loss aversion**: each individual frames alternatives and attributes context-dependent as changes (gains and losses) relative to an updated reference state, and most individuals value losses higher than gains of equivalent size.
- **Diminishing sensitivity**: the value function is concave for gains, convex for losses, and concave for states of assets.
- **Weighted probabilities**: most individuals weight expected probabilities of probabilistic and uncertain outcomes with a subjective non-linear probability weight factor
- **Mixed affective-utilitarian valuation**: affectively salient attributes will generally be valued on a qualitative affect dimension, other attributes of the same alternative might be valued on a monetary or medium scale.
- **Heterogeneity in choice behaviour strategies**: interpersonal differences in choice behaviour strategies may occur within the same choice context.

6.1.3 Methodology

The methodology that is followed in this chapter for the selection and interpretation of useful travel choice studies is essentially the same as chosen in Chapter 4 for the review of findings from the behavioural sciences. It concerns a systematic review, by means of secondary analyses of the recovered studies that are accounted for in a narrative discourse. Section 4.1 offers references and definitions of these approaches, the rationale behind the chosen methodology and the way in which its weaknesses are tackled. In Subsection 6.1.4 the selection process of the relevant publications is discussed in more detail. Compared to the secondary analyses in Chapter 4 the focus is more on a comparison of the descriptive abilities of the assumptions in terms of the correspondance of estimated and observed travel choices than on the applicability in terms of confirmation or rejection of hypotheses. Subsection 6.1.6 offers additional information about the assessment procedure followed in the secondary analyses and the kind of inferences that were drawn from them. The main difference with the methodology followed in Chapter 4 is that one set of studies was recovered that could be considered for all comparisons and that appeared to cover the whole field of travel behaviour contexts. This enables the inferences about each considered set of corresponding assumptions to be applied to a meta-analysis according to the vote-counting method[70]. A narrative discourse of these outcomes makes it possible to draw conclusions about the descriptive

[69] PT allows for within-context interpersonal differences in framing as well, but hardly if any reference was found in which this assumption was put into operation.

[70] According to Becker (2007: 401) '*Vote counting entails counting the number of studies that have statistically significant results in support of, and counter to, a particular hypothesis, as well as those with nonsignificant results. The category with the most votes "wins" and the set of all results is then characterized as supporting that view*'

ability[71] of the individual assumptions and comprehensive implementations of the concerned theories for travel behaviour research.

6.1.4 Selection of relevant publications

To assess the extent to which EPT allows for a better description of travellers' choice behaviour compared to UT and PT, the travel behaviour research literature was reviewed and re-examined on empirical findings and corresponding theoretical inferences that are useful as a base for comparison. To that aim a rather extensive survey was made to retrieve research findings of travellers' choice behaviour in surface transport[72]. This search for relevant literature started with a full-text query on the Internet, covering the largely overlapping fields of travel, transport and traffic. In addition to the assumed use of non-compensatory decision rules the assumptions that distinguish EPT from UT largely coincide with those of PT, including loss aversion. These keywords were employed in a full-text query on the Internet using the BOOLEAN ("Prospect Theory" AND/OR "Loss aversion" AND/OR "non-compensatory") AND (Traffic AND/OR Transport AND/OR Transportation AND/OR Travel). In the spring of 2005 this yielded almost 200 journal articles and approximately 3,000 more web results on scientific search engines and almost 20,000 more hits on a general engine. Most of those dealing with travellers' choice behaviour contained only a short reference to PT[73]. In view of the explanatory rather than operational character of the theory to date this is not particularly surprising. Screening all the references to articles as well as a few hundred additional web results left only a limited number of articles and discussion papers. Some additional sources were found in the references of the retrieved articles.

The Internet survey was supplemented with a conventional backward literature research, starting with a complete screening of the CD-ROM proceedings of the 2003 and 2006 conferences of the International Association of Travel Behaviour Research and the 2005 and 2006 European Transport Conferences. In addition to papers in which elements of PT and/or non-compensatory decision rules were applied to travel behaviour research, publications containing research designs together with tabulated choice data that could be re-examined to test the principles of EPT were searched for. Again, not many articles were found. This may be due to the fact that the 'raw' responses of individuals to surveys are generally not reported as most transport researchers confine themselves to the presentation of statistical measures of agreement between empirical findings and models based on the principles of Random Utility Maximization Theory. Most successful was the search for travel choice studies that were analysed with Random Utility Maximization models in which the specification of the deterministic part of the utility function discerned variables that could be considered as gains or losses relative to a reference state. Examples are departure time studies that follow the preferred arrival time formulation as proposed by Vickrey (1969), and the value-of-travel-time surveys that considered attribute level variations around a previously experienced real-life trip (e.g. Gunn 2001). This yielded quite a lot of revealed and stated choice surveys. Very

[71] For the establishment of the significance of treatment-effect and other measure-response relationships, the drawback of vote-counting compared to a classic meta-analysis or one of its derivatives is that it does not correct for sampling and measurement errors (Hedges and Olkin 1980). For the present comparison only robust differences in the 'votes' for corresponding assumptions will be used to draw inferences about their comparitive descriptive ability.

[72] In view of the extent to which transport modes are interchangeable, air and water-borne traffic are ignored here. Very few publications dealing with air traffic were encountered and none with water-borne traffic.

[73] A typical example is the footnote '*From a psychological point of view, minimizing disutility is different from maximizing utility (Kahneman and Tversky, 1979)*' in Gärling *et al.* (2000: 310), which is definitely relevant but not elaborated in that article.

few of these considered non-linear terms in the utility specification, which is a prerequisite to test the descriptive ability of the diminishing sensitivity principle.

6.1.5 Characterization of the retrieved studies

In the end, 85 studies were selected for which enough information could be retrieved about the choice context, research design and observed choices to allow inferences concerning the descriptive performance of at least one of the principles of EPT compared to the corresponding UT or PT assumption. Most were published in scientific journals. Where accessible, survey reports and conference papers on which the journal articles were based were also examined, but these are omitted from the reference list when the information in the journal article is sufficient to infer the degree of applicability of EPT. All the studies were categorized with respect to the real-life situation to which the findings of the study were presumed to apply on the one hand and to the elicitation context on the other, i.e. the actual experimental or real-life survey context in which subjects stated or revealed their judgments and/or choices. In Table 4 (page 114-115) the 85 studies are listed in agreement with these categorizations. A main distinction is made between nineteen strategic, 44 tactical and 22 operational travel choice processes. The definition of these categories is elaborated in Chapter 2. Where appropriate a secondary distinction is made between 32 revealed preference surveys and other observations of real-life behaviour, 26 Stated Preference surveys that were customized to the respondents' revealed real-life travel choice context and 27 observations of choices in fictitious or simulated circumstances. Within each of these groups the individual studies are listed in the sequence of the survey year and further classified. For each study only the main publication in which the survey was encountered is listed in the tables.

The real-life contexts of the studies are characterized by the country and the year in which the travel choices were observed, the strategic, tactical or operational character of the choice process and the travel behaviour domain in connection with the content of the choice decision. The 22 countries from which studies were retrieved are depicted in Figure 8. The apparent over-representation of the Netherlands reflects the author's relatively good accessibility to the underlying information. This suggests that much more survey data, suitable for comparing assumptions of EPT with UT, might still be retrievable by researchers from other countries. The survey years indicate an increase over the years, from 1972 to 2005, but there are no indications that the increase outnumbers the annual growth in scientific publications dealing with travel behaviour research. Though most studies dealt with tactical choice behaviour, observations of many strategic and operational travel choice contexts were recovered as well. Virtually all the domains that are the object of travel behaviour research appear to be represented in Table 4. Overall, the range of real-life contexts and contents reflects the diversity and extent of travellers' choice behaviour environments.

The research context in which the choice behaviour of individual travellers was elicited was categorized according to the character of the subjects' tasks, the research environment in which their tasks were performed and the ways in which their statements were reported. With respect to the task character, 21 studies relied on self-reports of the choices of travellers, in many cases by the completion of travel diaries. Stated choice surveys constitute the largest category, with 25 studies, while in eighteen experiments subjects either stated their choice explicitly or demonstrated it in a simulator. Several references yielded the opinions of experts about actual choices, others inferred choice behaviour from traffic and travel flow measurements or from observed judgments like preference ratings and contingent valuation. The picture is completed by a study that analysed actual transactions on the real estate market.

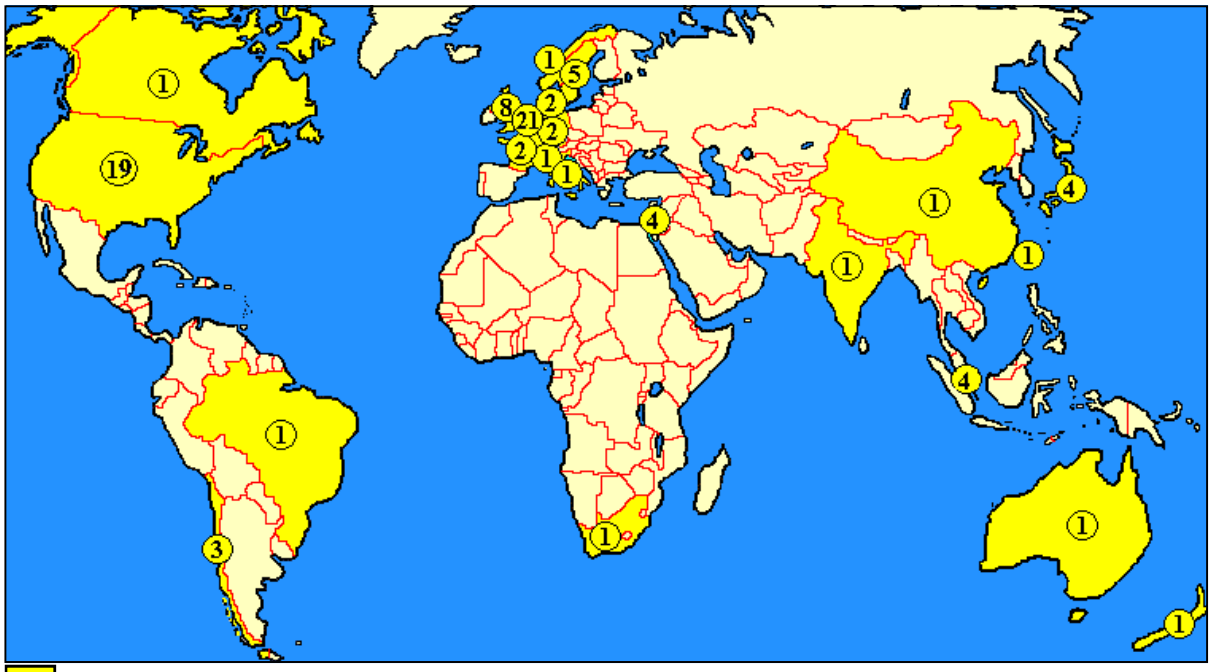
Table 4A: Overview of re-examined travel choice behaviour studies

Main reference to research description (in order of survey year)	Real-life travel choice context: Country and survey year [1]	Travel choice content	Elicitation context: Task charact. [2]	Res. env. [3]	Report mode [4]
Revealed or observed real-life strategic travel-related decision making					
Van Wee 1997	Netherlands 1994	Residence location	SSR	RL	PS
Genesove & Mayer 2001	USA 1997	Residence location	AMT	RL	PR
Andrews & Manrai 1998	USA 1997?	Car ownership	SEO	RL	PR
Stutzer & Frey 2003	Germany 1998	Residence location	SSR	RL	PS
Verhoef & Van Wee 2000	Netherlands 1999?	Car ownership	SEO	RL	PR
Pen 2002	Netherlands 2000	Firm location	SSR	RL	OI
Axhausen *et al.* 2004	Germany 2001	Residence location	SSR	RL	OI
Van Wee *et al.* 2002	Netherlands 2001	Residence location	SJS	RL	PP
Van der Waerden *et al.* 2003	Netherlands 2003	Travel mode	SSR	RL	PP
Orten & Ribbens 2003	Netherlands 2003	Car ownership	SEO	RL	OI
Hulsman 2004	Netherlands 2004	Residence location	SEO	RL	OI
Behrens & Del Mistro 2006	South Africa 2005	Travel mode	SSR	RL	OI
Beige & Axhausen 2006	Switzerland 2005	Travel mode	SSR	RL	PP
Srinivasan & Bhargavi 2006	India 2005	Travel mode	SSR	RL	OI
Stanbridge 2006	UK 2005	Travel mode	SSR	RL	PP
Strategic travel-related decision making under experimental circumstances					
Svenson 1989b	Sweden 1987?	Residence location	SCE	IF	OI
Tversky & Kahneman 1991	USA 1989?	Work location	SCE	IF	PP
Steg *et al.* 2001	Netherlands 1998?	Car ownership	SJE	IF	PP
Geurs *et al.* 2006	Netherlands 2005	Residence accessibility	SCS	IF	IS
Revealed or observed real-life tactical travel choices					
Small 1982	USA 1972	Departure time	SSR	RL	PS
Watson & Holland 1978	Singapore 1975	Travel mode	SSR	RL	PS
Foerster 1979	USA 1975	Travel mode	ATB	RL	PS
Timmermans 1983	Netherlands 1978	Destination	SSR	RL	PS
Hendrickson & Plank 1984	USA 1981?	Departure time & mode	SSR	RL	PS
Brownstone *et al.* 2003	USA 1998	Road pricing & reliab.	SSR	RL	OI
Lam & Small 2001	USA 1998	Road pricing & reliab.	SSR	RL	PP
Steimetz & Brownstone 2005	USA 1999	Road pricing & reliab.	SSR	RL	OI
Small *et al.* 2005	USA 2000	Road pricing & reliab.	SSR	RL	OI
Liu *et al.* 2004	USA 2000	Road pricing & reliab.	ATB	RL	CL
Nielsen 2004	Denmark 2002	Road pricing & route	ATB	RL	CL
Tactical choice behaviour in customized Stated Preference surveys					
Bovy & Den Adel 1985	Netherlands 1984?	Route choice	SCS	IR	PP
Gunn 2001, Van de Kaa 2006	Netherlands 1988	Travel time & cost	SCS	IR	PS
Senna 1994	Brazil 1990?	Travel time & cost	SCS	IR	PP
Gunn 2001, Mackie *et al.* 2001a	UK 1994	Travel time & cost	SCS	IR	PS
Hultkrantz & Mortazavi 2001	Sweden 1994	Travel time & cost	SCS	IR	OI
Tapley *et al.* 2006	UK 1994	Travel time & cost	SCS	IR	PS
Sælensminde 2001	Norway 1996	Travel time & cost	SCS	IR	PS
Van de Kaa 2006	Netherlands 1997	Travel time & cost	SCS	IR	PS
Cherchi & Ortúzar 2002	Italy 1998	Travel mode	SCS	IR	PP
Michea and Polak 2006	UK 1999	Travel time reliability	SJS	IR	OI
Hensher 2001b	New Zealnd 1999	Travel time reliability	SCS	IR	OI
De Palma *et al.* 2003	France 2000	Departure time	SCS	IR	OI
De Palma & Picard 2005	France 2000	Route choice	SCS	IR	OI
Rizzi & Ortúzar 2003	Chile 2000	Traffic safety & cost	SCS	IR	PS
Washbrook *et al.* 2006	Canada 2001	Travel mode	SCS	IR	PP
Richardson 2003	Singapore 2001	Travel time & cost	SJS	IR	OI

Table 4B: Overview of re-examined travel choice behaviour studies

Main reference (in order of survey year)	Country and survey year [1]	Travel choice content	Task char. [2]	Res. env. [3]	Report mode [4]
Tactical choice behaviour in customized Stated Preference surveys continued					
Iragüen and Ortúzar 2004	Chile 2002	Traffic safety & cost	SCS	IR	IS
Caussade *et al*. 2005	Chile 2003	Travel time & cost	SCS	IR	PS
Eliasson 2004	Sweden 2003?	Travel time reliability	SCS	IR	PP
Rouwendal & De Blaeij 2004	Netherlands 2003	Traffic safety & cost	SCS	IR	IS
De Borger & Fosgerau 2006	Denmark 2004	Travel time & cost	SCS	IR	OI
Hess *et al.* 2006	Australia 2004	Travel time & cost	SCS	IR	OI
Hollander 2006	UK 2004	Travel time reliability	SCS	IR	IS
Lo & Li 2006	China 2004	Travel mode	SJS	IR	OI
Van Amelsfort & Bliemer 2005	Netherlands 2004	Travel time reliability	SJS	IR	IS
Baiwa *et al.* 2006	Japan 2005?	Departure time & mode	SCS	IR	PP
Tactical travel choice behaviour under experimental circumstances					
Mahmassani 1990	USA 1985?	Departure time	SCE	IF	CL
Jones-Lee *et al.* 1995	UK 1991	Traffic safety & cost	SJS	IF	OI
Rietveld *et al*. 2001	Netherlands 1997	Travel time & cost	SCS	IF	PS
De Blaeij & VanVuuren 2003	Netherlands 2001?	Traffic safety & cost	SCE	IF	PP
Arentze & Timmermans 2005	Netherlands 2003	Destination	SEO	MM	PR
Bogers and & Zuylen 2004	Netherlands 2004	Route choice	SCS	IF	OI
Sumalee *et al*. 2005	UK 2005	Route choice	SEO	MM	PR
Revealed or observed real-life operational travel choices					
Mahmassani & Jou 2000	USA 1991	Departure time	SSR	RL	PS
Fujii & Kitamura 2004	Japan 1998	Travel time reliability	SSR	RL	PP
Gärling *et al.* 2000	Sweden 1998?	Travel mode	SSR	RL	OI
Olszewski & Xie 2005	Singapore 1999	Road pricing &tr. time	ATB	RL	CL
Senbil & Kitamura 2004	Japan 2002	Departure time	SSR	RL	PS
Olszewski & Xie 2006	Singapore 2003	Road pricing &dept.time	ATB	RL	CL
Operational travel choice behaviour under experimental circumstances					
Yamamoto *et al*. 2002	Japan 1997	Travel mode	SCE	IF	PP
Bonsall & Palmer 2004	UK 1998	Route choice	SCE	TS	CL
Gärling 2004	Sweden 1998?	Travel mode	SCE	IF	CL
Stern 1999	Israel 1998?	Lane switching	SCE	IF	PP
Swait 2001	USA 1998?	Vehicle rent	SCE	IF	PP
Hester *et al*. 2002	USA 1999?	Route choice	SCE	DS	CL
Katsikopoulos *et al*. 2000	USA 1999?	Route choice	SCE	DS	OI
Mahmassani & Srinivasan 2004	USA 1999?	Departure time	SCE	TS	CL
Avineri & Prashker 2005	Israel 2002?	Route choice	SCE	TS	CL
Avineri & Prashker 2006	Israel 2002?	Route choice	SCE	TS	CL
Katsikopoulos *et al*. 2002	USA 2002?	Route choice	SCE	DS	OI
Jou & Kitamura 2002	Taiwan 2002	Departure time	SEO	MM	PR
Avineri & Prashker 2004	Israel 2003?	Route choice	SCE	IF	PP
Bogers *et al*. 2005	Netherlands 2004	Route choice	SCE	TS	CL
Bogers *et al*. 2006	Netherlands 2005	Route choice	SCE	TS	CL
Chen & Mahmassani 2006	USA 2005?	Route choice	SEO	MM	PR

[1] ?: estimated. [2] Task character: AMT actual market transaction; ATB observed travel behaviour; SCE stated choice experiment; SCS stated choice survey; SEO stated expert opinion; SJE stated judgment experiment; SJS stated judgment survey; SSR subjective self-report. [3] Research environment: DS driving simulator; IF imaginary, fictitious; IR imaginary, related to real-life experience; MM mathematical model; RL real-life experience; TS travel simulator**.** [4] Report mode: CL computer loggings; IS internet survey; OI oral interview, verbal protocol; PS postal survey; PP paper and pencil; PR published report.



Country from which sufficient information about travel behaviour was recovered

(3) Number of re-examined studies from that country

Figure 8: Geographic distribution of retrieved travel behaviour studies

Most elicited choice behaviour was demonstrated in real-life contexts or in a stated preference survey, involving the subject reporting a recent real-life experience, mostly 'yesterday's trip' (32 and 26 of the studies, respectively). Nine studies employed travel or driving simulators to boost the behavioural realism. The remaining studies considered fictitious choice contexts or simulations with mathematical models. Six different report modes were found that showed a shift over time from paper and pencil experiments and postal surveys to computer loggings and internet-based surveys in all categories of elicitation and real-life contexts. Consequently, the range of real-life as well as research contexts reflects the diversity and extent of travel behaviour research approaches.

6.1.6 Assessment procedure for the descriptive performance of the considered assumptions

Table 3 lists the five sets of corresponding assumptions of EPT, UT and PT. For each of these sets it will be assessed whether or not the EPT assumption matches the observed choices better than those of UT and/or PT. The research designs and choice data recovered from the literature were not tuned to ease re-analysis of adherence to the assumptions of EPT compared to UT and PT. The most reliable assessment would be to compare all three corresponding assumptions against the choices of individuals. However, such data are rarely, if ever, available. Even aggregated choice data are only incidentally published. Most often the only quantitative empirical information that could be retrieved from a particular choice study consisted of parameters assessed with an econometric discrete choice model.

As no integral applications of EPT to travel behaviour contexts have been published[74] to date, the assessment will be based on assumptions in the reviewed literature that offer the closest match to the EPT assumptions. For example, the EPT assumptions i. and ii. above only differ

[74] Except for Van de Kaa (2006) who offers a preliminary analysis of EPT as developed in this book.

from the corresponding PT assumptions because they allow for a minority of research populations to follow the UT premises. From most studies, no data were available about the distribution of PT- and UT-conformable behaviour over population segments. For such studies the conclusion about the performance of the PT assumption, compared to its UT-counterpart, was adopted for the EPT assumption as well.

In the next sections the conclusions of all comparisons will be assembled in Tables 5, 6 and 7. They are reported in five qualification categories:

1. ES: **explicit statement**, if a publication in which the research results are presented refers explicitly to the relevant EPT-conformable assumption, or the theory from which it is derived, as a presumable or convincing explanation for the observed behaviour. This holds, for example, for assumption i. (reference-dependent framing and loss aversion) if the observed behaviour is attributed to 'loss aversion according to PT'. Such statements are considered as additional evidence for the descriptive ability of the EPT assumption, but only as far as they are based on choices observed in the re-examined study.
2. CD: **convincingly demonstrated**, if the considered EPT assumption appears to offer a better match for the observed choices than the corresponding UT assumption. Sometimes this qualification is based on reported choice data that are interpreted in the following sections. Most often it is based on a significant better fit of the empirical data with outcomes of a model containing a deterministic utility specification close to the EPT assumption.
3. PD: **presumably demonstrable**, if the available choice data indicate that a re-analysis will presumably demonstrate that the considered EPT assumption explains the empirical findings better than its UT counterpart. However, the retrieved data are insufficient for a re-analysis with a formal scientific method that allows for statistically significant conclusions.
4. NS: **neither supported nor rejected**, when the available information about the choices made in the considered context neither supports nor rejects a better match of the empirical data and the considered EPT assumption compared to the UT assumption.
5. CR: **clearly rejected**, if the published and re-analysed results from the research at hand yield information about observed choices that convincingly or presumably shows that this might better be explained by the UT assumption than the corresponding EPT assumption.

If convincing or plausible evidence is found for a better descriptive quality of one of the EPT assumptions compared to its UT counterpart this does not rule out that the UT paradigm offers a fair description and understanding of the choices observed in the context under consideration. In fact, most of the re-examinations that supported an EPT assumption drew on the results of UT-conformable parameter estimation. However, when any of the EPT assumptions offers a better explanation of choices observed in a particular context this signifies that one should be very careful when extrapolating the results found which agree with the UT paradigm to other contexts.

6.1.7 Chapter outline

From all the studies listed in Table 4 (page 114-115) sufficient information about observed choices was recovered to allow for a comparison of the degree to which the subjects followed one or more assumptions of EPT and the corresponding one of UT and/or PT. As the choice behaviour of subjects in real-life choice processes with a similar character and impact might

be relatively similar, these re-examinations are recapitulated below in sections covering the three choice character categories. Section 6.2 discusses the re-examinations of observed travel-related strategic decision making, Section 6.3 deals with the findings of travellers' choice behaviour in tactical contexts and Section 6.4 covers operational travel choice domains. Each section is concluded with a discussion of the descriptive ability of the five assumptions of EPT compared to UT and/or PT. The findings from these re-examinations are assembled and discussed in Section 6.5, together with a discussion of potentially fruitful applications of EPT to travel behaviour research.

6.2 Strategic decision making related to travel behaviour

This section reviews literature concerning transport-related work and residence location decisions, vehicle acquisition and replacement choices, and the Willingness-to-Pay for the quality of accessibility of locations by rail transport. Obviously such strategic decisions are generally made at the household level and are strongly interrelated. They generally linger on intermittently for days or even months or years. Once put into effect they can only be reversed at high cost while at the same time their long-term consequences are subject to a high degree of uncertainty. By and large these strategic decisions predetermine the operational daily choices that cause commuting and other travel, traffic flows, congestion, etc.

As far as the recovered information allows, the observed choices are re-examined on the descriptive ability of the five assumptions of EPT listed above, compared to the corresponding assumptions of UT. An important focus in this review is on the co-occurrence of affective (i.e. on a qualitative affective or attractiveness scale like good-bad, pleasant-unpleasant) and 'utilitarian' (i.e. in money or another 'rational' medium) valuation of attributes, as according to many psychologists this plays a decisive role in such strategic choices: '*Quite often "I decided in favor of **X**" is not more than "I liked **X**" ... We buy the cars we "like", choose the jobs and houses we find "attractive", and then justify these choices by various reasons*' (Zajonc 1980: 155). This section concludes with a summary of the most important findings.

6.2.1 Location choice decisions

Location choices might be considered among the most strategic decisions for travellers. Such decision processes generally linger on intermittently for months or even years. By and large these predetermine the operational daily choices that cause commuting and other trips that in turn, on an aggregate level generate traffic flows, congestion etc. In the longer term, particularly the impact of the loss-aversive behaviour of location decisions on the transport system might be more significant than any of the operational daily choice decisions. This holds as much for choice of residence and firm as well as job.

Residence location choice

In cognitive psychology many experiments are reported concerning the choice of residence. The experimental subjects are commonly presented with a choice set described by numerical characteristics of the residence *per se*, like their sizes and prices, and of their locations, often in terms of their accessibility as characterised, for example, by their distance to the university or city centre (e.g. Sundström 1989; Dijksterhuis 2004). Most experiments demonstrate the importance that subjects attribute to these and other 'utilitarian' factors. Amongst others the verbal protocol study of Svenson (1989b), in which married couples choose a residence from

nicely illustrated marketing booklets, showed a prominent role for affectively salient attributes. Svenson's examples of verbal protocols leave little doubt about the co-occurrence of affective and utilitarian valuations as well as about the use of non-compensatory decision rules. Several other residence choice experiments support the claim that affective valuation is often decisively important for residence location decisions, mostly in interplay with utilitarian attributes like the price one can afford (e.g. Dijksterhuis 2004). A compensatory evaluation according to UT requires a cross-dimensional mapping of such a mixture of affective and instrumental factors on a monetary or other non-bounded utilitarian scale. EPT presumes that in such contexts some individuals follow a compensatory choice behaviour strategy with an intuitive overall evaluation of alternatives on an affect scale, or that they apply non-compensatory decision rules. From the reports of such experiments it appears that many buyers employ price and other attribute values as elimination criteria while others may treat them in a compensatory manner. Several residential choice experiments have indeed observed the use of non-compensatory decision rules.

Many surveys concerning the functioning of the housing market also reveal that affective feelings, often related to style and stage of living, may be decisive factors in the choice of residence (e.g. Hagen 2002). This is extensively reflected by articles and statements in Dutch newspapers, magazines and other light reading, see e.g. Hulsman (2004) citing Hagen: '*Immovable property becomes emotionally moving property…Buying or renting a residence looks more and more like buying a car: people want to express themselves with it*'. Location decisions of residences as observed in real-life surveys are obviously also the result of a mixture of affective and instrumental factors.

Verbal protocol analysis of location choice experiments reveals the occurrence of reference-dependent framing, see e.g. the following citation in Svenson (1989b: 91): '*we gain ten thousand in pay down… on the other hand we lose ten square metres…and win some windows*'. In connection with loss aversion the significance of the reference state in the field was also found in a long-term large-scale econometric analysis of list and selling prices and withdrawals of residences on the Boston real-estate market. Genesove and Mayer (2001) showed that the behaviour of sellers could be explained from the loss-aversive valuation of the selling price, with the original purchase price as reference. They found that during a collapse in the market '*sellers subject to losses set higher asking prices of 25-35% of the difference between the expected selling price of a property and their original purchase price*' (Genesove and Mayer: 1255). These loss-aversive sellers either withdrew from the market or attained higher selling prices of 3-18% of this difference, at the cost of a relatively long time on the market.

A very thorough survey and analysis of individual household location choices in Germany is reported by Axhausen *et al.* (2004). Using concurrent information from the housing market they added a set of fifteen alternative houses in the same urban region and market segment to each observed 'new' residence. For each alternative they assessed the conventional attributes, like size and buying price or rent for the new residence, and its accessibility measures relative to work and study locations, shopping and activity centres. The distance to the previous residence location and a 'change in type of location' variable were also incorporated. Both variables had a large, very significant parameter in the estimated Logit models. The authors highlight the large impact of previous strategic long-term decisions on successive strategic and operational choices. Apparently, the type of neighbourhood and accessibility characteristics that were experienced in the 'old' residence might be considered as the experienced outcomes of such a previous decision and thus as definite indicators of context-dependent preferences. Their significance in the Logit model estimation makes it plausible

that when these attributes are left out of the models the corresponding location-dependent variables will be valued as loss aversive, if they are expressed as changes relative to those of the previous location.

Location choice by firms

The relocation decisions of firms in the Netherlands appear to be heavily influenced by the emotional-affective attributes of the alternatives in addition to their more utilitarian qualities (Pen 2000; 2002). The application of non-compensatory decision rules might therefore also be expected here. The interviews in Pen's dissertation suggest that loss aversion of attributes compared to the pre-relocation situation played a role in several relocation decisions. The number and elaboration of these interviews is however insufficient to draw any firmer conclusions.

Residence and job location trade-off decisions

Tversky and Kahneman (1991) published a 'classic' choice experiment about the importance of framing in the trade-off between job location and daily travel time. In a hypothetical choice context 106 participants were asked to choose between two jobs after a preceding training job similar to the alternatives offered, differing only in the amount of social contact and the daily travel time to the job location. Job *x* offered limited social contact with others and 20 minutes travel time. Job *y* was moderately sociable and required 60 minutes travel time. The results suggest that many if not most of the respondents framed the training job as the reference state and the expected social contacts and travel times in Jobs *x* and *y* as changes with respect to the reference state. When the preceding job was described as '*isolated for long stretches; ten minutes daily travel time*', 70% of the respondents choose Job *x*. The social contact attribute was apparently considered as a gain, the travel time as a loss and the 40 minutes additional time loss of job *y* weighted more than the extra gain in social contacts. When the preceding job was described as '*much pleasant social interaction; 80 minutes daily travel time*' only 33% choose alternative *x*. Now the 40 minutes less travel time of Job *x* compared to Job *y* was apparently valued as a gain but did not compensate for the extra loss of social contacts. This 37% preference shift between 'objectively' identical job alternatives emphasizes the importance of paying attention to framing effects in the, admittedly much more complicated, real-life job location selection decisions. However, most subjects did choose the same alternative in both choice contexts.

Stutzer and Frey (2003) assessed the effects of residence location choice on the subjective well-being of commuters. They considered subjective well-being (i.e. the self-reported happiness or overall satisfaction with life) as a proxy for the overall utility derived from preceding decisions on the labour and housing markets. Their rationale starts from UT's presumptions: '*If commuting has extra psychological costs, then travelling longer distances to and from work is only chosen if it is compensated either by an intrinsically or financially rewarding job or by additional welfare gained from a pleasant living environment. Accordingly, commuting is determined by an equilibrium state of the housing and labor market, in which individuals' well-being or utility is equalized over all actual combinations of alternatives in these two markets*' (Stutzer and Frey: 2). They analysed the 1985 to 1998 subjective well-being data from the German Socio-Economic Panel that also contained information about individual commuting time. Only survey results of respondents that actually commuted and reported being employed or self-employed were analysed. The statistical analyses showed an ongoing decrease in subjective well-being with increasing one-way commute time. The strongest decrease was found between the one-way commuting time classes of 11-20 and 20-30 minutes. The authors concluded that individuals who choose to spend more time commuting were unable to attain

complete compensation for the associated burden. After rejecting several interpretations that fit into the current economic theories Stutzer and Frey (2003: 17,18) arrived at three possible explanations that undermine the validity of UT assumptions: '*First, people ... might rely on inadequate intuitive theories when they predict how they are affected by commuting…; Second, people's weak will power might be another reason why long commutes are not compensated; Third, loss aversion may play a role…Prospect Theory captures the asymmetry in people's perception of gains and losses…people remain in the status quo with commuting longer than optimal…*'. The first explanation holds if the experienced and/or remembered value of commuting is lower than its expected decision value before the move to the present residence. This is a well-known element of human judgment (see Section 4.3.3) that would cause a shift in the reference state between the previous strategic decision to move home and a possible future strategic decision to move back to the previous location. It implies that one's subjective well-being is not an appropriate match for one's decision utility. The second explanation is very hard to verify but might bias the answers to stated preference surveys. The third explanation is obvious. As Stutzer and Frey found that commuting was reported to be more stressful during congestion, an increase in congestion on the German roads might be an additional explanation for the reported decline in subjective well-being with increasing trip duration. However, the database used does not contain information to test this latter assumption.

Van Wee and Van der Hoorn (2002) demonstrated that the effects of office relocation on mobility are by and large determined by the responses of the employees, in terms of relocation of their residence and/or a change of employer. Their paper summarizes the contents of a book on the subject by Van Wee (1997). He compiled a list of the persons employed in three government offices six months before a relocation of some 20 km to Rotterdam. Four and a half years after relocation these individuals received a questionnaire that, in addition to personal and household characteristics, enquired about mobility behaviour, job changes and residential moves. More than 50% of the employees responded, of which more than half had not moved or changed job, 25% had moved house and about 15% had changed jobs. Most individuals that moved to another residence stayed in the neighbourhood where they had lived before and very few employees moved to a residence in the area of the new office location, though the travelling distances by and large increased. Van Wee developed a Multinomial Logit Random Utility Maximization model to simulate the responses of employees as a function of their personal and household characteristics and the accessibility of residential and job locations. The model fitted the survey results and was used for an assessment of the effects on mobility of large-scale employment relocation. The author compared this with the effects as predicted by traditional models assuming long-term equilibrium in home and work locations. Van Wee concluded that these overestimate the long-term mobility effects of firm relocations. He explained the difference by assuming that some employees might move home or change job more than 4.5 years after relocation while others might not respond any more to the relocation but be replaced in the long term, e.g. after retirement, by employees whose daily commutes fit in the long-term equilibrium pattern. Implicitly one might presume that this is a consequence of context-dependent and reference-dependent, change-oriented framing and the loss-aversive valuation of the residence and job location decisions by the employees, where the reference state shifts either instantaneously or soon after the office relocation.

6.2.2 Travel mode and vehicle ownership decisions

Choices of individuals and households on vehicle ownership (number and character of cars) and their common use and replacement are often closely related to location decisions. In such a context these might be included as alternatives in one strategic household decision frame

and/or considered as a consequence of such decisions. Obviously, other events like the passing of one's driving test or a job change may also initiate mode or vehicle ownership decisions.

Interrelationship of location decisions and travel mode choice

Van Wee *et al.* (2002) studied the impact of individual's stated preferences for transport modes on the residence location choice between similar Dutch neighbourhoods that differed mainly with respect to their attractiveness for car drivers, public transport passengers and cyclists. They found a clear association, particularly for public transport users and cyclists. Drawing on UT-conformable preference assessments Van Wee *et al*. discussed the consequences of this self-selection process of neighbourhood choice. In particular they inferred that when the existing pattern of public transport use, in connection with the accessibility of stops and stations and frequency and quality of services, is 'extrapolated' to the effect of opening new stops/stations in neighbourhoods that are less attractive for transit users, this results in an overestimation of the use of the new service. Their findings and reasoning are, to a large extent, consistent with the concept of reference-dependent framing and loss-aversive valuation. As the attractiveness of the previous residence location for different modes was not investigated this study yields only plausible evidence for the use of this principle in the residential choice process. It is, however, very illustrative for the relevance of the 'weak strategic-operational choice hierarchy' as presumed in EPT.

The significance of this latter principle for the understanding of travel behaviour is also illustrated by a qualitative research in Bristol (UK) of people's travel behaviour considerations during recent residential relocations (Stanbridge 2006). She showed that travel as a reason to move only played a role in a minority (less than 10%) of the respondents, but that most of them (over 70%) took travel into consideration in the early stages of the relocation decision process, mostly very seriously. Less than 10% considered travel matters mainly after the physical move, and most respondents who paid little or no attention to travel considerations (30%) moved over small distances. This is in line with other findings (e.g. Van Wee 1997, Stutzer and Frey 2003): tactical and operational travel experiences hardly ever incite people to remove, but the strategic decision of residential relocation gives rise to strategic, tactical and operational follow-up choices with respect to travel. For example, Beige and Axhausen (2006) found that 30 to 40% of all residential moves over a 20-year period resulted in a change in car availability and/or in public transport season ticket ownership within a year after relocation, even though 35% of all respondents had a car available for the whole period and 20 to 30% kept a season ticket continuously.

Impact of strategic choices on travel mode choice

Behrens and Del Mistro (2006) asked South African travellers to report when their last change in travel behaviour during their morning commute took place and then asked them the reason for this change. Even for the changes in home departure time, of which 55% occurred in the previous week, 30% were the consequence of a move of residence or change of job. This is in agreement with the almost 25% reported changes in departure time that occurred more than one year before and illustrates the importance of strategic decision making on tactical travel choices and/or script-based or habitual travel behaviour. Of the reported changes in travel mode, about 70% occurred more than a year before, which reflects the low propensity to change these choices once a strategic decision followed by a tactical choice is made. The progress in travel mode changes and trip origin or destination changes over the last two years suggests that many of the former changes are a consequence of the latter, a suggestion that is corroborated by several responses from follow-up interviews with respondents as cited in

Behrens and Del Mistro (2006). Earlier, Van der Waerden *et al.* (2003) observed that also in the Netherlands such strategic decisions[75] often initiate a switch in transport mode. They also found that, following the outcome of the strategic decision, many respondents reported a marked positive change in their attitude to the comfort, privacy and luggage carrying possibilities offered by their current mode. This may largely be caused by the shift from 'other' modes to car driving that occurred after each type of decision and amounted to 60% (on balance) for the whole survey population. Both the South African and the Dutch studies are illustrations of the relevance of the change in the respondents' reference state following the outcome of the strategic decision.

Srinivasan and Bhargavi (2006) surveyed the changes in travel mode commuting patterns in Chennai, India between 2000 and 2005. They developed Mixed Logit models that described the individual respondents' mode choice as a function of current travel time, current vehicle ownership, current residence location, and mode employed five years ago, and compared their descriptive performance with a model that considered cross-sectional mode choice data. The 'dynamic' models outperformed the conventional model. The previous choices had a large impact on the currently used travel modes. This and several more specific findings are indicative of reference-dependent framing and loss-aversive behaviour. The authors describe, for example, a different response by motorized two-wheeler riders and car drivers to increasing congestion. From the perspective of EPT this seems an apparent consequence of the same valuation principle – loss aversion – used within interpersonal different choice behaviour strategies.

Willingness-to-pay for strategic accessibility

It is generally considered that accessibility plays a crucial role in location choice decisions. In the transport and land-use literature over a hundred definitions of accessibility are proposed that range from the ease of daily traffic movement to the connection of a particular location with the transport system (e.g. Geurs and Ritsema van Eck 2001). Obviously vehicle ownership or the renouncement of it largely determines the quality of the daily traffic movements of citizens to and from their residence. However, the more strategic type of accessibility, as originally defined by Hansen (1959: 73, emphasis added), '*Accessibility is the **potential** of opportunities for interaction*', implies that even households where all the members have a vehicle at their disposal also may value the accessibility of their residence location by other travel modes. This might result in an increased bidding price in residence acquisition decisions or in a Willingness-to-Pay for such options at the actual address.

In an internet-based stated choice survey, Geurs *et al.* (2006) examine the willingness of people living in the neighbourhood of two regional railway links to pay for the continued availability of these rail services. Participants appeared inclined to pay considerable amounts for the continuation of these services, whether they used the railway frequently, incidentally or not at all. These '*option values*' come on top of the Willingness-to-Pay for actual use. They reflect the Willingness-to-Pay for the continuation of the service as back-up for a potential future use of the railway. The option values that current regular and incidental train passengers and potential future passengers were willing to pay were of the same order of magnitude. Geurs *et al.* also assessed the Willingness-to-Pay for continuation of the railway service for non-user purposes, like the preservation of this public good and the use of the

[75] Actually, they investigated the impact of '*key events*', notably moving house, starting to work, changing job, passing driving test and getting a car. It is easy to see that these events are consequences of preceding strategic decision-making.

service by visitors and family members without a vehicle. It appeared that for all categories of travellers the use of the service by family members had a large impact on the Willingness-to-Pay for non-use. This value was much lower for prospective non-users than for current train passengers, with prospective future optional users in an intermediate position. This might reflect a loss-aversive attitude to the railway service.

In addition to the continuation and ending of the present service level, the number of railway stations and the frequency of the time-table were varied between the submitted alternatives. Geurs *et al.* found that halving the frequency was valued more than twice as much as doubling it. The value attached to closing existing halts was even more than twice as high as for adding additional ones. The differences in valuation were observed for frequent and incidental rail travellers as well as for respondents that currently made no use of the railway. Referring to the principles of PT the authors explicitly attributed these findings to the loss aversive valuation of deteriorations compared to the actual situation (reference state). Their findings leave little doubt that overt loss aversive valuation of the continuation of the railway service takes place, as well as of its frequency and the proximity of its stations. The observed Willingness-to-Pay for continuation of the railway service for reasons like conservation as a public good or for non-user purposes, like the use by visitors and family members, indicate that affectively valued attributes might also have influenced the option values.

Car ownership decisions

Strategic car ownership decisions and the propensity to use the car in traffic are often explained presuming deliberately utility-maximizing consumers who consider the predominantly utilitarian attributes of the alternatives (Steg *et al.* 1998). In a recent overview of car ownership models, De Jong *et al.* (2004) showed that those with a theoretical basis almost exclusively follow Random Utility Maximization Theory. The authors mention these as the models in which attitudinal variables can be included, thus implicitly stating that this is not generally the case and disregarding the cross-dimensional mapping problem. From a survey of the relevant literature, Steg *et al.* (1998) found a range of so-called symbolic-affective motives that influence car ownership, such as privacy, status, and feelings of freedom, power and superiority. An interesting category of affects relate to social comparison, strongly interrelated to personality and lifestyle. Steg *et al.* (2001) presumed that the preponderance of instrumentally-reasoned motives for car ownership as found in transport psychology might largely be caused by the use of self-reports. These generally will overestimate deliberate choice behaviour (e.g. Montgomery and Svenson 1989b).

Vehicle type and brand choices

When an individual has decided to buy a car, either for the first time or as a replacement, she is confronted with a huge range of alternatives in terms of hundreds of different models. Moreover, each model is characterized by a large number of attributes, like brand name, vehicle size, cost, taxes, fuel economy, colour, safety appliances and so on. Thus it is not surprising to find that Tversky (1972: 285) used the purchase of a new car as the first example in the theoretical explanation of his Elimination-By-Aspects decision rule. Andrews and Manrai (1998) used the car acquisition process even more extensively in the introduction to their feature-based elimination model. Thus, for acquisition decisions of a vehicle many people may use a non-compensatory two-stage choice process consisting of a first-stage aspect-based elimination rule followed by a second-stage rule that might often be the Linear-Additive Value rule. Nevertheless, in transport research the most commonly presumed choice behaviour strategy is Random Utility Maximization, often in terms of a two-stage nested Logit model (e.g. Mohammadian and Miller 2003).

The choice of a car brand and type may have important effects on the transport system, particularly in view of the dependency of the impact of vehicle size and engine characteristics on traffic safety and the environment. This choice is strongly influenced by affective motives related to the personality and lifestyle of the subject. This is illustrated by the following quote from an interview with Jan Des Bouvrie, a famous contemporary Dutch designer: '*One can become just as devoted to a car as to a home, says the furniture designer. He just told about a friend in London who sold his Bentley, but much to his regret. "He bought it back. He missed the scent. In the long run, a car smells of yourself"*' (Orten and Ribbens 2003). It is just one of a huge range of statements of both professionals and layman in newspapers and magazines that support this notion. It is just one of a huge range of statements made by both professionals and layman in newspapers and magazines that support this notion. These illustrate clearly that any model which aims to describe the replacement decisions for vehicles would be better accounting for the loss aversive behaviour of many people with respect to the affectively-valued attributes of the reference/previous car.

Vehicle acquisition decisions may largely determine the effects of policies with respect to the external effects of the transport system. Verhoef and Van Wee (2000) used the literature on subjective well-being to define a government tax policy[76] that might promote the well-being of the population in the Benthamian sense This tax policy was accommodated into a model of the neo-classical utility persuasion that could take social comparison ('status') effects in car type choice decisions into account. The model results showed that social comparison affects the optimal taxes: taxes should be adjusted downward for low-quality cars and upward for high-quality cars, where quality is conceived in terms of social comparison and status. The authors conclude from these calculations that '*an overall shift to more fuel-efficient cars may result in only a limited loss of welfare…if all other car owners "down-grade" and buy more fuel-efficient cars, too*' (Verhoef and Van Wee: 52). One might, however, realize that the model developed did not take loss aversion, in particular of the affectively-valued attribute characteristics, into account. This might result in a loss in the subjective well-being of persons even if they are not affected by social comparison. The authors discuss several potential policy alternatives that might discourage the trend towards ever larger and sturdier cars with its negative consequences for CO_2 emissions. They consider that policy measures such as pricing instruments or regulations that put fuel-inefficient cars at a disadvantage will evoke much opposition. They therefore suggest a fee-bate policy and/or tradable permits. Though they do not refer to PT it is obvious that these suggestions are well in line with presumed loss-aversive behaviour of travellers with respect to their vehicle: individuals do not want to be worse off compared to other individuals. It also demonstrates that introducing loss aversion in their type of models might be a powerful tool to optimise sustainable transport policy with respect to public support.

Choice to make use of the vehicle

Steg *et al.* (2001) examined the judgment of 185 car owners from two Dutch cities with respect to different consequences of car ownership and its use. The experiment started from a series of 33 positive and 27 negative motives for car ownership as found in Steg *et al.* (1998). Using these as building blocks, a series of 32 car-use episodes were constructed that

[76] This approach to tax policy is an interesting way of thinking. Several authors suggest treating subjective well-being as the '*decision value*'. The latter, as defined by Kahneman and Tversky (1984), determines individual choice behaviour. As subjective well-being is based on '*experience value*' this seems inappropriate as a determinant for concrete choices (e.g. Kahneman 1999; Bennett *et al.* 2004; Annex A.3). However, in the tradition of Bentham's (1789) '*greatest happiness principle*' the maximization of the well-being of citizens might be considered the most relevant decision utility for any government decision.

comprised different positive and negative aspects of car ownership and use. The experimental subjects had to first sort out these episodes intuitively with respect to their similarity. Next, they had to order and value them on a scale from very attractive to very unattractive. Finally, they had to rate their agreement ('*totally agree*' to '*totally disagree*') with the 60 original motives. For the analysis, state-of-the-art stochastic models from social sciences were applied to the survey population as a whole. The sorting task revealed one instrumental (lack of control of car), one mixed (risky driving behaviour) and two affective sorting criteria (limits of freedom and social comparison). In the attractiveness ordering and valuing task the episodes that were considered most attractive as well as those considered the least attractive comprised affective aspects. The agreement ratings yielded a preponderance of instrumentally-reasoned motives. One might, however, consider that many motives categorized by Steg *et al.* (1998: sect. 3.8) as '*instrumental*', like '*the car brings me anywhere I want*' and '*I am not dependent on others*' may have a predominantly affective overtone for many people. The average agreement of all respondents with social comparison motives like '*the car gives me prestige*' or '*the car gives me power in traffic*' was low. Nevertheless the standard deviation presented by the authors is indicative for quite a large minority that supports social comparison motives. A caveat might be that Steg *et al.* (2001) analysed judgments (that might reveal remembered utility) rather than choices. To elicit attribute valuation that principally guides choice behaviour one would be better analysing the outcomes of decision tasks. In choice behaviour in which the personal interests of decision makers are at stake individuals appear to value the most important attribute higher than in judgment tasks (e.g. Tversky *et al.* 1988: 371): '*the more prominent dimension looms larger in choice than in matching*'. This might be caused by a propensity to rely more on the affect heuristic in 'personal interest' choice tasks than in 'cool' judgment tasks. Thus, Steg *et al.* (2001) may have under rather than overestimated the importance of affective motives and attributes for car ownership and use. They did, however, demonstrate the co-occurrence of affective and utilitarian motives convincingly.

6.2.3 Summary of findings from strategic travel choice behaviour

The previous subsections have re-examined 19 studies of strategic decision making relevant for travel behaviour. All contained sufficient information for a comparison of the adherence of at least one assumption of EPT to the corresponding UT assumption. The findings are juxtaposed in Table 5 (next page). None of the reviewed studies contained information demonstrating that one or more of the assumptions of EPT should be rejected because the corresponding UT assumption explained the observed choices better. This is conspicuous as the search terms used to select these studies were neutral with respect to the applicability of EPT and/or UT. Thus any published analysis of choice behaviour from which e.g. UT's reference-independent attribute valuation appeared to explain observed choices better than PT's loss aversion would have had the same chance of being found as studies in which the reverse was found.

In four studies the assumption that most individuals frame their alternatives as gains and losses relative to some reference state and value the attributes loss aversive was explicitly hypothesised and convincingly demonstrated by the authors. They showed that many individuals violated the UT assumptions of context-independent preferences and state-dependent, loss-neutral valuation. Re-examination of twelve more studies indicated the same pattern. The domains and elicitation contexts of all these studies appeared to differ strongly. The other three studies revealed no information that allowed a comparison of this EPT and PT assumption with the corresponding UT assumption such that they could be either rejected or accepted.

Table 5: Evidence for the descriptive ability of EPT in strategic travel choice behaviour contexts

Strategic travel choice behaviour domain	Evidence[1] supporting the descriptive ability of EPT assumption:				
Main reference to research description (in order of survey year)	Reference-dep.framing and loss aversion	Diminishing sensitivity	Non-linear weighted probabilities	Mixed affective-utilitarian valuation	Heterogen. in choice behaviour strategies
Location decisions					
Svenson 1989	PD	-	-	ES,CD	ES, CD
Tversky and Kahneman 1991	ES, CD	-	-	PD	-
Van Wee 1997	PD	-	-	-	-
Genesove and Mayer 2001	ES, CD	-	-	-	-
Stutzer and Frey 2003	ES, CD	-	-	ES, PD	-
Pen 2002	PD	-	-	ES, CD	PD
Axhausen *et al.* 2004	PD	-	-	-	-
Hulsman 2004	-	-	-	ES, CD	PD
Travel mode and vehicle ownership decisions					
Andrews and Manrai 1998	-	-	-	-	ES, CD
Steg *et al*. 2001	-	-	-	ES, CD	PD
Verhoef and Van Wee 2000	PD	-	-	ES, CD	-
Van Wee *et al.* 2002	PD	-	-	-	-
Orten and Ribbens 2003	PD	-	-	ES, PD	-
Van der Waerden *et al.* 2003	PD	-	-	ES, CD	-
Behrens and Del Mistro 2006	PD	-	-	-	-
Beige and Axhausen 2006	PD	-	-	-	-
Geurs *et al.* 2006	ES, CD	-	-	PD	-
Srinivasan and Bhargavi 2006	PD	-	-	-	PD
Stanbridge 2006	PD	-	-	-	-

[1] -: no information that confirmed or rejected the assumptions; CR: Clearly rejected; ES: Explicit statement in reference; CD: Convincingly demonstrated; PD: Presumably demonstrable; NS: Neither supported nor rejected. See Section 6.1.6 for more explanation.

No studies were recovered in which non-linearities in the value function were elicited. This prevents inferences being drawn about the appropriateness of the diminishing sensitivity assumption for strategic choice behaviour. No publications were encountered that dealt with the subjective valuation or assessment of the associated probabilities either. In view of the many uncertainties and risks that are attached to the outcomes of strategic decisions this is remarkable. It might reflect a general propensity of human decision-makers to focus on the short-term 'certain' outcomes of e.g. residential moves and vehicle acquisitions, disregarding the probabilities of sudden changes in e.g. property taxes, fuel prices, public transport services or traffic patterns. Such myopic (i.e. short-sighted) framing is abundantly reported in other domains (Chapter 4).

Strategic location and vehicle acquisition decisions in the context of choice experiments and as observed in real-life obviously may be the result of a mixture of affective and instrumental factors. In six studies this was demonstrated convincingly while re-examination of four more studies made this co-occurrence very plausible. No evidence to the contrary was encountered in the remaining nine studies. This finding on strategic decision making in connection with travel behaviour fits with observations from psychology that, particularly in strategic decisions, affects may play a decisive role (e.g. Zajonc 1980; Slovic 1995; Slovic *et al.* 2002; Dijksterhuis 2004).

Re-examination of two sources showed convincingly that people might follow a non-compensatory choice process in strategic acquisition decisions. Four more studies yielded circumstantial evidence. No evidence to the contrary was encountered.

Overall these findings show that for strategic decision making related to travel behaviour three of the evaluated UT assumptions evaluated are too restrictive. They corroborate the descriptive ability of the three corresponding, less restrictive EPT assumptions. This review gives no clues for the acceptance or rejection of the diminishing sensitivity principle and the assumption that the expected probabilities of the outcomes of travel-related strategic decisions are weighted with a subjective non-linear weight factor.

6.3 Tactical travel choice behaviour

Tactical travel choice behaviour is conceived here as the choice process that sets up the conditions for operational travel choices. This includes discrete choices, such as the acquisition of a monthly train travel pass, as well as the establishment of mental scripts or habits that govern the idiosyncratic patterns of operational trip planning, like commuters' home departure times and daily recurrent route choices (see Section 2.1). Tactical travel choice behaviour may be provoked by structural changes in the travel context or may be needed as a consequence of earlier choices at a higher level of the strategic-operational choice hierarchy. Particularly if tactical choices are required to implement a strategic decision, for example a residential remove or the acquisition of a vehicle, the tactical travel choice process may continue over a confined period of 'trial and error', say a few weeks. In this case it covers a sequence of operational travel choices that contribute to the tactical process but are primarily focused on the pursuit of the travellers' current interests. To complicate matters, when individuals' operational choices are analysed as a function of a few attributes that characterize a travel context that is constant over time while disregarding contextual factors that vary from day to day, the assumed and elicited operational choices will be similar to the tactical choice they put into operation.

Constructs like travellers' Willingness-to-Pay for traffic safety or their value of travel time savings (VTTS)[77] are most often elicited from surveys in which travellers are asked to state their choices from alternatives that differ in some attributes, like trip costs or travel time, from their daily 'reference trip'. The research setting in which these constructs are commonly elicited may last from minutes to hours and mostly concerns a series of recurrent choices in which the subject, if she so wishes, is allowed sufficient time for a deliberate consideration.

[77] Following hedonic valuation principles as discussed in Section 4.2.3, the monetary value of travel time savings (in €/h) (VTTS) is defined as: the ratio [(-/h)/(-/€)] of an individual's psychological value arising from a unit decrease in travel time (-/h) and her psychological value arising from a unit decrease in monetary travel expenses (-/€) (posited here). See Section 7.4.2 for an extensive elaboration.

Obviously, such choice tasks closely resemble most real-life tactical choice processes, like trip planning after a change of job or after the opening of an additional toll road in the daily commute corridor. They are therefore discussed under the current heading.

This section re-examines the adherence to assumptions of EPT compared to those of UT as observed in 44 studies, aimed to reveal such patterns of trip planning with respect to destination, departure time travel mode and constructs like the values of traffic safety and VTTS that follow from trade-offs of trip characteristics and travel costs. Also the responses to the introduction of road pricing are considered. It concludes with a discussion and summary of findings concerning the descriptive performance of the assumptions of EPT in the considered domains and contexts.

6.3.1 Tactical trip planning

Before a traveller sets out on a trip she always has to decide which vehicle and/or travel mode to take, what time to leave, and, most often, also which route to follow. Sometimes the destination is also considered explicitly. For recurrent trips like their daily commute and once-a-week shopping most people adhere to a combination of these trip attributes that was settled sometime in the past. From the perspective of EPT these recurrent choices rely on a previous implicit or explicit tactical choice. This would be chosen from a reference-dependent subjective consideration set that covers all these diverse alternatives but does not contain alternatives and attribute levels that were rejected earlier, at higher levels of the strategic-operational choice hierarchy. The context-independent, stable preference order of the ruling UT paradigm enables the evaluation of any set of alternatives at a time, whether relevant in a strategic or operational choice context. As most re-examined studies follow this paradigm they elicit choices from homogeneous consideration sets. The observed choices from sets with alternative destinations, travel modes, routes and departure times are now discussed.

Destination choice behaviour patterns

Timmermans (1983) evaluated the preference of consumers for different shopping centres in their area. The survey used for this evaluation concerned personal home interviews with 771 persons responsible for the shopping of their households. The respondents were asked about their acceptable travel time for shopping, familiarity with different shopping centres, the importance rating of eleven shopping centre attributes, the attribute values for the centres on a nine-point scale, and the frequency of shopping in different centres. The statements of the interviewees thus concerned judgments rather than choices.

Timmermans compared the predictive ability of several decision rules with respect to the choice by the interviewees of shopping centres, in which the most frequently visited shopping centre was conceived as the 'chosen' one. He considered the familiarity of an acceptable travel time to the different centres as *a priori* constraints that reduce the choice set for all evaluated decision rules. On this reduced choice set the predictions of five decision rules[78] were tested. It appeared that compensatory rules (a weighted-additive as well as a multiplicative rule) performed best (77%). Next came rough approximations of two-stage conjunctive-weighted additive rules (57%) followed by the disjunctive-weighted additive

[78] Weighted-additive value: assesses the sum of the products of the individual attribute values and their subjective decision weights; Conjunctive: chosen alternative must meet requirements for all attributes; Disjunctive: accepts any alternative with an attribute which exceeds a certain criterion; Strong lexicographic: selects the alternative with the highest value on the most important attribute or, in case of a draw, the next important one, even if the differences in attribute values are small (see Section 4.4).

rules (50%). As no threshold values were assessed for these rules maximum scores on attributes were used as such, which might have reduced their explanatory performance. The Strong Lexicographic rule only explained almost 39%, still well above chance. Timmermans (1983: 453-454) states '*that more respondents appear to base their behaviour on some minimum acceptable levels defined on the attributes of the alternatives than on a screening of the alternatives on the most important attribute … the predictive ability of these rules is satisfactory, although less than that of compensatory rules*'. One might realize that as these compensatory rules were applied to a reduced choice set[79] the alleged choice behaviour strategy deviates from UT in its strictest sense: the same reduced choice set would remain after application of a first-stage non-compensatory elimination rule with appropriate cut-off criteria. As the distribution of the use of these different non-compensatory and compensatory decision rules within the survey population was not investigated the findings above might only be conceived as circumstantial evidence for the co-occurrence of different decision rules.

Arentze and Timmermans (2005) developed a simulation model to describe how individuals in a less familiar environment might choose destinations and routes aimed at improving their spatial knowledge. The expected values of destinations were explicitly modelled according to the principles of PT, taking loss aversion into account with respect to a reference state defined as the attribute values following from the previous (last) time step. These attribute values of locations are conceived as the traveller's beliefs of their probabilistic environment that may be conceived as their '*mental map*' that is updated during each trip. The simulation results seem very plausible. However, as these are neither compared with empirical data nor with simulations presuming loss-neutral valuation, the assumptions of reference-dependent framing and loss-aversive valuation can neither be supported nor rejected.

Departure time choice behaviour patterns

Mahmassani (1990) discussed three morning commute simulations that were previously reported by him and several colleagues. In two experiments the participants had to imagine that they lived in one of a series of five neighbourhoods that were connected by a single road to a single work location, and to choose their home departure time on up to 33 consecutive days. Their answers were on each particular day fed into a traffic simulation model that assessed the realized individual arrival times. In experiment 1 the participants were informed about their work arrival time on the previous day, before they could choose their departure time for the current day. In experiment 2 each subject was also informed about all her previously experienced arrival times. In experiment 3 participants also had to choose between two available route alternatives. It appeared that most participants changed their departure times and/or route frequently in the first days of the experiments but after a week or two most of them left each day at the same time and followed the same route. After 30 days only 5-10% of the participants in experiment 3 still made daily adjustments after 30 days.

Mahmassani (1990: 472) referred to extensive tests in which analysis of '*the standard micro-economic utility-theoretic formulation for departure time selection … revealed … this formulation to be generally inadequate for capturing day-to-day departure time choice behaviour*'. He presumed that the participants applied a satisficing decision rule, by not changing their departure time and/or route as long as the arrival time remained within an indifference band and conceived these bands as latent variables that '*can only be estimated based on the discrete choices made by individual commuters*' (Mahmassani: 470). These individual discrete choices were apparently not analysed. However, models treating these bands as random variables distributed over days

[79] Only alternatives with an 'acceptable' travel time were considered.

and across commuters could explain the observed switches well. It appeared that the previous day's experience had a dominant influence on departure time adjustments. He reports some more results which suggest that loss aversion played an important role: '*the (indifference) band tends to increase in response to unsuccessful experiences ... whereas successful experiences have the reverse effect; the impact of unsuccessful experience is generally more drastic and tends to last longer than that of successful ones*' (Mahmassani: 471).

Though the indifference band concept has proven its worth as a descriptive model for departure time adjustment, its explanation from the application of a satisficing rule (i.e. a version of Tversky's (1969) Lexicographic Semi-order rule, see also Chapter 4) seems less plausible. If this was the dominant decision rule of the participants in the experiments one might expect that at least some of them would also choose their departure time at random between similar bands. However, the departure time of participants systematically converged to some apparently idiosyncratic optimal value. If participants were aware of the stochastic character of trip duration, and thus of arrival time, they might have traded-off the utility of 'certain' later departure times against the disutility of the probability density of late arrivals. Such a maximizing rule would result in an idiosyncratic optimal departure time. As long as experience does not lead to changes in the subjective expected probability distribution of arrival times such subjects will keep to their optimal departure time. This is the same result as that according to the indifference band concept. Conceived in this way, and in view of the inadequacy of UT and the importance of '*unsuccessful experiences*' as reported by Mahmassani (1990: 471-472), reference-dependent framing in connection with the loss-aversive valuation of changes in departure time, travel time and arrival time and maybe subjective weighted probabilities might quite definitely explain the observed choices in these experiments. The fast convergence to a constant departure time (within a week for most, and within a month for almost all participants) in these experiments, where the choice context remained the same, is a nice example of the tactical choice concept as a process that covers a limited number of operational choices in a novel context and results in the 'choice' of a script or habit.

Transport mode choice behaviour patterns

Foerster (1979) analysed a 1975 evaluation survey of a local bus transit system that had been started shortly before in Chapel Hill, a small town in the USA until then deprived of public transport. He specified five types of models which simulated the Weighted-additive decision rule; a Lexicographic Semi-order rule; a Maximin rule; a Conjunctive rule followed by a second-stage Weighted-additive rule; and a Conjunctive rule followed by a second-stage Lexicographic Semi-order rule. The correlation between the predicted and observed mode choice was good for the conjunctive-lexicographic strategy and good to fair for the Lexicographic Semi-order rule. It was fair to average for the Conjunctive-compensatory strategy, average to poor for the Weighted-additive rule and poor for the Maximin rule. The weak predictive power of the Maximin rule is not surprising in view of the information presented in the previous chapter. At first glance, the low correlation of the observed choices with those predicted by the Weighted-additive rule is striking, in particular in view of the small number of alternatives (2) and attributes (2) considered. One should keep in mind, however, that this rule assumed a loss-neutral attribute valuation. This might also explain the good performance of the Conjunctive and Lexicographic Semi-order rules. The Conjunctive rule as applied in this study was very similar to the Reference-Based Elimination rule proposed in Section 4.4: '*Since the ratings were generated by five-point scales with center zero points, and since the importance scales included an "unimportant" category, it was assumed that any mode receiving a negative rating on time or cost was conjunctively unacceptable provided that the*

attribute was not rated as unimportant' (Foerster: 24). The neglect of loss-aversive valuation might explain Foerster's conclusion '*that lexicographic models provide the best descriptions of the behaviour of auto users*' (Foerster: 26). The high correlation of predicted and observed mode choices with the outcomes of two-stage strategies based on the conjunctive rule suggests that loss aversion might have played an important role in the mode choice decisions of many travellers.

The inclination of Canadian commuters to switch from solo car driving to car pooling or to a new express bus service was investigated in a stated choice experiment by Washbrook *et al*. (2006). In-vehicle times for solo driving and express bus trips were valued at the same level, but the participants were more aversive to carpool in-vehicle time. Particularly pickup time (carpool) and wait time for buses were valued twice to four times as high as in-vehicle time. As the considered variables did not distinguish between gains and losses relative to the reference state, and the extension of negative and positive travel time changes differed between solo driving and the other alternatives, this offers only weak evidence for loss-aversive valuation. The authors considered first and second order terms of travel time and cost components. Except for the carpool alternative these differed in sign. As this change of sign was not observed in the carpool alternative the support from this study for the diminishing sensitivity in the loss domain is weak.

The modal shift from travel by bus to a newly opened railway line that connects two new towns to the central business districts of Hong Kong was evaluated in Lo and Li (2006). They found that in addition to travel time and monetary costs the number of transfers and perceptions of mode-specific reliability, comfort and safety level explained the observed mode choices. However, to explain the large differences in the modal shares of bus and train their models also rely heavily on an alternative-specific parameter. In view of the average costs and travel times from both new towns to Hong Kong, as presented in the paper, the limited shift from bus to train might well be explained by reference-dependent framing and loss-aversive valuation of the costs and travel time changes that the train mode offers to the remaining bus users. This holds particularly if the interpersonal differences in access-egress times are taken into account.

Another modal shift study was reported from Italy by Cherchi and Ortúzar (2002). Following the completion of a travel diary by car drivers and transit (mainly bus) passengers, these travellers participated in a stated choice survey, where they could choose between their current mode and one alternative, an improved train service in the same corridor with several levels of service. Based on the revealed real-life trips of the participants, the stated choice questionnaires were highly customized. The given levels of the train alternative relative to the current bus alternative differed systematically from those given to the current car drivers. From the perspective of EPT, all the train prospects offered to bus users were in the loss domain for expenses (fare 10, 25 or 33% higher), and in the gain domain for travel time (zero, 25 of 33% lower) and comfort (at least as good or definitely better). If we assume that the VTTS for bus and train users is the same and there is a loss-neutral valuation, comfort would be left as the decisive choice criterion, and would predict a much higher preference for train than the observed 60% shift. However, loss-aversive valuation of the fare increase might counterbalance the gains in travel time and comfort for many public transport users[80]. Possibly the negative alternative-specific constant for the train service, as reported by Cherchi

[80] Those bus passengers that used the new train service for a period of time would experience a loss in travel time and comfort and a gain in money savings when they returned to the bus, which makes this switch back very unlikely.

and Ortúzar (2002; 2006) from a series of different Mixed Logit model assessments, caught this loss aversion effect to some degree. The prospects for current car drivers implied cost savings between 10 and 30%, longer (25%) or shorter (25 to 33%) travel time and good to sufficient comfort. From the perspective of EPT, loss-aversive valuation would largely neutralize the overall improved travel time offered by the stated choice design, and would highlight the difference in comfort. Moreover, a mode shift confronts car users with walking time to the station and adjustments of arrival times to the train schedule, time components that according to the Mixed Logit analyses appeared to be valued more negatively than the in-vehicle time in public transport. All in all, reference-dependent framing of the choice context and loss-aversive valuation of trip attributes might improve the understanding of why only 50% of the car drivers showed an intention to switch to the new train service. Again, the alternative-specific constants in the Mixed Logit models might have covered this effect to some extent. An interesting observation in the context of the present book is that Mixed Logit models that allowed for both random and systematic differences in choice behaviour between population segments had the best descriptive performance. The corresponding interaction effects discussed in these papers might be indicative for interpersonal differences in choice behaviour strategies.

All four re-examined modal choice studies reveal a large asymmetry in travellers' preferences, dependent on the travel mode that was used before the considered choice process. This mode was apparently considered as part of the individuals' reference state. Several surveys showed interpersonal differences in choice behaviour strategies with respect to the framing or evaluation-and-choice functions, while incidentally support for the mixed affective-utilitarian valuation and for the diminishing sensitivity principles were observed.

Route choice behaviour patterns

Bovy and Stern (1990) cite the following results from a Dutch discrete choice-type stated preference survey on the route choices of cyclists: '*seen from the average situation, deteriorations in route attributes have a far greater effect on utility than improvements of roughly equal magnitude*'. The underlying study is reported in Bovy and Den Adel (1985). These researchers interviewed 137 bicycle commuters from Delft that worked in the Delft University of Technology. The stated choice game comprised nine alternative routes compared to a '*reference route*'. Each alternative was described with four attributes: travel time; cycle track type; road surface quality; and traffic intensity, and three different characteristics for each attribute (e.g. for travel time nine, twelve and fifteen minutes). The survey panel was split into three groups. The route alternatives presented to each group differed, though the reference alternative stayed the same for the whole panel. Moreover, the information concerning the attribute characteristics that was offered to the interviewees differed between the sample groups. In two groups they were asked to indicate which pre-defined attribute characteristics of each of the four attributes were the best match for their personal commute.

Significant differences were found in the choices of the different groups. Thus, the idiosyncratic preferences were not context-independent and stable but depended on the way the alternatives – from the standpoint of the researchers 'objectively' identical – were framed, as might be expected in view of EPT: supplying additional information could evoke the availability heuristic with an associated 'overvaluation' of that information. The rating of one's own commute could have given rise to an inclination of interviewees to adopt this 'status quo' as their reference state, instead of the reference route described by the researchers. Though Bovy and Den Adel (1985: 60, 59) were not informed about the framing

premises of PT[81], they intuitively had a good appreciation of these phenomena: '*Different from everyday reality, where alternatives are inseparable entities and differences between alternatives are often hard to discern, these differences are offered on a silver platter in a stated preference survey and the test subject cannot overlook them*'; '*as the qualitative attributes are explained and presented more comprehensively, they are considered more important relative to travel time… The rating of one's own route thus evokes two problems: the test subjects are confused about the meaning of the choice attribute characteristics, and the differences in perception within the subgroups that rated their own route will be greater than within the other subgroups*'.

The authors presumed that the route choices of the cyclists complied with the assumptions of Random Utility Maximization Theory. Several formulations of the utility function were tested, including kinked-linear ones. These made it feasible to discern 'gains' and 'losses' compared to the reference state and resulted in the best fit to the experimental results. Figure 9 shows some results of these analyses, together with an example of the stated choice questions as submitted to the interviewees. Attribute levels that implied a loss relative to the reference alternative appear to be valued approximately 50 to 100% higher than gains. The corresponding loss aversion factors (λ = 1.5 to 2.0) fit nicely in the lower half of the range found in Section 4.3.

Bovy and Den Adel attributed the difference in valuation between an improvement and a deterioration of the attribute levels to the concave character of the utility function. Generally this character is considered to be caused by a desensitisation effect as a consequence of the adaptation level principle (e.g. Frederick and Loewenstein 1999: 303). For the three qualitative attributes their assumption can neither be confirmed nor rejected, as the attribute levels are nominal variables and the concave utility function is based on a rational scale. Obviously, a hypothesis that the respondents' choice behaviour was consistent with PT cannot be rejected either. However, travel time is a rational quantity, and was presented to the survey panel on a rational scale. Generally speaking, adaptation and desensitisation occur both for positively and negatively valued goods. Desensitisation of the disutility of travel time would imply a larger disutility of an increase in travel time from nine to twelve minutes than from twelve to fifteen minutes, but the opposite is true. Thus, under the assumptions of UT the observed asymmetry in the valuation of travel time gains and losses implies a convex disutility function of travel time for commutes in the range of nine to fifteen minutes.

Several authors report that the reluctance of commuters to accept longer travel times does not increase strongly with one-way travel times up to about 30 minutes, whilst only from that time onwards does the reluctance grow progressively (e.g. Van Wee 1997). Mokhtarian and Salomon (2001) even report an average *ideal* one-way commuting time of over sixteen minutes for workers in the San Francisco Bay area, where almost half of the respondents preferred a commute of twenty minutes and more. In view of these findings it seems highly unlikely that the observed valuation of travel time complies with UT. One might consider these results as a convincing demonstration of the loss aversion principle.

Bogers and Van Zuylen (2004; preliminary results in Van Zuylen 2004) investigated the preferences of truck drivers when confronted with choices between a route with a low mean but highly variable travel time and another route with a high mean but very reliable travel time. The more unreliable the, on average, less time-consuming route was, the more they chose for the more reliable though on average longer route. Though the authors primarily attributed this finding to risk aversive behaviour, it may be inferred from the preceding that

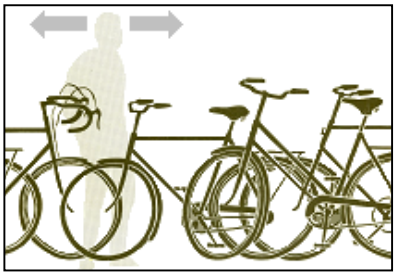
[81] According to Bovy (31-10-2006, personal communication).

INVESTIGATED ATTRIBUTE VALUES					
Attribute	**Travel time**	**Cycle track type**	**Road surface quality**	**Traffic intensity**	**Interaction term**
Reference	**12 minutes**	**Cycle lane**	**So-so**	**Average**	**Cyclepath, smooth surface**
Positive	**9 minutes**	**Cycle path**	**Smooth**	**Calm**	
Negative	**15 minutes**	**No separation**	**Bumpy**	**Busy**	**No seperation, bumpy surface**
ATTRIBUTE VALUATION with respect to the REFERENCE ALTERNATVE					
Value of gain	**+1.14**	**+1.08**	**+1.15**	**+0.70**	**-0.85**
Value of loss	**-1.69**	**-1.76**	**-1.72**	**-1.36**	**+1.27**
Loss/gain ratio	**1.48**	**1.63**	**1.50**	**1.94**	

Please indicate below which of both routes you prefer

Choice situation	Route	Route Characteristics				*Mark for each of the nine choice situations the strength of your preference for one of both routes*			
		Cycle track type	Road surface quality	Traffic inten-sity	Travel time (min.)	Definitely always	More likely	Presum-ably	No pref-erence
1	*basic*	*lane*	*so-so*	*average*	*12*				
	other	**none**	**so-so**	**calm**	**15**				
2	*basic*	*lane*	*so-so*	*average*	*12*				
	other	**path**	**so-so**	**busy**	**9**				
3									

Questionnaire lay-out with seven-points scale-rating question



Adapted from
Bovy and Den Adel (1985)

Figure 9: Valuation of route attributes by cycling commuters in Delft

this presumably was in interplay with loss aversion. The article contains insufficient information about the responses of the truck drivers to the different choice sets for a more thorough re-examination that might lead to more definite conclusions.

De Palma and Picard (2005) discussed a large-scale travel behaviour survey among citizens of the Paris metropolitan area. Participants were phoned and asked questions, including one about the duration of their first trip that day. In the first of three stated choice questions they had to choose between a route with the same, certain travel time as on their morning trip and an alternative with a fifty-fifty chance of a 33% longer or shorter duration. It appeared that 61% choose the certain and 33% the risky alternative – the remaining respondents were indifferent. Successively two similar choice sets were submitted to the so-called '*risk avoiders*' and '*risk lovers*'. The certain alternative and the chances of the risky alternative remained the same but the potential '*time losses*' were lowered for the '*risk avoiders*' and the '*time gains*' for the '*risk lovers*'. The authors attributed the different answers to differences in acceptable expected utilities that reflect different degrees of risk-seeking and risk-avoidance. The presumed choice behaviour strategy is equivalent to a compensatory evaluation of expected utilities followed by the elimination of alternatives that do not meet an idiosyncratic expected utility threshold. This is obviously at odds with the assumptions of UT to which the risk-neutral respondents adhered. Allowing for some interpersonal variation in loss aversion factor and adopted reference state, most observed risk-avoiding and some risk-seeking choice sequences follow straight from the assumptions of cumulative PT that are adopted in EPT. However, even then over 30% cannot be explained by these assumptions. Thus reference-dependent framing, loss aversion and presumably also non-linear probability weights

followed by an overall value maximization rule might explain most choices. Non-compensatory decision rules were also definitely applied by many respondents.

Sumalee *et al.* (2005) investigated the applicability of PT in a route-choice model. They considered a value function that complied with the PT assumption of diminishing sensitivity and substituted its essentially deterministic decision rule (taking a probability weight factor into account) for the weighted-additive utility expression of the Random Utility Maximization model. However, the employed weighted probabilities are a far cry from those found in experiments and the authors seem to disregard loss-aversive valuation. As furthermore their paper contains no empirical evidence that substantiates this approach it offers no clues for the assessment of the performance of EPT assumptions. It nevertheless opens a perspective on a potentially fruitful field of applications of a fully-fledged EPT implementation.

Three out of the four tactical route choice behaviour studies discussed above showed evidence for reference-dependent, loss-aversive attribute valuation, of which two also offered indications that probabilities were weighed in a non-linear manner and one clearly showed that different individuals used different decision frames in their choice behaviour strategies.

6.3.2 Traffic safety – travel time – cost trade-off choices

In 1991, the values that UK travellers attributed to a reduction in the chance of non-fatal accident were investigated with two different research approaches, contingent valuation (direct assessment of a monetary value for a reduction in risk) and the standard gamble approach (assessing the risky prospect equivalent for a certain alternative) (Jones-Lee *et al.* 1995). There were large differences between the methods in the elicited value attributed to the same reduction. The standard gamble approach yielded much larger differences between values for certain and risky prospects than would follow from the contingent valuation approach. The results are indicative of a strong non-linear weighing of probabilities and are also indicative of an embedding effect (Kahneman and Knetsch 1992). This occurs when the value attributed to a public good is lower than the sum of the values attributed to its constituents, and is quite commonly observed in the valuation of attributes or objects with an affective and/or ethical overtone (e.g. Kahneman and Knetsch 1992; Slovic *et al.* 2002). Morrison (2000) re-examined the results with a model in which the alternatives were split up in two components: traffic safety, which is provided by all alternatives, and a complementary component (e.g. probability to pass away) that is specific for each alternative and found that '*These results indicate that our approach…removes…the embedding effect*' (Morrison: 30). Her paper demonstrates the problems one might encounter when individuals are asked to map affective feelings with regard to traffic safety, in this case presumably of an ethical-deontological character, on a monetary scale. As such it is a convincing demonstration of mixed affective-utilitarian valuation. She also found indications that the value attributed to a particular risk reduction was considered to be lower than for the acceptance of an equivalent increase, which yields plausible evidence for the occurrence of loss-aversive valuation.

De Blaeij and Van Vuuren (2003) presented a confined pilot survey amongst university personnel about the Willingness-to-Pay in order to avoid road accidents. Explicitly following the principles of PT on decision making under uncertainty they framed their research such that it is possible to discern between the perception of probabilities, or 'risks', and of the associated outcomes. They found that if the probabilities to succumb or to become severely disabled are low, the Willingness-to-Pay to avoid that risk was largely determined by the possible outcome rather than by the value of the chance. Therefore they concluded that '*most people simply lack intuition to estimate very small probabilities in an adequate fashion*' (De Blaeij

and Van Vuuren: 174). Another observation was that the respondents were hardly able to discern between large chances ($1 > p > 0{,}01$) on the occurrence of a particular outcome. These outcomes are consistent with findings from earlier research: '*when consequences carry sharp and strong affective meaning, as in the case of winning the lottery jackpot or a cancer, …variation in probability often carries too little weight…If the emotional outcome of a gamble is emotionally powerful, its attractiveness or unattractiveness is relatively insensitive to changes in probability as great as from .99 to .01*' (Slovic *et al.* 2002: 409). Though the survey panel size of De Blaeij and Van Vuuren (2003) was too low to arrive at definite conclusions, this similarity with earlier results in other disciplines strongly supports the idea that subjective weighted probabilities play an important role in the valuation of the mixture of instrumental and affective attributes that are relevant for the assessment of travellers' choice behaviour when confronted with transport safety matters.

Rizzi and Ortúzar (2003) performed a stated choice survey on the valuation of Chilean interurban road safety and its effect on route choice. The alternatives were two different routes characterized by three attributes: toll charge, travel time and annual number of fatal accidents. The aim of Rizzi and Ortúzar (2003: 16) was '*to value improvements in safety, not a worsening of it*'. Thus, the surveyed fatal accident levels were almost exclusively 'gains' compared to the status quo. Rizzi and Ortúzar found a small difference in the valuation of a marginal decrease in traffic safety compared to an equivalent increase, and concluded that this might well be explained by the diminishing marginal utility principle of UT. They reported that a large part of the 342 respondents chose according to the Strong Lexicographic rule by systematically preferring the route alternatives with the lowest accident risk (21%), travel time (17%) or toll charge (6%). This is particularly surprising in view of the low complexity of the choice task, from which one would expect a predominantly compensatory evaluation (Chapter 4). Following Cairns and Van der Pol (2004) one might wonder if extending the range of travel times, costs and fatal accidents would leave much in terms of lexicographic answers. On the other hand at least some of the interviewees might have valued the attribute '*annual number of fatal accidents*' as an affectively more salient public good compared to the utilitarian cost and time attributes with their undisputed 'personal interest' character. Apparently the 'non-trading' lexicographic choices of such travellers might also result from the application of an elimination rule for alternatives that do not meet a satisficing safety level. Actually, recently Cantillo and Ortúzar (2005) re-analysed the results of Rizzi and Ortúzar with discrete choice models that allowed for a two-stage conjunctive-weighted additive evaluation. While models considering thresholds for toll fare or travel time did not perform better than the common Multinomial Logit model, those with a threshold for traffic safety had a better goodness of fit. These findings support the assumptions of intrapersonal differences in the valuation of affective and utilitarian attributes as well as the use of non-compensatory decision rules by a part of the survey populations.

Some other stated choice surveys aimed at the valuation of traffic safety confirm the extensive occurrence of lexicographic answering. Iragüen and Ortúzar (2004) used the same design as Rizzi and Ortúzar: two route alternatives characterized by the annual number of traffic casualties, toll and trip duration. This was applied in an internet-based survey of 320 car-users of Chilean urban roads. They reported similar frequencies of strong lexicographic answering (accident risk 21%; travel time 10%; travel cost 7%) as Rizzi and Ortúzar (2003) found for interurban roads. Rouwendal and De Blaeij (2004) used a similar route choice problem in an Internet survey answered by 1055 Dutch car users. An important difference compared to the Chilean surveys reviewed above was in the salience of the choice context. In those surveys this was highly customized, i.e. related to a concrete real-life trip that was actually made by

the subject. The Dutch study concerned a fictitious situation, and the respondents were from a panel of citizens that regularly filled in questionnaires and were paid for completion. Moreover, the submitted toll fare varied much more between alternatives and the trip duration much less than in the Chilean surveys. This may explain the slight differences in the observed frequency of strong lexicographic answering (accident risk and/or travel time 21%; travel cost 10%), although they remain in the same order-of-magnitude.

Rouwendal and de Blaeij (2004) also tested to what extent the subjects followed the transitivity[82] principle of UT. Of all respondents, 37% violated it. Taking the extent of strong lexicographic answering into account this supports the notion that the survey population employed a mixture of compensatory and non-compensatory decision rules. The stated choice questionnaire further contained two identical questions, the second and tenth (last) one. As much as 15% made different choices from these sets. This leaves puzzling questions as to whether this is caused by this particular survey context or reveals large-scale truly inconsistent intrapersonal within-context choice behaviour. The latter would be at odds with an important assumption of both UT and EPT.

The five stated preference surveys discussed in this subsection were primarily aimed to assess the economic values of traffic safety, which is undoubtedly a more highly affective and ethically salient topic than travel time or money. Although the experimental designs presented it as a 'personal interest' attribute, three surveys showed evidence that many individuals valued it differently compared to the more 'utilitarian' attributes. Presumably related to this effect, one of these three yielded evidence of interpersonal differences in evaluation-and-choice strategies, and so did the two other studies. Two surveys yielded some support for loss aversive valuation, while one other tested it but failed to find an effect because all the submitted attribute levels were in or close to the gain domain. Non-linear probability weights were also revealed from two studies.

6.3.3 Travel time – cost trade-off choices

In the past decades many stated preference surveys to elicit the VTTS were held in many countries. A recent review of the experimental set-up of VTTS-surveys covers studies in seven countries in which the core of the survey consisted of a series of choice sets with between two and four attributes, including at least trip duration and monetary cost, compared to some reference trip that is often included in several choice sets (Burge *et al*. 2004). However, several other survey designs are met in the travel behaviour literature, some drawing on, for example, judgments rather than choices (e.g. Richardson 2001). Again other surveys were aimed to elicit the value that travellers attribute to the reliability of travel time (e.g. Rietveld *et al*. 2001). The responses of almost all these studies were analysed with Logit-type models in accordance with Random Utility Maximization Theory. After an extensive discussion of the national Dutch and UK surveys this subsection provides an overview of the other surveys in which information about a 'reference trip' allowed inferences about the appropriateness of EPT premises.

[82] Transitive choice behaviour means that a subject should always choose A over C when she chooses A over B and B over C in the same sequence. Rouwendal and De Blaaij (2004) and other travel behaviour researchers call this behaviour '*consistent*' (e.g. Sælensminde 2001). However, there is ample evidence for choice conditions where '*consistent and predictive intransitivities can be demonstrated*' (Tversky 1969: 31). Therefore, in this book 'consistent' is not used as a synonym of 'transitive', to avoid confusion with its meaning as conceived in EPT (see Chapter 5).

The Dutch and UK national VTTS-surveys

Three national VTTS surveys with very similar designs were held in the Netherlands (1988 and 1997) and the UK (1994). These were extensively reported in survey reports (HCG 1990; 1998; AMR 1999) and discussed in the transport literature (Bates 1999; Gunn 2001; Mackie *et al.* 2001a; Van de Kaa 2005; 2006).

The final report of the first Dutch study contains an extensive description of the survey design (HCG 1990). The researchers did not aspire to survey a representative sample of the population. The survey panel members were recruited at petrol stations, parking lots, train stations and bus or tram stops where they were 'on their way' for business, commuting or other purposes. The recruitment was continued until a sufficient sample for nine trip purpose-travel mode combinations was attained. Eventually the total response amounted to over 2000 usable questionnaires. The interviewees answered questions on the spot about their actual trip and whether they were willing to participate in a postal survey. If so, they were sent a questionnaire of which the core consisted of bi-optional choice sets with time-cost trade-off questions. The presented alternatives were retrospective, with the actual trip of the respondent during their recruitment as a reference. An example is the choice between '*A. Trip travel time the same as on the recruitment day, travel costs 2 guilders lower than for that trip*' and '*B. Trip travel time 20 minutes shorter than on the recruitment day, travel costs 1 guider higher than for that trip*'. Depending on the duration of the reference trip, time savings and losses from five up to 40 minutes with respect to the actual trip were submitted, along with cost increases and reductions. For the Dutch 1997 study the 1988 survey design was replicated, with minor adaptations (HCG 1998). The sample size of this survey was much larger than in 1988, with over 5000 usable questionnaires recovered. The 1994 UK value-of-time survey followed the same design as the Dutch surveys (AMR 1999). Public transport passengers were not interviewed. The sample size was rather large, resulting in more than 4000 usable questionnaires.

The designs, with their emphasis on a real-life reference trip, seem well in line with the assumptions about framing of (E)PT. This 'reference state' was clearly circumscribed in the questionnaire. Embedding effects or feel-good biases in the interviewees' judgments (Section 4.3) therefore seem highly unlikely. The choice sets forwarded did not mention the duration and cost of the reference trip, thus for some subjects the accessibility of that information might have been low respective to the provided information on time and cost differences. This might have supported a minimal account appraisal rather than a topical one (Section 4.3) and it is hard to imagine that any respondent attempted to value the total trip time. The limited complexity of the choice task presupposes the use of a compensatory decision rule by most interviewees (Section 4.4).

In these studies the choice behaviour of the survey subjects was presumed to comply with UT: '*The basic paradigm was of individuals as utility maximizers constrained by time and money budgets*' (AMR 1999: 5). Logit models were used for the analyses. The utility of each alternative was calculated based on the cost and time differences with respect to the reference, with household income, journey purpose etc. as explanatory variables. The final report of the first Dutch study mentions: '*there was strong evidence that travellers value time savings at a much lower rate than time losses. For commuters, in particular, losses were valued around 50% higher than average, and savings around 50% lower*' which did not come as a surprise: '*this sort of effect has frequently been found in other market research exercises using similar techniques*' and evoked the, not particularly 'rational', inference '*that the more robust approach will be to base the analysis on both time savings and losses together*' (HCG 1990: 21). The final report does not contain further

information about the provisional results regarding the valuation of time losses versus time gains. The second Dutch survey pays no attention to differences in the valuation of gains and losses. The UK survey was analysed with several models, some of which distinguished between the size and sign (gains and losses) of the time and cost differences. These showed a much better fit than a simple model using only time and cost as variables.

The results of the Dutch and UK surveys show a remarkable resemblance in the 'mean' value of travel time, as illustrated by Gunn (2001: 178). With respect to loss aversion, the only quantitative information about the outcomes of the provisional analyses of the first Dutch survey was also found in Gunn (2001: 180-181). Results from the UK survey were tabulated in the final report (AMR 1999: 181), preceded by a thorough description of the model used for the analysis. All the recovered data are inflated, adapted to the present-day currency and presented in Figure 10. These data were assessed with models that did not discern between monetary cost increases and decreases but discerned the travel time changes with respect to size and sign. Thus, they cannot be considered as VTTS values as defined within the EPT paradigm. The elicited values for time gains might be considered as approximate averages for the values of time in the 'equivalent gain' and 'Willingness-to-Pay' quadrants of the indifference map (see Figure 5 on page 57): they are subject to the loss-aversive valuation of increases in money exchanges and thus will underestimate the VTTS. Likewise, the values for time losses will approximate averages for the values that apply in the 'Willingness-to-Accept' and 'equivalent loss' quadrants and will thus be higher than VTTS. Consequently, from the perspective of PT and EPT the effect of the loss-aversive valuation of increased money expenses is approximately 'averaged' in the retrieved values for travel time gains as well as losses, and the remaining differences in valuation should be attributed to the loss-aversive valuation of travel time changes only.

The VTTS values in Figure 10 demonstrate the difference in the valuation of gains and losses. For 'other' trip purposes small gains were hardly or not at all valued, while small losses were definitely valued, though not particularly highly. The valuation of travel time for commuting was much higher, though here, too, small gains were valued lowly, particularly in the Netherlands. Commuters valued small travel time losses much more highly than small gains, though lower than losses from ten minutes onwards. For business purposes, small gains were definitely not 'worthless', though here, too, losses were valued much higher. It should be mentioned here that the valuation of travel time for business purposes was the appraisal by the travellers themselves and did not take into account the associated employer's expenses. It seems obvious that the difference in valuation may be attributed to the loss aversion principle. Except for low time changes the loss aversion factor λ, which as discussed above applies to the travel time changes only, lies typically in the range of 1.5 to 2.0, which is within the lower range of those found in Section 4.3. In the UK study the ratios between travel cost increases and equally-sized decreases appear to lie in the 1.5 to 2.0 range (AMR 1999: Tables 83 –85).

In the final reports of the survey and in later articles that discussed these outcomes (Bates 1999; Gunn 2001; Mackie *et al.* 2001a) neither PT nor the loss aversion concept is mentioned. Re-examination from the perspective of PT or EPT of the results presented in the latter reference suggests a loss aversion factor of about 2.5 for travel costs and between 2.0 and 3.5 for travel time, see Van de Kaa (2005). Bates (1999: 312-313) refers to the declining marginal utility of money and the status quo effect as possible explanations for the different valuation of travel cost increases and decreases. He and Mackie *et al.* (2001a: Sect. 2.1) presumed that the difference in valuation could be explained by '*the presence of an inertia effect. In this context,*

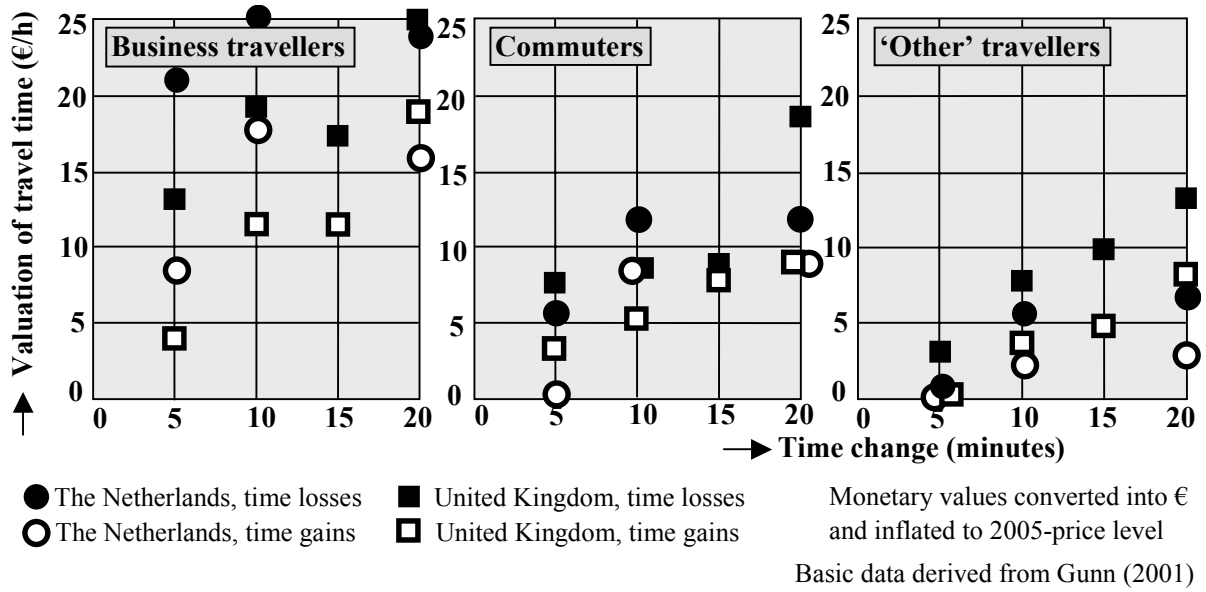


Figure 10: Valuation of travel time in the UK and the Netherlands

inertia is a preference for the current situation in order to simplify the task of answering the SP questions'. The authors gave no grounds for their suggestion that the many thousands of British respondents that put in a great effort to complete the questionnaires were simplifying this part of their self-selected job. By introducing an 'inertia variable' to the specifications of a Random Utility Maximization model they were able to arrive at approximately the same values for gains and losses of the same size. One might consider that there is effectively no difference between the introduction of an inertia variable or a variable that takes care of the status quo bias. From the preceding it will be obvious that a strong status quo bias has to be taken for granted when one analyses loss-aversive choices with loss-neutral utility maximizing models. However, Van de Kaa (2005) showed that an inertia effect alone could not explain the extent of loss-aversive valuation in the Dutch surveys. This latter view is supported by a Chilean stated choice survey with a variable range of three to five route alternatives characterized by three to six cost and time attributes, with a recently experienced trip alternative as reference state in each choice set. Caussade *et al.* (2005: 630) observed that the outcomes of the analyses were '*suggesting there is no (inertia) effect to pick as first option the current route*'. These observations and the similarity of the UK survey design and outcomes with those in the Netherlands make it obvious that the difference in valuation of gains and losses in the UK survey should be attributed to the loss aversion principle.

Van de Kaa (2005) re-analysed the individual responses in both Dutch surveys. Only the individual responses of some of the respondents (i.e. car drivers) were considered, to ease comparison with the UK survey, which did not question public transport passengers. This amounted to 3947 respondents who completed all twelve stated choice questions. An analysis of the aggregated answers showed similar very low valuations of small time gains as well as a higher valuation of losses compared to gains of equivalent size, for all the time changes considered. Checking the transitivity principle showed that only 34% of the respondents complied with it, almost half (15%) of these by Strong Lexicographic answering. Thus 66% violated this assumption of UT. On the other hand, a consistency check, as defined in EPT, showed that 56% of the responses could be explained from a consistent use of framing and loss-aversive valuation followed by a weighted-additive decision rule. These 56% included almost all the choice sequences that could be explained by adherence to the UT assumptions. In a later article, Van de Kaa (2006) also showed that 56% of the complete survey

populations, including the 3216 public transport passengers, might have chosen in agreement with these premises. Of the remaining 44% of the choice sequences 21% could be the result of the elimination of alternatives with mostly high monetary or time losses, followed by a compensatory evaluation if more than one alternative remained. At least 6% could be explained by random errors (mistakes, miscalculations, or genuine inconsistencies) in frequently observed choice sequences. The remaining, less than 20%, might be explained by the host of other compensatory and non-compensatory strategies. These analyses leave no doubt that many if not most subjects demonstrated loss-aversive valuation and that, in addition to the majority that just applied a compensatory decision rule, a minority used non-compensatory strategies.

Other travel time – cost trade-offs

Richardson (2001; 2002; 2003) described elements of the design and analysis of a VTTS survey amongst car drivers and public transport passengers in Singapore. During home interviews, respondents reported details of a trip made on the previous day. Successively they were asked to state the strength of their preference for this 'reference trip' compared to one alternative at a time, on a seven-point scale ranging from '*Strong preference for A*' via '*No preference for either*' to '*Strong preference for B*'. Several choice sets were submitted, with different trip durations and costs. An initially estimated VTTS and the submitted levels of the attributes were adjusted after each preference statement, using a Binomial Logit model. After just three questions this resulted in a 'stable' individual VTTS. Richardson (2003: 108) stated that '*those who choose the same option in each game, even though the ordering of the time-saving option was reversed in every alternative, were regarded as "nontraders" who were not seriously playing the SP game*'.

The share of these alleged 'non-traders' extended over 21% of the survey population. In connection with other statements in these papers this shows that the reference trip was part of each submitted choice set. If this reference state was chosen from the first choice set and the alternative implied a travel time gain, the alternative in the second set apparently changed to a travel time loss and in the third set it moved back to a time gain, with corresponding, but opposite, cost changes. If a travel time loss compared to the reference trip was submitted in the first set, the next contained a time gain and the third, again, a time loss. As demonstrated in Richardson (2002), such a process should converge quickly if all travellers chose according to a loss-neutral UT paradigm, whatever the value of the initial VTTS estimate was. The same holds if the respondents valued the alternatives loss-aversely, as long as the sign of the travel time change does not change in successive choice sets. However, if time gains and losses alternated and the individual's VTTS was between, say, 50% and 200% of the initially estimated VTTS, loss-aversive respondents, who valued increases in travel time and travel expenses twice as highly as equally sized decreases, would systematically choose the reference alternative. If time changes were valued loss-aversely and money expenses loss neutrally, this propensity to opt for the reference would largely depend on whether the first set contained a travel time gain or loss. The alleged non-traders will have therefore actually demonstrated loss aversion in a very consistent way. As the adaptive choice set generation process may also result in a converging VTTS of loss-aversive respondents, particularly if the VTTS initially estimated was far below or beyond the individuals' actual VTTS, loss aversion might have been much more wide-spread than the 21% for which it was clearly demonstrated by the systematic choice for the reference alternative. The distribution of the remaining 2,450 individual VTTS values over the survey population was not random but showed that some 23% of the public transport users '*had a zero value of time*', thus answered according to the Strong Lexicographic rule.

Sælensminde (2001; 2002) assessed to what extent respondents to the Norwegian VTTS study (1994-1996) and to a 1993 '*environmental survey*' followed the transitivity principle of UT. Both articles differ mainly in the shares of the survey populations that were covered in the described analyses. The choice sets submitted in these studies comprised two alternatives characterized by three attributes (price, travel time and one other attribute). The VTTS study contained nine choice sets, the environmental study only four. This may explain the huge extent of strong lexicographic answers (almost 75%) for the environmental study, compared to almost 30% of the car drivers in the VTTS study. The 2002 article gives no data on the percentages of lexicographic answering. Combining the available information shows that some 40% to 50% violated the transitivity principle while almost two-thirds of the remaining chose lexicographically. This leaves little doubt for the application of non-compensatory decision rules by a minority of the interviewees. As loss-aversive valuation almost certainly results in violation of the transitivity principle it is highly plausible that at least some of the survey populations exhibited it.

A stated choice survey by Caussade *et al.* (2005) aimed to assess the influence of design dimensions on choice behaviour. It consisted of a stated route choice survey. By varying the number of choice sets, alternatives, attributes, attribute size levels and the range of these levels, sixteen different stated choice games were played by different segments of the survey population. Basically the alternatives were characterized by three attributes: total trip costs (tolls plus running costs), total travel time (free flow plus slowed down plus stop-start) and trip time variability. Designs with more attributes were generated by splitting up the cost and/or travel time attributes such that the total cost and total travel time remained the same. The results were analysed with Random Utility Maximization-based Logit models. These showed subadditivity of attribute values, i.e. the value of a covering attribute appeared to be lower than the sum of the values of its constituents. The 'total travel time' was even valued below that of its free flow constituent. Subadditivity of attribute characters is well known from judgment and choice experiments of affectively salient goods (Kahneman *et al.* 1999b; Kahneman and Frederick 2002). Obviously, splitting up a predominantly utilitarian attribute characteristic like total travel time into a mixture of affective and utilitarian attributes will result in an embedding effect (Kahneman and Knetsch 1992). This is caused by the higher valuation of the affectively more salient travel time attributes, compared to the value attached to the affectively less salient total travel time. The resulting higher values for 'summed total travel time' might be a more realistic measure for the values attached to actual trips than those following from the 'holistic' assessment of 'inclusive total travel time'. In the latter, several relevant characteristics of the trip were not explicitly submitted to the respondents who subsequently presumably disregarded them. On the other hand one might wonder whether many travellers would take the differences in affective valuation of the experiences of travel circumstances during different short episodes of the trip into account in their real-life travel choices. Anyhow, the mixture of affective and utilitarian salient attributes might have provoked the use of non-compensatory decision rules by at least some of the respondents (Chapter 4).

Caussade *et al*. also found that the number of attributes, thus the degree of splitting up, strongly increased the variance in the answers. One should bear in mind that loss-aversive valuation as a deviation of UT will have been attributed to the error term in the Random Utility Maximization model employed by the authors. The sum of the characteristics, e.g. time components, of the subdivided attributes remained the same as the original, inclusive level. Thus both the summed time gains and summed time losses relative to the reference travel time increased due to the splitting up. Consequently, when the loss-aversive valuation

of attributes occurs in stated choice games with attributes that are split up, this reveals both subadditivity of constituent attribute values and a higher error term/variance than in designs with fewer 'overall' attribute characteristics if the survey is analysed with a 'loss neutral' Random Utility Maximization model. Both the low value found for inclusive total travel time and the increase in variance due to an increase in attributes might, at least partly, be explained by loss aversion in combination with an increase in the affective salience of total travel time after split-up and an increase in non-compensatory evaluation.

Several more stated choice surveys investigated the responses of travellers to positive and negative monetary and time changes with respect to a 'revealed preference' base or reference trip. Recently, some of these were re-examined from the perspective of PT (Hultkrantz and Mortazavi 2001; De Borger and Fosgerau 2006; Hess *et al.* 2006; Tapley *et al.* 2006). Hultkrantz and Mortazavi (2001) re-analysed the 1994 Swedish VTTS survey in which travellers were asked to state four choices from four bi-optional choice sets in the Willingness-to-Pay domain (i.e. travel time decreases and money increases compared to a reference alternative) and four choices from similar choice sets in the Willingness-to-Accept domain. They employed a Logit model with a non-linear specification of utility according to a Taylor expansion, comprising both first and second order terms and interactions. The estimated values for the Willingness-to-Accept increases in travel time as inferred from Figures 1 and 2 in Hultkrantz and Mortazavi's article are about 2.0 to 2.4 as high as the corresponding Willingness-to-Pay[83], at least for travel time changes from fifteen to 40 minutes. For changes below and beyond this range they suggest much higher ratios. As according to PT or EPT this ratio is equal to the product of the loss aversion factors for travel time and cost these might, averaged over the whole range of attribute sizes, be both in the 1.5 to 2.0 ranges if they were the same. The model specifications did not comprise a power function with an exponent below unity. The mixture of linear, quadratic and interaction terms yielded a definitely concave value function for travel time changes in the gain domain, as expected according to both UT and EPT. In the loss domain, the general behaviour seems convex rather than concave but for high travel time losses the model suggests a change to concavity. Based on this re-examination the diminishing sensitivity principle can be neither rejected nor established. Closer re-examination suggests that Hultkrantz and Mortazavi's VTTS-function might reflect the use of Attribute-Based Elimination rules by a significant part of the respondents.

De Borger and Fosgerau (2006) and Fosgerau *et al*. (2006) tested the applicability of PT to the responses of the Danish national VTTS-survey. Following earlier work by Fosgerau (2005) they tested models with the VTTS as the parameter for travel time, which apparently prevented some of the problems posed by the 'attribute-size independent' error term according to Random Utility Maximization Theory. De Borger and Fosgerau (2006) assessed separate values of travel time for the four categories of choice sets that were submitted to the Danish travellers: all attributes in the gain domain, all in the loss domain, travel time decreases (gains) combined with money increases (Willingness-to-Pay domain) and travel time increases combined with money savings (Willingness-to-Accept domain). From a kinked-linear specification of the value function followed a loss aversion factor of between 2.6 and 2.8 for travel time and between 1.5 and 1.6 for money. When the same value of the

[83] For a linear specification without inertia term they found a Willingness-to-Accept/Willingness-to-Pay ratio of 1.9, composed of a small ratio of about 1.1 for the cost attribute and 1.7 for travel time. A range of models estimated by Algers *et al*. (1998) yielded Willingness-to-Accept/Willingness-to-Pay ratios between 1.1 and 2.7, with 1.75 for the model with the best loglikelihood. However, a strongly varying inertia term in their models might have biased these findings in a downward direction.

loss aversion factor was enforced in all four domains, the fit to the observed choices remained virtually the same and the loss aversion factors became $\lambda_{\text{time}} = 2.7$ and $\lambda_{\text{money}} = 1.6$, remaining the same for different linear specifications tested. Fosgerau *et al*. (2006) applied a slightly different linear model specification to the same data and found $\lambda_{\text{time}} = 2.7$ and $\lambda_{\text{money}} = 1.7$, in the same range as found for the Dutch and UK VTTS surveys (Van de Kaa 2005). In agreement with PT's diminishing sensitivity principle, a power function (exponent below 1) yielded an even better model fit compared to the linear specifications (De Borger and Fosgerau 2006). This shows convincing evidence for the diminishing sensitivity principle in the context at hand.

Hess *et al.* (2006) analysed the revealed and stated choices of car drivers who were confronted with different tolls and congestion levels in the morning rush-hour on a corridor in Sydney. The travellers had the choice between a reference trip and two alternatives, each characterized by free flow and slowed down travel time, a time variability margin, running costs and toll costs. They analysed this with two types of models. In one type the correlation between the sixteen successive choice statements of the same individual was accounted for to a large extent, while the other type ignored it. The first type systematically showed a better fit to the observed choices. Another distinction was between models that discerned between increases and decreases in attribute levels compared to the reference state and models that did not. The models that discerned between gains and losses relative to the reference trip yielded a large increase in model fit. All models used linear specifications of running costs, toll expenses, free flow and slowed-down traffic times, supplemented with several alternative-specific and attribute-specific parameters. These comprised: one alternative-specific constant for the reference alternative and one for the first stated choice alternative; one parameter that was only estimated when a toll was charged for the concerned alternative and another one that was estimated when the alternative was fully congested; and three parameters for choices from sets in which the toll, free flow time or slowed down time were zero in the reference state. According to these models, non-commuters ($\lambda = 0.95$) as well as commuters ($\lambda = 1.05$) showed hardly if any loss aversion with respect to running costs. When the estimated parameters for the toll increase and decrease attributes are compared, they suggest that both commuters and non-commuters were very sensitive to increases in toll expenses ($\lambda = 3.2$ and 6.6, respectively). The loss aversion factors that could be assessed for the valuation of the free flow time by commuters ($\lambda = 2.7$) and non-commuters ($\lambda = 1.5$) also fit well into this picture. However, reductions in slowed down time were apparently preferred to increases in it ($\lambda = 0.9$ for commuters and $\lambda = 0.4$ for non-commuters), which is counter-intuitive. The large differences in loss aversion factors compared to those found in the earlier discussed VTTS studies might, to a certain extent, also be caused by the division of the travel cost and time attributes into two components each. When, for example, the parameters for the running cost and toll attributes are added, the loss aversion factor for overall trip costs becomes $\lambda = 1.6$ for commuters and $\lambda = 2.0$ for non-commuters, which is virtually the same range as found in the European national VOT surveys discussed above. The loss aversion factors assessed from the parameters estimated in this study might be biased by the other parameters that considered differences in toll rates, free flow time and slowed down time between alternatives. Notwithstanding this, the findings of Hess *et al*. are a convincing demonstration of the descriptive performance of reference-dependent framing and loss-aversive valuation.

Tapley *et al*. (2006) used 1985 and 1994 revealed preference data about travellers' choices between a tolled and non-tolled UK river crossing, as an approximation of the reference state. This enabled a re-analysis of corresponding stated choice data in agreement with PT. For a

linear model specification they found that in 40% of the cases losses were valued significantly higher than gains while in the majority of cases there was no significant difference. The average loss aversion factors that might be inferred from this study were low compared to the studies reviewed above. However, one should realize that their model contained a 'tolled road' attribute that had a highly significant, negative parameter. This might have caught a considerable part of the effect of loss-aversive valuation, which might also explain that a power function specification yielded no improvement in model fit at all. A lack of agreement between the revealed preference statements adopted as the individuals' reference states and their actual real-life reference might be another explanation for the poor support for the EPT premises. All in all, the evidence for loss aversion and reference-dependent framing found from this study might be considered as plausible but not really convincing.

Most of the VTTS surveys discussed in this subsection have shown convincing evidence for the loss-aversive valuation of time and money attributes relative to an actually experienced real-life trip that apparently acted as reference state. The models used for the elicitation strongly differed, but all surveys were also analysed with straightforward Random Utility Maximization-based Multinomial Logit models containing linear utility specifications that allowed for a kink at the reference travel time. Those recovered findings that allowed for a more or less reliable order-of-magnitude assessment of loss aversion factors yielded ratios from 1.5 to 3.5, both for increases of travel expenses conceived as out-of-pocket costs and for travel times. As the choice sets of all surveys only contained trips with 'certain' travel times, the use of non-linear probability weights could not be assessed. One survey offered information that mixed affective-utilitarian attribute valuation might have played a role, as an explanation for the subadditivity of travel time components. One should realize that all survey designs presumed only one choice behaviour strategy for all respondents. Still, in six surveys it was found that the followed strategies differed within the survey population. Three surveys were also analysed with non-linear utility specifications. For one of these, the diminishing sensitivity of travellers to increasing losses was firmly established, but it could neither be supported nor rejected for the other two.

Travel time reliability – cost trade-offs

Several stated choice surveys assumed that travellers consider the travel time and its unreliability as distinct attributes. They use measures like means and standard deviations to distinguish these quantities. Some examples of such approaches are reviewed in this subsection. All the studies considered that all survey respondents followed the same choice behaviour strategy, thus implicitly attributing interpersonal choice heterogeneity solely to differences in the valuation of observed and unobserved attributes.

Starting from the premise that utility is a power function of travel time, Senna (1994) derived an expected utility expression in agreement with Expected Utility Theory that comprised both travel time and its variance. Obviously, this reduces to a linear function of mean travel time for loss-neutral travellers. He asked Brazilian travellers to express their preference between two alternatives characterized by a distribution of travel times over five 20% frequency classes. As he did not elicit different responses to positive and negative changes relative to a reference state, his empirical results do not allow a definite conclusion about the adherence of his respondents to EPT assumptions. The much higher VTTS of commuters with fixed arrival time and the degree of risk seeking of this group, both relative to commuters with a flexible arrival time and to non-commuters, are indicative of loss aversion and non-linear weighing of probabilities.

Rietveld *et al.* (2001) compared the valuation of scheduled travel times and delay probabilities as inferred from a 1997 stated choice survey of the importance of unreliability of public transport chains. They cited the following choice set: '*Alternative 1 is characterized by the following features: scheduled travel time 80 minutes; probability of a delay 0%; probability of getting a seat 100%; price Dfl 12.50*[84]*. Alternative 2 is characterized by: scheduled travel time 70 minutes; probability of a fifteen minute delay 50%; probability of getting a seat 100%; price Dfl 12.50*'. Alternative 2 therefore had a lower expected travel time but it appeared that a clear majority (85%) of the respondents chose the 'certain' Alternative 1. Reframing of this choice set in terms of gains and losses, relative to a reference state of 80 minutes travel time and 'certainly' no delay, yields an alternative with a 50% chance of at least five minutes delay and the same chance of a gain of ten minutes. With weighting probabilities π^+. p = 0.4 for a positive and π^-. p = 0.43 for a negative prospect with probability p = 0.5 (Tversky and Kahneman 1992: 311), individuals with a conceived loss aversion factor $\lambda > 1.9$ will choose the first alternative. The 15% share of individuals that appear less loss averse is in the same order of magnitude as encountered in many choice experiments and surveys reported in the preceding chapters. The authors analysed the stated choices with a Logit model, with the scheduled travel time and the 50% probability of a fifteen minutes delay, among others, as attributes. They found a marginal value of €0.15 for one minute 'certain' travel time and €0.35 for a 50% chance of two minutes delay, which is equivalent to an expected one minute delay according to Expected Utility Theory with linear utility specification. This implies that an uncertain delay is valued about 2.5 times as high as one minute time according to the schedule, well within the range of loss aversion factors as found in a previous subsection. Rietveld *et al*. attributed their results to an on-average risk-aversive attitude of the travellers but the difference is far beyond the degree that might be explained from the diminishing marginal utility principle for comparable relative differences in the states of assets. Overall, reference-dependent framing, weighted probabilities and the loss-aversive valuation of 'expected' travel time distributions by most travellers might offer a better explanation of the choices of the interviewed public transport users than context-independent framing and valuation of the mean and variance in travel time according to Random Utility Maximization Theory. Thus, EPT gives a good explanation for the responses of the majority to this particular choice set.

A different concept of travel time variance was used by Hensher (2001b) in a stated choice survey among car drivers in New Zealand. He submitted an '*uncertainty allowance*' attribute to his respondents – urban commuters – defined as '*the contingency time that a traveller includes in the face of uncertainty in respect of arrival time at a destination*' (Hensher: 114). Other attributes included free flow, slowed down and stop-start time components, running costs and toll. The levels of all time attributes, including uncertainty, were presented in minutes and customized as symmetrical and proportional deviations relative to a recently experienced trip. From the perspective of a commuter who is familiar with the day-to-day variance in travel time the changes in uncertainty allowance level compared to the one reported from his last trip might appear ambiguous. For some of them, there might be the fear that a lower-than-usual allowance might increase the probability of late arrival and a larger-than-usual allowance might cause the opposite feeling. Obviously, others might immediately frame and value the decrease in uncertainty allowance as a gain and the increase as a loss reduction. This ambiguity might explain the value of the thus defined uncertainty, averaged over the survey population, which was only 55 to 65% of the free flow time, depending on the discrete choice model used for parameter estimation[85]. Both from an UT and a PT perspective one might

[84] Dfl 1 = €0.45; hereafter monetary values are converted to € and inflated to 2005 price level.
[85] In addition to a Multinomial Logit model several Mixed Logit models were applied.

expect it to be of the same order of magnitude. The slowed down time was valued 1.1 to 1.45 times as high as the free flow time and the stop-start time 2.1 to 2.8 times, which seems indicative of a minor and quite large loss-aversive valuation, respectively. Obviously, a more conclusive assessment of the degree of loss aversion requires re-examination of the individual choice data in connection with the individuals' reference states.

In three stated choice surveys that differed in several other respects the route and/or travel mode alternatives from which car drivers had to choose were characterized by an uncertainty interval around the average travel time, in addition to the common attributes of average travel time and/or its disaggregates, like free flow and congested time, and travel expenses, in terms of total out-of-pocket costs and/or tolls (Eliasson 2004; Caussade *et al.* 2005; Van Amelsfort and Bliemer 2005). The questionnaires were customized to recent real-life trips of the respondents and the responses were analysed with Multinomial Logit models comprising linear-additive utility specifications. All the studies showed a significant negative contribution of the travel time variability interval to the total disutility of travel time. Exploratory re-examinations easily showed that, again, these contributions were much higher than what might be expected from the diminishing marginal utility principle, taking the relative levels of uncertainty and total travel time into account. Thus, the findings from these three studies violate Expected Utility Theory. Loss-aversive valuation, possibly combined with the non-linear weighing of probabilities, can explain these violations. This holds definitely for the Dutch study, where high levels of congestion and uncertainty in the stated choice alternatives were correlated with high levels of total travel time compared to the reference trip duration (Van Amelsfort and Bliemer 2005). For Swedish drivers Eliasson (2004) also elicited the value of a large, unexpected delay (10% exceeding frequency) and found that this was valued much more highly than the variability interval. However, exploratory calculations show that both the values attributed to the 'unexpected' deviations and the variability interval might be explained by loss-aversive valuation combined with probability weighting[86] according to cumulative PT. Eliasson (2004) further reported a 50% higher value for driving in congested traffic compared to the average VTTS, while Caussade *et al*. (2005) found that in Chili congested time was valued 1.7 to 2.8 times as high as free flow or total travel time. Both findings indicate that many respondents might have valued these components loss aversely.

The reviewed findings in this subsection support the notion that loss aversion as presumed in PT and EPT yields a solid explanation for '*the conventional wisdom that excess time is perceived as twice as irksome as in-vehicle time*' (Bonsall and Palmer 2004: 325). The studies that offered indications for the size of the loss aversion effect on attribute valuation suggested average values between 1.5 and 2.8, almost the same range as elicited from choices between 'certain' alternatives. Most studies that distinguished between a value of mean travel time and the value of its components also offered plausible evidence for non-linear probability weighing.

6.3.4 Schedule delay – cost trade-off choices

The value-of-time studies discussed in the previous sections assumed that travellers attributed different values to different travel time components or considered the travel time and its variance as distinct attributes. When travellers were confronted with alternatives that exhibited an instantaneous structural change in travel time or its variance compared to a recurrently experienced trip, they appeared well able to choose a suitable one. The re-

[86] To that aim the mean travel time was used as a rough estimate for the reference state and the travel time bandwidth was treated as the 95% confidence interval of a standard-normal distribution, following Eliasson's treatment. More definite conclusions require a re-analysis of the individual-specific responses to this survey.

examinations of stated preference surveys showed large differences between the values attributed to positive and negative changes in travel time. The logical explanation as to why individuals react so differently to structural increases and decreases in travel time lay in the consequences for the time allotted to other purposes. These consequences link an individual's trip planning to her daily activity scheduling. The schedule-delay approach to VTTS-assessment exploits this logic to elicit VTTS from choices between trip alternatives with different arrival and/or departure times relative to a corresponding preferred moment. Some surveys that investigated the valuation of travel time variability *and* schedule by the same travellers found that the uncertainty variable loses significance once schedule delay variables were added to the utility specification, thus supporting the suggestion that these are indeed interchangeable (Van Amelsfort and Bliemer 2005; Hollander 2006).

An EPT perspective on schedule delay and VTTS

To illustrate the similarities and differences between travel time-cost and schedule delay-cost trade-offs, one can put oneself in the position of a traveller who, in a stated choice survey, is confronted with an alternative that implies a structural increase in travel time compared to her usual daily morning commute. According to the UT paradigm, she would first compare all the feasible alternative combinations of departure time, travel mode and route, would next assess the corresponding money expenses, trip duration and arrival time probability distributions, would successively determine the generalized costs of the money expenses, the expected trip duration, the additional or lost time spent at the origin and the expected utilities of the probability distributions of activity time lost or gained at the destination. She might even reconsider the complete daily activity calendar of her family, and would finally add the generalized costs into an expected utility and choose the alternative combination that promises her the highest utility. Obviously, an analyst would select a few attributes that she considers to be the most relevant ones in the context at hand, could conceive some segmentation of the survey population in groups that might exhibit different preferences for these attributes and might trust that randomness in one or several parameters takes care of the remaining intra- and interpersonal variance in observed choices. According to the PT paradigm, the same traveller might frame the same choice context in terms of the same alternatives and attributes, but would only consider and value the changes relative to her reference trip, would attribute a loss aversion factor to losses and a weight factor to probabilities, and choose the best.

EPT presumes that each individual compares the actual context with her previous choices at the same or a higher level in the strategic-operational choice hierarchy, and only considers those alternatives and attributes that might yield acceptable outcomes. Thus, a traveller with a fixed work start-time may consider a particular probability of violating it as an elimination rule and only consider an earlier home departure time, unless an alternative route or mode is available with the same or a shorter trip duration. In the latter case, she will just trade-off the lost time spent at home against the increased expense and inconvenience of the alternative mode or route. Another respondent, who is not able to advance her departure, e.g. because of child care, might consider this as an elimination criterion, would trade-off the threatening late arrival at the workplace against the available alternatives and might be apt to spend a lot of money and/or take high risks to avoid the imminent losses, particularly in the case of a fixed arrival time. Following this EPT-perspective, these two individuals' values of travel time may differ considerably. For the first traveller it is equivalent to the value of the earlier departure from home, which, again, for a night person may be quite high while an early bird might not care about it. For the second person it is equivalent to the value of late arrival at the destination, where earlier arrivals may be valued positively or may be disregarded or even

valued negatively. The actual values of travel time for the first person might be much lower than those of the second one while both might have attributed the same value to late arrivals if they have valued it at all. Under the UT paradigm most 'schedule delay' VTTS assessments infer values of time for trip duration, late and early arrivals. As both persons would be very reluctant to choose alternatives that imply a high chance of late arrival, a high value for lateness may be taken for granted. The attribution of the 'remaining' values of travel time over early arrival and trip duration will depend on the applied survey design in connection with the parameter estimation model. Of course, these latter values as elicited in agreement with a UT-conformable assessment of schedule delays can be recombined into one overall value of travel time savings. Based on the previous reasoning it is hypothesized here that the average ratio of the value of late arrival compared to the 'recombined' VTTS from such studies might be above the 1.7 to 3.5 range of loss aversion factors found from direct travel time-cost trade-offs, even if the effect of probability weighting is disregarded.

When confronted with a choice between trips that differ in their mean travel time and in the variance around it a traveller might trade-off the experienced consequences of the different travel conditions rather than the conditions themselves. These concern 'certain' differences in the time spent before departure and a probability distribution of arrival time. The schedule delay concept presumes that the value of travel time attached to time spent after a preferred arrival time differs from the value of average travel time and from the value of travel time associated with arrivals before the preferred arrival time. These values follow from observed choices under the assumption of linear probability weighting. As discussed above, under the EPT paradigm the individual might have just one idiosyncratic VTTS. Rather than some 'certain' degree of lateness the probability distribution of arrivals might be considered as the relevant arrival time attribute. The possibility of arrivals after the preferred arrival time might then be valued as travel time losses and the possible arrival before the preferred arrival time as travel time gains, assuming that the preferred arrival time is the same as in the reference state. Compared to an assessment in agreement with Expected Utility Theory the value of late arrivals will then be boosted if, in addition to loss aversion, the traveller applies non-linear probability weights. The effect on the elicited ratio between travel time or arrival time losses and travel time or departure time gains will depend on the considered probabilities.

The principles of the schedule-delay approach

Unreliability in travel time results in a similar unreliability in arrival time and in its consequences for an individual's activity schedule. Gaver (1968) considered different strategies that a traveller, confronted with congestion, may follow to optimise her daily departure time. He discusses three categories of time spending due to unreliability: '*Lateness*' (the time lost due to late arrival), '*Waiting*' (early arrival) and '*Headstart*' (early departure). In one model he considers lateness and waiting, in a second one he disregards the costs for waiting and only considers lateness and headstart and '*this (latter) model may be more reasonable (than the former) under many circumstances, for here the headstart time is completely wasted even if the traveller arrives early*' (Gaver: 175). Almost simultaneously Vickrey (1969) also posited that the value that commuters attribute to the time spent for travelling differed, depending on its consequences for other activities. He suggested that the value of the time 'lost' at the workplace due to late arrivals might be four times higher than the time 'gained' by early arrivals, and twice the value of time spent at home. Though both articles lack empirical support one might consider these approaches to the travellers' VTTS as reference-dependent framing of the choice context, combined with loss aversion before the term existed.

Small (1982) disregarded the value of departure time changes because of '*its complexity and lack of data on departures*' and introduced the term '*schedule delay*' for early and late work arrival time relative to the '*work start time*' that later authors generalized to the '*preferred arrival time*'. He conceived a kinked-linear (dis)utility function of these schedule delays and travel time, and added a step function for lateness. Applied to revealed preference data on the flexibility of work start time and chosen work arrival time of commuters in the San Francisco Bay area this showed that '*on average, urban commuters will shift their schedules by 1 to 2 minutes towards the early side, or by 1/3 to 1 minute towards the late side, to save a minute of travel time*' (Small: 477). This illustrates loss-aversive behaviour with respect to late compared to early arrivals. He also observed important effects of factors like family status and flexibility of work start time, which suggest that different groups use different choice behaviour strategies. From the perspective of EPT, Small considered only the arrival time as a 'reference state' and disregarded the significance of the commuter's usual home departure time and the fact that adjustment of this time was the only available alternative in the considered choice context, with uncertain travel and arrival times as attributes or consequences of the choice.

From the perspective of EPT, the preferred arrival time can be conceived as part of the subject's reference state. An observed 'step' in disutility when the preferred arrival time is exceeded in connection with a kinked-linear specification of late arrivals might be indicative of the diminishing sensitivity principle. Late arrivals are in the loss domain, and very late arrivals with low probabilities will be valued disproportionately high. Elicitation of the value of average schedule delay based on the principles of Expected Utility Theory will thus overestimate the VTTS that caused it. From the same EPT-perspective, Small's early arrival time variable is an aggregate of an early departure time loss relative to a 'preferred departure time' reference, and an early arrival time margin that, depending on the individual's activity constraints at the destination, may be valued as a gain, a loss, or not at all. On an aggregate level it will be valued lower than an earlier than preferred departure time.

Small (1982) disregarded travel time variability. However, according to the Expected Utility Theory assumptions of the linear weighting of probabilities the expected value of a schedule-delay distribution is equal to that of its arithmetical mean. The theoretical validity of this principle has only occasionally been demonstrated (Polak 1987; Bates *et al.* 2001; Noland and Polak 2002). In a stated choice survey aimed to elicit valuations of unreliability Bates *et al*. (2001: 222) asked rail passengers to rank alternatives with different probabilistic levels of service, from the perspective that '*you prefer to be at London Paddington at 11.00 AM*'. The survey design thus framed the preferred arrival time as reference and paid no special attention to deviations from a preferred home departure time. An Expected Utility Theory-based estimation yielded values of time for average delay, late arrival time and early arrival time, which were listed for a long-distance corridor. Bates *et al*. based their time and cost variables on an accurate interpretation of Expected Utility Theory. However, according to this theory their average delay variable is equal to the weighted average of late and early schedule delay. When these parameters are converted to values of travel time savings[87] in the gain and loss domains this yields about €70/h[88] in the gain domain and €240/h for losses. Travel time changes that result in violations of the 'fixed' arrival time were thus valued 3.5 times higher than travel time gains. This is at the low side of the range that one might expect from the combined effect of loss aversion and probability weighting. Compared to the VTTS reported

[87] Without any loss of generality one might substitute (ESDL –ESDE) for the average delay (μ) in Bates *et al*.'s (2001: 223) Equation 21. Taking their estimated parameters into account yields early arrivals with respect to the preferred arrival time (or travel time reductions) as gains and late arrivals (or travel time increases) as losses.
[88] Converted to € and inflated to the 2007 UK consumer price level.

from other UK surveys these values for average delay, early and late arrival times were extremely high (e.g. AMR 1999: about €20/h for car driving with business purposes). The design included a headway variable and a 'hierarchical' parameter, of which the first attracted a small negative value and the second a high positive one. Maybe the high positive utility caught by this latter parameter boosted these values of time.

Elicitation of values for travel time related schedule delay

Recently, Michea and Polak (2006) re-examined Bates *et al.*'s data for the long-distance rail corridor (1.5 to 2 h travel time) and also considered similar results from the same survey for a short-distance link (35 to 45 minutes). They used the same deterministic utility specification, except for the headway and hierarchical parameters, which they disregarded. Following an Expected Utility Theory-based VTTS assessment, taking inflation into account and transforming their schedule-delay parameters yields VTTS values in the gain domain of €14/h for the long distance corridor and €9/h for the short distance. Both these values are about the same as the average VTTS for work-related car trips in the UK with the same duration (AMR 1999: 10). For the short-distance link the values of time spent travelling after the preferred arrival time appear to be four times higher than the VTTS in the gain domain. For the long-distance link this was nine times. One should consider that the offered alternatives contained, at least for the long-distance corridor, 10% 'worst' chance of late arrivals that might amount to over 50% of the regular travel time while for earliness the corresponding 10% 'best' chances were at most a few percent of the scheduled time. This suggests that non-linear probability weighting makes a large contribution to the ratio nine between travel time losses and gains as inferred above. But even when non-linear probability weighting is taken into account the loss-gain ratio is on the high side of the range of loss aversion factors found from other VTTS-assessment approaches, as hypothesized above.

Another study from which the large dispersion in the value of late arrival as elicited by Random Utility Maximization-based discrete choice models appears is the revealed preference survey of departure time and mode choice during the morning commute in Pittsburgh (Hendrickson and Plank 1984). The survey concerned 1800 travellers who worked in the Central Business District and of whom 55% were transit passengers, 24% shared a ride, 16% were solo drivers and the remaining went by slow modes. The elicited values for late arrival, defined as after the official work start time, were 30 to 60 times higher than those for earliness. However, one should consider that separate parameters were elicited for in-vehicle free flow and congestion time, access and waiting time for transit. Taking into account the relative contributions of these different constituents of the overall travel time and after substitution of early and late arrivals for changes in overall travel time a VTTS of about US$5/h was found for the gain domain, and of about US$35/h for the loss or late arrival domain. Here, too, probability weighting might partly explain the elicited high ratio between losses and gains. Another explanation might be that most individuals' actual reference arrival times might have been before their official work start time. Hendrickson and Plank also elicited second-order parameters for early and late arrivals. After the substitution of early and late arrivals into changes in overall travel time relative to the work start time this confirms the convexity of the value function in the loss domain and the concavity in the gain domain and thus offers convincing evidence for the diminishing sensitivity principle of PT. Another conspicuous finding presented by Hendrickson and Plank is the large interpersonal dispersal in the degree of earliness of arrival time relative to the official work start time, which supports the notion of interpersonal differences in choice behaviour strategies.

Michea and Polak (2006) also compared the descriptive performance of several non-expected utility theories combined with a Multinomial Logit model on Bates *et al*.'s data. The early and late schedule delays as submitted in the original survey were the considered probabilistic attributes. Both for linear and for power specifications of attribute utilities or values, all models with non-linear probability weights offered a higher log-likelihood than Expected Utility Theory. For the long distance corridor, PT offered the best model fit for both linear[89] and power specifications of the value function, compared to all the alternatives considered. For the short distance corridor an alternative probability weight concept, Prospective Reference Theory, offered the best log-likelihood but PT scored much better than Expected Utility Theory with a linear utility specification and also better, though not significantly, than Expected Utility Theory with a power specification for diminishing sensitivity The performance of Prospective Reference Theory was compared with Expected Utility Theory for a reduced sample of about 50% of the survey population for which estimates of the actual experienced delay by individual respondents were known. The weight factors applied for the Prospective Reference Theory implementation were based on these estimates, which accounts to some extent for a 'deterministic' personalized treatment of interpersonal differences in judgments. The other alternatives for Expected Utility Theory considered the weight factors at the population level. With respect to PT, the cumulative functional was applied to the early and late schedule-delay probabilities which were all considered to be in the loss domain, and some 'average' Multinomial Logit-based ordering of these delays was assessed for the population as a whole. One might wonder how much better the performance of PT would be if information about usual travel and arrival times had been available at the individual's level and if travel time had been used as the stochastic attribute, with the usual arrival time as reference state that separates travel time loss and gain domains. Notwithstanding that, this survey and its re-examinations yield convincing evidence for the applicability of the loss aversion, probability weighting and diminishing sensitivity principles of PT and EPT.

A similar survey, in which prospects for the morning commute, which contained a probability distribution of travel times, were submitted to bus passengers in a UK town, is described in Hollander (2006). Again, the preferred arrival time ('*You have to be at your destination at 9:00*') was primed before each choice question, without further reference to the daily experienced departure and travel time. After trying several value specifications for average travel time, early and late arrival times in a Multinomial Logit model he found that average travel time and early arrival time could best be combined, which offers an empirical underpinning for the theoretical derivation of this principle as discussed above. The inferred values for travel time savings (€5/h) and average travel time after the preferred arrival time (€15/h) were well below those for short distance train passengers as derived above from the Michea and Polak (2006) study, but this difference in valuation for both modes is quite commonly found (e.g. HCG 1998). The 'loss aversion factor,' about 3.0, is within the range elicited from VTTS assessment studies that do not consider schedule delays explicitly. The possible contribution of non-linear probability weight is apparently small compared to the study of Bates *et al*. (2001). This may be caused by the smaller differences between the early and late arrivals compared to the average travel time as submitted to the respondents.

[89] Actually, Michea and Polak tested Rank Dependent Utility Theory (RDT) as proposed by Quiggin (1982). However, Tversky and Kahneman (1992) integrated this in cumulative PT. RDT is conceived here as a special case of cumulative PT, where the diminishing sensitivity principle is disregarded by applying a linear value function instead of a power function with exponent <1. One should further note that the probabilistic schedule delay attributes as considered by Michea and Polak were completely in the loss domain, thus the loss aversion principle was not evaluated in connection with the other elements of PT.

Another approach to the elicitation of a value for travel time variability was followed by Bajwa *et al*. (2006). They designed a stated choice game for the choice between rail and car modes[90] by car drivers and transit passengers in Tokyo. In all submitted choice sets the rail mode had the same departure time, costs and travel time, resulting in certain arrival at the preferred arrival time. For the car alternative, travel times were lower or equal to the train alternative but the departure time varied between the choice sets such that different early and late arrival times were simulated. The costs for the car alternatives varied from 100 to 200% of the train costs. The values for travel time, early and late arrival as assessed with linear Multinomial Logit models were in the proportion of 1:0.56:2.8 to each other, which seems well in line with previous findings. However, for the Mixed Nested Logit Model, which had the best log-likelihood among seventeen different nested and/or Mixed Logit models, these proportions changed to 1:0.7:7.2. When interpreting these findings one should realize that all Mixed and/or Nested Logit models revealed a large positive value for an alternative-specific rail constant as well as a large positive parameter for a car availability variable. The sizes of these variables differ strongly between the different models, but show the same pattern of variation between the models and attain almost the highest values for the 'best' Mixed Logit specification. Unfortunately, no information could be retrieved about the respondents' commonly used mode, which would have offered excellent material for reference state-induced differences in valuation. Nevertheless, the ratio of the values of travel time after and before the preferred arrival time is above the commonly observed range of loss aversion factors, as might be expected in view of the character of the stated choice game and the absence of a departure time reference in the analysis.

De Palma *et al.* (2003) asked commuters in the Paris region to describe their latest morning peak-hour trip in terms of home departure time, free flow travel time, preferred and actual arrival time and asked them to state their choice between that 'reference' trip and customized alternatives that differed systematically with respect to all these attributes. Estimation with a Binomial Logit model comprising a linear utility specification showed that commuters valued congested time more than 1.4 times more than the free flow time. More interestingly, they distinguished the values attributed to earlier-than-usual home departure time on the one hand and early arrivals on the other, and found that the former was valued 1.5 times higher than the free flow time while the second was a hardly significant fraction (13%) of it. Apparently, early arrivals were primarily felt as a loss of time spent at home. Travel time after the preferred arrival time was valued 2.5 to 3.0 times higher than the free flow time. However, in a Mixed Logit model specification the average of this factor was only 1.4, the same as the ratio between congested and free flow values of travel time. The survey design contained no probabilistic time attributes, thus non-linear probability weighting did not boost these factors. Though the differences between the results from Logit and Mixed Logit model specifications are large the results leave little doubt about the applicability of the loss aversion principle to the earlier than usual home departures, later than desired arrivals and longer than expected travel times. The results also confirm the hypothesis that the relative value of travel time spent after the preferred arrival time is reduced when the other travel time components are also framed as changes relative to a reference state. The authors also show that the different time components are valued differently, dependent on the trip purpose of respondents. For example, early arrivals after the morning rush-hour were valued very negatively for shopping

[90] Note that, contrary to the previous studies, all alternatives were characterized with **certain** outcomes (travel times, schedule delays) and all arrivals of rail passengers were at the preferred arrival time. According to PT and EPT, alternatives with late arrivals will commonly be rejected as they imply certain losses. In the previous studies, alternatives with relatively large probabilistically **expected** late arrivals might have been chosen at the expense of alternatives with smaller, but more certain, lateness.

purposes but not significant for trips to school, while the inverse holds for late arrivals. This underlines the application of different choice behaviour strategies within a population. However, the authors found a higher VTTS for arrivals with more than 30 minutes lateness compared to less late arrivals. This indicates a concave rather than convex value function in the loss domain and violates the EPT premise.

In the previously mentioned Dutch stated choice survey of car driver's valuation of travel time uncertainty (Van Amelsfort and Bliemer 2005), the alternatives were characterized by many mutually coherent attributes. These comprised discrete values for travel cost components, departure time and free flow time, and intervals for travel time, congested travel time and arrival time. Using Multinomial Logit models, the authors tested fifteen different linear utility specifications that included the travel time interval width[91] as a 'certain' outcome. These might be conceived as behaviourally more or less plausible idiosyncratic decision frames. In most models VTTS was valued about the same as early and late arrival time, suggesting that the uncertainty interval caught loss aversion and probability weighting. Some models considered a late home departure time that would result in a certain late arrival. This 'certain loss' was valued four times higher than VTTS.

Tseng *et al*. (2005) analysed the same survey results, also with a Multinomial Logit model. They followed the Expected Utility Theory interpretation of Small's (1982) utility specification as discussed above, using the median of the travel time interval to find expected values for the average travel time and the average early and late arrival relative to the preferred arrival time. A linear model revealed a significant value for arrivals after the preferred arrival time, a 40% higher value for earlier and an 80% higher value for late arrivals compared to mean travel time. The 'step function' for late arrival is indicative of diminishing sensitivity of travel time in the loss domain. Adding a second order term for early schedule delay resulted in a significant contribution with the same (negative) sign as the linear term, while the (positive) coefficient for the second order late schedule delay was insignificant. When the same substitution of mean travel time by average late minus average early arrival time is applied to the results as was done to the Bates *et al*. (2001) data, this finding also confirms the diminishing marginal utility and diminishing sensitivity principles as shared by UT and PT for the gain domain. The ratio of the values of travel time after and before the preferred arrival time increases to 6.5, again far above the 'common' loss aversion factors for travel time, as hypothesized above. Constraints in late work arrival time and early home departure time result in a higher VTTS in the gain domain, as might be expected. Individuals who cannot leave home later than some set departure time also reveal a negative value for travel time savings, which again makes sense from their perspective. The combined findings in Van Amelsfort and Bliemer (2005), Tseng *et al*. (2005) and from the present re-examination suggest that analysis based on EPT-consistent individual-specific choice behaviour strategies might yield a better description of the observed choices. They yield convincing evidence for reference-dependent framing, loss-aversive valuation of attributes, diminishing sensitivity and interpersonal differences in choice behaviour strategies.

The preceding overview of six surveys demonstrates the many ways in which schedule delays in connection with uncertain travel time can be investigated. When linear specifications are used they reveal a drastic kink at the preferred arrival time, which was firmly anchored as 'reference' in most surveys. When this kink is interpreted as a consequence of loss aversion

[91] The authors observed that the uncertainty variable lost significance when it was elicited together with 'average' schedule delays and considered with different combinations of shortest or longest travel time, earliest or latest arrival times etcetera.

without considering probability weighting, it reveals a loss aversion factor at the high side or far above the range that was inferred in the previous subsections. As hypothesized above, this might largely be caused by an overrating of the preferred arrival time compared to other attributes of the reference state, particularly the reference departure time, and by the neglect of probability weighting in connection with loss aversion in the assessment of the value of uncertainty intervals. One might consider that the loss aversion ratios found by De Palma *et al*. (2003), who did not consider probabilistic travel times and gave the whole reference state room in the submitted choice sets and their analyses, were within the 'common' range as found from Multinomial Logit analyses. Where choice observations and analyses enabled inferences to be made about the non-linear weighting of probabilities and interpersonal differences in choice behaviour strategies, the EPT premises were confirmed. However, while some studies showed convincing (Tseng *et al*. 2005; Michea and Polak 2006) or plausible (Small 1982) evidence for diminishing sensitivity in the loss domain, De Palma *et al*. (2003) showed that this EPT premise was violated in their survey.

6.3.5 Tactical choice behaviour to cope with Road Pricing

Road pricing has been introduced or investigated in many places as a means to reduce congestion by changing the travel behaviour of car drivers. The most well-known pricing strategies charge for the passing of cordons that enclose concentrations of trip destinations, payment for access to express lanes that circumvent the congestion on parallel 'free' roadways, and a congestion-dependent fare that differs over the road network and in time. Of course, the alternatives that the traveller might consider to cope with road pricing depend on the applied pricing strategy. This subsection reviews studies of responses to all three strategy types.

Singapore's area license scheme

In 1975, road pricing started in Singapore with the introduction of the Area License Scheme that required payment by car drivers who wanted to pass a cordon around the core of the Central Business District in downtown Singapore. It had a very strong impact on inbound traffic during the restricted period (7:30 to 10:15 a.m.). The introduction was accompanied by a large survey in which the same households completed travel diaries before and after the implementation of the system. This made it possible to analyse the changes in travel behaviour, as documented in a World Bank report (Watson and Holland 1978). The responses concerned different mode shifts, departure time adjustments, route changes, and payment of the license to continue driving in the usual way at the usual time. About a quarter of the private drivers chose the latter alternative. A more thorough re-examination of the responses to the introduction of road pricing in Singapore will be presented in Chapter 7.

Six months after its introduction the license fee was increased by one-third. This caused a significant additional number of drivers to change their usual travel behaviour, whatever reasonable distribution of tastes or VTTS values of the concerned drivers one considers, and whether one presumes the loss-aversive or loss-neutral valuation of travel time. However, from the perspective of EPT one would expect that six months after the initial introduction the remaining drivers would consider the initial fee as part of their 'updated' reference state and would only consider the fare increase as a loss if they continued their usual travel behaviour. Calculations assuming this reference shift and loss aversion showed that virtually no private drivers changed their mode or schedule as a consequence of this 33% increase in fee. Similar calculations, which assumed a loss-neutral valuation, indicated a clear further shift to transit and other alternatives that avoided paying the fee. As all the private drivers for whom this

choice was relevant paid the increased fee, this offers convincing evidence for reference-dependent framing and loss-aversive valuation.

California's Express Lanes

In the 1990s, toll lanes were opened to ease congestion along two Southern Californian highways, one 10-mile facility along the SR-91 in the Los Angeles region and one 8-mile roadway along the I-15 near San Diego. These enabled researchers to make a real-life assessment of the trade-offs that travellers make between travel time (average and dispersion) and monetary costs. A large number of publications discuss several surveys of these choices. Brownstone and Small (2005) offer a brief overview of most of the surveys.

All analyses on travellers' VTTS and reliability in these contexts that are reviewed below are fully consistent with the Random Utility Maximization paradigm. Within this paradigm, binomial, Multinomial Logit and/or Mixed Logit models with many different specifications of the utility function were applied, depending on the observed alternatives and attributes that are considered and on the stochastic treatment of the unobserved alternatives and attributes. The choice from feasible alternatives with their essentially probabilistic outcomes was treated as a choice under certainty. Travellers were assumed to consider the expected travel time as two separate 'certain' time attributes, the median time and a travel time with a cumulative frequency of 80% or 90% that was considered to characterize 'reliability'. From a descriptive-behavioural perspective each Random Utility Maximization model specification that was used can be conceived as a choice behaviour strategy, i.e. a combination of a decision frame (observed alternatives and attributes, and stochastic representation of unobserved ones), valuation principle (here: complete and context-independent preference order, loss-neutral valuation) and evaluation-and-choice rule (compensatory utility maximization). All studies assumed that one model specification could be applied to all survey respondents, thus implicitly attributed interpersonal choice heterogeneity to interpersonal differences in the valuation of the specified attributes plus random unobserved taste differences. Where more than one level of the strategic-operational choice hierarchy was relevant in the same situation, these were lumped together in one model formulation, as allowed by the UT premises of complete and context-independent preference orders. This holds, for example, for the non-recurring acquisition of a transponder that allows entrance to the tolled express lane and the daily recurrent choice between tolled and non-tolled lanes (e.g. Brownstone and Small 2005). After a description and discussion of these studies the findings will be re-examined hereafter from the perspective of EPT.

The core of the published information was based on the outcomes of several revealed preference surveys. These elicited the choices that morning peak-hour travellers made between the tolled 'express lanes' and the, on average congested, toll-free lanes. They were complemented with stated choice surveys and traffic flow observations. For the SR-91 facility these comprise a 1988-revealed preference survey analysed with several Logit models (Lam and Small 2001), a collection of revealed and stated choice surveys taken in 1999 and 2000 and analysed with several Mixed Logit models (Small *et al.* 2005), and an 11-day loop detector registration of actual travel times, performed in 2000 and, after combination with the corresponding toll levels, analysed with a Mixed Logit model (Liu *et al*. 2004). Those on the I-15 comprise a Logit model analysis of a 1998-revealed preference survey (Brownstone *et al.* 2003), and a Logit analysis of revealed preferences combined with the associated tolls and measured travel times (Steimetz and Brownstone 2005).

Small *et al*. (2005) pooled revealed and stated preference data of the SR-91 facility and analysed these with a Mixed Logit model. They found values of about US$22/h for reduction of the congestion-induced median travel times on the non-tolled roadway[92] and US$20/h for reduction of unreliability (defined as the 80% minus 50% cumulative frequency of travel time). These values lie within the ranges that were earlier found by Lam and Small (2001) with several Logit models. Liu *et al*. analysed the observed traffic flows and toll levels with a Mixed Logit model. They found the same US$20/h for reliability but a much smaller VTTS (US$13/h), which on closer inspection may be caused by a 'risk avoidance' variable added into their model. Two revealed preference surveys of I-15 travellers yielded about US$30/h for reduction of the congestion-induced median travel times and established no value of reliability (Brownstone *et al.* 2003; Steimetz and Brownstone 2005). However, from the distribution of travel times and the toll rates as presented in Brownstone *et al.* (2003) a VTTS of about US$20/h to US$25/h range would provide a better match. A remarkable finding is the low VTTS found from stated preference surveys, US$13/h for the SR-91 and US$13/h to US$16/h cited by Brownstone and Small (2005: 284) from a thesis describing the I-15 survey.

All studies observed very high interpersonal heterogeneity in the values of time and reliability. The sensitivity of model outcomes to different utility specifications as presented by Lam and Small (2001) indicates that this may be caused by interpersonal differences in choice behaviour strategies, at least to some extent. Small *et al*. (2005: 1378) suggest that the difference between their stated and revealed preference results may reflect '*a tendency of travellers to overstate the travel time they experience during congestion*'. However, the descriptions of the experimental design of the stated choice survey and the way in which intrapersonal consistency in the answers is analysed (Hensher 2001a; Van de Kaa 2006) does not rule out other explanations, like underestimation of loss aversion due to a less clear 'anchoring' of the choice context in real-life experiences. Most reviewed articles conclude that travellers value a reduction in travel time variability highly, according to Liu *et al*. (2003) even more highly than the same reduction in travel time saving itself. From the perspective of Expected Utility Theory one might note that, for a particular moment of the day, the probability distribution of travel time would yield the same utility as the average time found from the distribution. The relatively bad fit of models containing the 'average travel time' compared to those that use the 'median travel time' and the significance of the '80% minus 50% cumulative frequency' variable suggests that the observed choices may be explained by the use of non-linear probability decision weights by the travellers.

Studies from both facilities found that most travellers took either the tolled road or the 'free lanes' day after day, while a few made different choices on different days. From the perspective of EPT, the observed behaviour may be conceived as a consequence of two different choice processes. One is a tactical choice process that results, amongst other things, in the acquisition or disposal of a transponder that allows the use of the tolled lanes. The other is the daily recurrent, operational 'en-route' choice to take either the tolled or the free lanes. For both choice categories the possession of a transponder implies a major distinction in the reference state between two groups of travellers. A small majority of the travellers in both the SR-91 and I-15 corridors had one. The transponder owners could be divided into travellers who commonly take the express lanes and an almost equally sized subgroup who frequently switch from one roadway to the other.

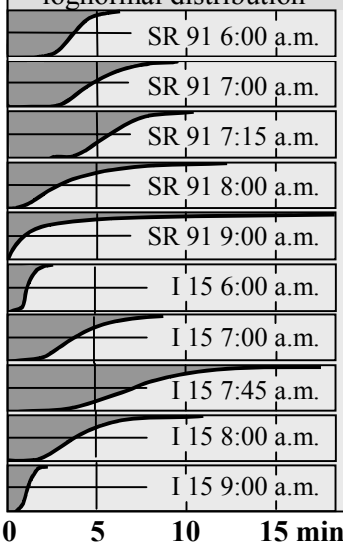
[92] See also table A.II in Small *et al*. (2005), Supplement to "Uncovering the distribution of motorists' preferences for travel time and reliability", *Econometrica Supplementary Material*.

Travellers without a transponder are captives of the toll-free roadway. Daily they experience the extent and variation in delays relative to their fellow travellers on the express roadway, who can always go faster but have to pay the toll. As they are accustomed to these relative delays and 'money savings' these could be considered as part of their reference state. The expressway alternative offers them a certain 'loss' in dollar expenses and a 'probability density function' of travel time gains[93]. This latter distribution might be approached by fitting a lognormal function through the median and 80% (SR-91) or 90% (I-15) cumulative frequencies for different times of the morning, as were published in Brownstone *et al.* (2003), Liu *et al.* (2003) and Small *et al.* (2005). Applying a weight factor to the probabilities in agreement with cumulative PT (Tversky and Kahneman 1992) and assuming a linear value function allows the assessment of an equivalent travel time gain of toll lane use. Some probability density functions and corresponding equivalent travel times are assembled in Figure 11. In addition to that, the far righthand column of Figure 11 shows the VTTS levels below which drivers who trade-off their expected travel time and cost according to Expected Utlity Theory would take the free lanes under the considered circumstances, and above which they would take the tolled lanes. The third column from the right indicates that drivers who choose according to PT would take the free lanes if their VTTS is below the indicated level, even if they commonly take the tolled lanes. The second column from the right lists the range of VTTS values above which all drivers would choose the tolled lanes under the corresponding circumstances.

A comparison of the values of these time gains with the corresponding money losses incurred by the toll rates yields the threshold VTTS for transponder acquisition. The money losses might be estimated by applying a common loss aversion factor $\lambda = 2.0$. For those travellers that commonly pass these corridors at the peak of congestion this yields threshold VTTS values of about US$65/h (SR-91) and US$50/h (I-15). One should note that these 'rough-and-ready' calculations cover the value that travellers attribute to travel time *and* its dispersion. The results are, obviously, sensitive to the actual perceived distribution, idiosyncratic loss aversion factors etcetera. However, the height of the inferred VTTS might be prohibitive for most of these 'free roadway captives' to consider the nuisance of acquiring a transponder. For drivers that pass the SR-91 during the shoulders of the peak hour the threshold is even higher, reflected by the much lower share of express lane traffic during those periods, as reported by Liu *et al.* (2003).

[93] Directly after the express lanes were opened many travellers on the free lanes might have experienced the recurrently overtaking by express-lane users as a loss, which would reduce the threshold to acquire a transponder considerably. However, hedonic adaptation will presumably have neutralized such feelings for those who did not acquire a transponder before the time of the reviewed surveys.

Travel time difference of free versus tolled lanes (minutes)				Toll	Threshold to switch from reference to:		
Cumulative frequency for lognormal distribution	Median	Mean (EUT)	Weighted (PT)	US$	Free lanes (time loss)	Tolled lanes (money loss)	Either (loss neutral)
SR 91 6:00 a.m.	3.7	3.8	3.8	2.9	< 23 US$/h	> 91 US$/h	46 US$/h
SR 91 7:00 a.m.	4.7	5.0	5.1	3.0	< 18 US$/h	> 71 US$/h	36 US$/h
SR 91 7:15 a.m.	5.7	5.9	6.0	3.3	< 16 US$/h	> 65 US$/h	33 US$/h
SR 91 8:00 a.m.	2.9	3.8	4.4	2.9	< 20 US$/h	> 79 US$/h	45 US$/h
SR 91 9:00 a.m.	1.0	2.7	4.2	2.0	< 14 US$/h	> 55 US$/h	43 US$/h
I 15 6:00 a.m.	1.1	1.2	1.2	0.5	< 12 US$/h	> 50 US$/h	25 US$/h
I 15 7:00 a.m.	3.8	4.2	4.4	1.0	< 7 US$/h	> 27 US$/h	14 US$/h
I 15 7:45 a.m.	7.2	7.9	8.3	3.5	< 13 US$/h	> 51 US$/h	27 US$/h
I 15 8:00 a.m.	6.4	7.0	7.2	2.0	< 8 US$/h	> 33 US$/h	17 US$/h
I 15 9:00 a.m.	2.7	3.0	3.1	0.8	< 8 US$/h	> 31 US$/h	16 US$/h



Elaborated from data found in
Tversky and Kahneman (prob. weights), Brownstone *et al*. 2003 (I 15),
Mastako 2003, Liu *et al*. 2004 and Small *et al*. 2005 (SR 51)

Figure 11: Travel time differences and VTTS thresholds on the SR 91 and I 15 motorways in California

Travellers that are already endowed with a transponder and commonly take the tolled lanes experience every day the absence of the delays that their fellow travellers encounter on the free lanes. Assuming that they are accustomed to these 'money losses' and relative time savings, e.g. by having 'cashed' a five minutes later home departure, these relative costs and savings will no longer be considered as gains and losses but as part of their reference state. The 'free lanes alternative' offers them a 'probability density function' of travel time losses combined with a certain 'gain' in dollar expenses. Similar calculations as for the free roadway captives yields threshold VTTS in the US$10/h to US$20/h range, below which an 'average' commuter might make a tactical choice to discontinue her transponder endowment and become a free roadway captive[94].

If a transponder owner has no reliable information about actual deviations of her conceived long-term delay distribution her best rational tactic is to stick to the roadway that offers her on average the highest idiosyncratic value-for-money. It is not hard to prove that this tactic is superior to myopic updating of her choice depending on experiences that are irrelevant for the expected actual travel time. Psychological experiments, however, demonstrate that many individuals are so eager to beat chance that in the absence of relevant information they rely on completely irrelevant cues (e.g. Schul and Mayo 2003). The reported use of the posted toll fares at the I-15 as indicators for the congestion level at the free roadway demonstrates that some individuals may indeed use this 'circumstantial' traffic information in their operational choice behaviour. Those transponder owners who would be able to use this or other actual travel information to switch more or less frequently from the tolled to the non-tolled roadway

[94] For obvious reasons, the participants in the re-examined SR-91 and I-15 stated choice games were implicitly or explicitly asked to assume that they owned a transponder. The thus induced 'reference shift' of free roadway captives to transponder owners might be another explanation for the lower VTTS found from these stated choice surveys compared to the revealed preference results.

whenever the delay there is low, would have an even lower threshold VTTS for tactical transponder disposal choice than the US$10/h to US$20/h range. For those travellers that are not very successful in this optimisation endeavour the threshold might be higher, as their reference state would include some degree of travel time delay.

The daily recurrent, operational roadway choice process is only relevant for the transponder owners. The actual compared to the usual (reference) arrival time at the entrance to the express lanes might be a decisive attribute for them. Early arrivals, due to earlier than usual home departure and/or easier than normal traffic conditions might boost the propensity to choose the free lanes while late arrivals would support the reverse choice, maybe at very high costs to avoid the imminent 'loss' of late arrival. An individual might also utilize her knowledge of day-of-the-week correlated traffic density and time-of-day dependent variations in delays to optimise her expected arrival time by choosing the 'best' departure time and route. Such contingencies might explain the high, 60% share of SR 91 travellers who reported that they '*leave early or late to avoid peak period congestion*' as answer to the question '*in your usual peak period travel, please tell me if you use any of the following strategies to avoid traffic congestion*' as found by Mastako (2003: 118). From the perspective of EPT it is obvious that these responses are indicative of choice behaviour on the tactical rather than operational level. Mastako found also that about 8% more respondents made at least one recent trip outside the peak period or reported that they changed their departure time compared to two years before. Part of these 8% may also be attributed to a tactical choice, another part to day-to-day operational choices, for example in connection with changes in the importance of late arrival. Also the carpool choices discussed by Mastako may be attributed predominantly to the tactical level of the strategic-operational choice hierarchy. Mastako did not distinguish between tactical and operational choices. She found that most of her respondents considered mixed 'consideration' choice sets of route, departure time and/or mode (including carpooling arrangements) and found that models that accounted for this offered a better match for the observed choices than models starting from the 'complete' choice set. This can be considered as a violation of the context-indifferent preference order according to the UT-paradigm. Her concept of a mixture of heterogeneous alternatives is in agreement with EPT, but a distinction between the tactical and operational choices as discussed above might be a better way to clarify the predominantly 'habitual' day-to-day travel behaviour. There was no further information found, either in Mastako's revealed preference survey or in the other reviewed surveys, for the understanding of the 'operational' roadway choices of travellers.

Overall, the the express lane studies as presented in the reviewed articles reveal a large extent of non-linear probability weighting. Reference-dependent framing and, in some studies, interpersonally different choice behaviour strategies are also obvious. The re-examination from the perspective of EPT underlines these observations.

Copenhagen's km-based rush-hour charging experiment

The nowadays available technology for tracking and tracing enables observation of the responses of travellers to a permanent change in their travel conditions in a real-life situation. Nielsen (2004) observed the travel patterns of 500 cars in the Copenhagen region, for an eight to twelve days 'normal' period followed by an equally long 'trial' period in which a road-pricing scheme was simulated. In the trial period participants had in-vehicle information about the actual road pricing. One group was promised the money they would have had to pay during the 'normal' period, if the road-pricing scheme had been in operation, minus the amount they would have had to pay in the 'trial' period. On average, this group 'earned' 15% of their potential toll expenses. Another group received the money they would have had to

pay during the 'normal' period before the 'trial' period started, under the provision that they had to pay back their 'actual' tolls in the trial period. This group 'saved' 30% of their potential toll expenses. While in the first group only 24 to 50% of the participants earned any money[95], 75% of the second group saved some. This is a nice real-life example of the 'instant endowment' effect, as demonstrated in a host of laboratory settings in cognitive psychology and related disciplines (see Section 4.3). The reference state of most of the participants in the second group apparently shifted as soon as they received their money, and their endeavour to avoid the toll was driven by loss aversion[96], whereas the first group was motivated by potential gains. These findings underline the supposition that the adopted reference state should be updated after each relevant choice decision, as is actually formulated in the definition of EPT's 'reference-dependent framing and loss aversion' assumption in Table 3 (page 99).

6.3.6 Summary of findings from tactical travel choice behaviour

The findings from a re-examination of 44 studies aiming to elicit tactical travel choice behaviour are summarized in Table 6. Except for one possible violation of the diminishing sensitivity principle none of the reviewed studies contained information demonstrating that one or more of the assumptions of EPT should be rejected because the corresponding UT assumption explained the observed choices better.

Reference-dependent framing and loss-aversive valuation were presupposed in publications that analysed thirteen studies. Two of these supplied no empirical information that allowed for an assessment of its descriptive ability compared to UT. In one other reference the authors investigated the loss aversion assumption explicitly in comparison with the corresponding UT assumption. They found that UT could explain the observed valuation sufficiently but observed that as all attributes were almost completely in the gain domain this finding does not demonstrate the invalidity of PT. Re-examination convincingly showed that in 35 of the 41 remaining studies most respondents framed their alternatives as gains and losses relative to some reference state and valued attributes loss aversely, and in doing so violated the UT assumptions of context-independent preferences and state-dependent, loss-neutral valuation. Another thirteen studies suggested the same pattern. Three re-examinations revealed no information that indicated rejection or support for these assumptions.

Many studies offered indications about the degree of loss aversion in tactical choice situations. At least two studies supported the notion that the reference against which the losses and gains are assessed is updated almost immediately after a change in the subject's choice context. A few articles suggested that car drivers might value their running costs loss neutrally, although they may attribute very high loss aversion factors to tolls. According to most of the studies re-examined the loss aversion factors for 'certain' changes in travel time, route quality and travel expenses vary in the 1.4 to 2.8 ranges. This endorses the usefulness of travel behaviour modelling of the 'average' factor 2.0 as found in behavioural sciences (Chapter 4), if more tailored information is lacking.

[95] The first group tested several road-pricing schemes, the second group only one. 50% holds for the average of all price schemes tested in the first group, 24% for the sub-sample of this group that tested the same scheme as the second group, as far as they did not misinterpret the experimental task.

[96] Loss aversion might also explain the 60% higher value of congestion time (defined by Nielsen as the extra expected travel time caused by congestion) compared to the free flow time, as observed in both the real-life behaviour and in a pre-experiment stated preference survey with the same participants.

When the preferred arrival time is conceived as part of the reference state and changes in travel time experienced as increasing lateness of arrival after the preferred arrival time are considered as travel time losses, while changes that might increase earliness are considered as gains, loss aversion factors in the range 2.5 to 9.0 are found. The highest values were found from studies where the value of travel time uncertainty was considered. Non-linear probability weights might have been responsible for a significant share of this factor. Even then several loss aversion factors were far beyond those found for studies in which travel time and/or its variance were valued as such. One might consider that the characteristics of, for example, the morning commute are not the only relevant attributes for the trade-off of different arrival times, given the distribution of expected travel times. A more appropriate choice frame might consider the consequences of late arrival on the employment contract and the co-operation with the colleagues against the consequences of early home departure. For most travellers this might rank higher on the strategic-operational choice hierarchy than the tactical travel choice. It might yield an idiosyncratic threshold for the frequency of late arrival that, once violated due to changes in the traffic conditions, results in adjustment of the actual tactical trip planning. Though the behavioural explanations for such behaviour are quite different it is descriptively synonymous to the 'indifference band' concept of Mahmassani (1990).

The diminishing sensitivity principle could be considered from a re-examination of nine studies. It was explicitly mentioned in three references and convincingly corroborated by two of them. The third reference offered no conclusive information about rejection or acceptance. Re-examination of six more studies yielded two convincing and two plausible confirmations of the principle, one non-conclusive result and one study offered good grounds to reject it. Taking into account that no personalized choice contexts and corresponding choices were considered, the overall picture is that diminishing sensitivity has only a weak influence on tactical travel choice behaviour and may only play a prominent role when the attribute levels are large, whilst in by far the most contexts a kinked-linear approximation of the value function will suffice for a useful description.

Eight studies offered convincing and another ten studies plausible evidence that subjects applied non-linear weighting of probabilities. These studies showed that the expected UT principle had to be rejected. Another study supposed behaviour according to PT but supplied no information that allowed a comparison with UT. All of the other studies re-examined did not consider that individuals might value the outcomes of alternatives in a probabilistic way at all.

Two studies supported the notion that an individual might value alternatives as a mixture of affective and instrumental attributes convincingly. Plausible indications for the appropriateness of this assumption in tactical choice contexts were found in three more surveys. In three of these five studies the value of fatal accidents was at stake. Affective valuation seems less significant in most tactical choice constructs. However, except for fatal accident levels, the attributes submitted to the subjects in the reviewed studies were time and money components that might be easily commensurable for most individuals.

All the studies that enabled inferences about the co-occurrence of different choice behaviour strategies within the survey populations supported this. It was convincingly demonstrated in fifteen studies and appeared plausible from the observed behaviour in eight more surveys. No evidence to the contrary was encountered. The Strong Lexicographic rule was most frequently encountered, but this might also be conceived as a particular case of the Weighted-additive rule (Chapter 4). On the other hand, the choice sets submitted in these experiments and

Table 6A: Evidence for the descriptive ability of EPT assumptions in tactical travel choice

Tactical travel choice behaviour domain	Evidence[1] supporting the descriptive ability of EPT assumption:				
Main reference to research description (in order of survey year)	Reference-dependent framing&loss aversion	Diminishing sensitivity	Non-linear weighted probabilities	Mixed affective-utilitarian valuation	Heterog. in choice behaviour strategies
Tactical trip planning					
Foerster 1979	PD	-	-	-	CD
Timmermans 1983	-	-	-	-	ES, PD
Bovy & Den Adel 1985	CD	-	-	-	-
Mahmassani 1990	CD	-	PD	-	PD
Cherchi and Ortúzar 2002	PD	-	-	-	PD
De Palma and Picard 2005	ES, CD	-	PD	-	ES, CD
Washbrook *et al*. 2006	PD	PD	-	-	-
Arentze and Timmermans 2005	ES, NS	-	-	-	-
Lo and Li 2006	PD	-	-	PD	-
Bogers and Van Zuylen 2004	PD	-	PD	-	-
Sumalee *et al.* 2005	ES, NS	-	ES, NS	-	-
Traffic safety-time-cost trade-offs					
Jones-Lee *et al.* 1995	ES, PD	-	PD	ES, CD	-
Rizzi and Ortúzar 2003	ES, NS	-	-	CD	ES, CD
De Blaeij and VanVuuren 2003	ES, PD	-	ES, CD	PD	-
Iragüen and Ortúzar 2004	-	-	-	-	PD
Rouwendal and De Blaeij 2004	-	-	-	-	ES, CD
Travel time-cost trade-offs					
Gunn 2001, Van de Kaa 2006	ES, CD	-	-	-	ES, CD
Senna 1994	PD	-	PD	-	-
Tapley *et al.* 2006	ES, CD	ES, NS	-	-	-
Gunn 2001, Mackie *et al*. 2001a	ES, CD	-	-	-	-
Hultkrantz and Mortazavi 2001	ES, CD	NS	-	-	PD
Sælensminde 2001, 2002	PD	-	-	-	ES, CD
Rietveld *et al*. 2001	PD	-	PD	-	-
Van de Kaa 2006	ES, CD	-	-	-	ES, CD
Hensher 2001b	PD	-	PD	-	-
Richardson 2003	PD	-	-	-	PD
Eliasson 2004	CD	-	PD	-	-
Caussade *et al*. 2005	CD	-	-	PD	PD
Van Amelsfort and Bliemer 2005	CD	CD	CD	-	CD
Hess *et al.* 2006	ES, CD	-	-	-	-
De Borger and Fosgerau 2006	ES, CD	ES, CD	-	-	-

Table 6B: Evidence for the descriptive ability of EPT assumptions in tactical travel choice - continued

Tactical travel choice behaviour domain	Evidence[1] supporting the descriptive ability of EPT assumption:				
Main reference to research description (in order of survey year)	Reference-dependent framing and loss aversion	Diminishing sensitivity	Non-linear weighted probabilities	Mixed affective-utilitarian valuation	Heterog. in choice behaviour strategies
Schedule delay-cost trade-offs					
Small 1982	CD	PD	-	-	PD
Hendrickson and Plank 1984	CD	CD	PD	-	CD
Michea and Polak 2006	CD	ES, CD	ES, CD	-	-
De Palma *et al*. 2003	CD	CR	-	-	CD
Hollander 2006	CD	-	PD	-	CD
Bajwa *et al.* 2006	PD	-	-	-	-
Road-pricing response planning					
Watson and Holland 1978	CD	-	-	-	-
Brownstone *et al.* 2003	CD	-	CD	-	CD
Lam and Small 2001	CD	-	CD	-	CD
Steimetz and Brownstone 2005	CD	-	CD	-	CD
Liu *et al.* 2004	CD	-	CD	-	-
Small *et al.* 2005	CD	-	CD	-	CD
Nielsen 2004	CD	-	-	-	-

[1] -: no information that confirmed or rejected the assumptions; CR: Clearly rejected; ES: Explicit statement in reference; CD: Convincingly demonstrated; PD: Presumably demonstrable; NS: Neither supported nor rejected. See Section 'Search and selection of appropriate travel behaviour studies' for a more extensive explanation.

surveys contained few alternatives and attributes. The two-stage conjunctive-weighted additive rule might thus be more widespread than would be expected based on these studies.

Overall these findings from studies that elicit tactical choice constructs show that the assumptions of UT are too restrictive. They corroborate the better descriptive ability and importance of three corresponding, less restrictive EPT assumptions in several tactical travel choice contexts. However, the relevance of the diminishing sensitivity principle might be disputed, as a kinked-linear approximation of the value function might most often suffice. In several circumstances the co-occurrence of affective and utilitarian valuation might be less prominent than in strategic decision making.

6.4 Operational travel choice behaviour

Operational travel choice behaviour, as dealt with in this section, is conceived as a mental process that is directly followed by concrete actions. Recurrent operational travel choices like the daily trip planning are usually strongly influenced by the scripts or habits that are the outcomes of tactical choices. They may imply that each day the same 'habitual' travel mode, trip schedule and route are chosen as found from a preceding tactical choice, except if the

choice context makes a difference. Such sequences of 'habitual' operational choice behaviour will generally last from the end of a tactical choice period (see previous section) until an instantaneous structural change occurs in one of the choice attributes or the implementation of the next strategic decision in a field affects the behaviour and introduces a new tactical choice period. Some examples of operational choices are the daily recurrent departure time assessments and decisions of car drivers en-route like lane switching. These operational choice processes may last from split seconds to minutes.

This section re-examines the adherence of travellers to the five assumptions of EPT compared to those of UT, as observed in 22 different operational choice contexts. These covered daily recurrent travel mode, departure time and pre-trip route choice situations, as well as the choice behaviour of car drivers en-route. It concludes with a discussion and summary of findings about the descriptive performance of the considered assumptions of UT and EPT in operational travel choice domains.

6.4.1 Operational trip planning

Before a traveller sets out on a trip she always has to decide on which vehicle and/or travel mode to take, what time to leave, and, most often, also which route to follow. In many circumstances the question will be whether the circumstances allow adherance to a previously chosen tactical plan or if they differ from the usual state of the world to such an extent that they necessitate some adjustment or another plan. However, many other pre-trip choices are incidental rather than recurrent. This subsection describes studies in which several different pre-trip choices were investigated.

Pre-trip vehicle choice behaviour

Hiring a car can be considered as an isolated rather than a recurrent operational decision. In a stated choice survey Swait (2001) asked USA citizens to choose a rental agency and vehicle category for personal use from four choice sets, with alternatives characterized by, for example, car brand, price and insurance attributes. In addition to the choice tasks the respondents were asked about their cut-offs, for example whether or not they would hire a car from a particular company or above a particular price. He compared the descriptive performance of a conventional Multinomial Logit model and a Mixed Logit model, both without attribute cut-offs, and a Mixed Logit model with cut-offs. The Mixed Logit model with cut-offs outperformed the models without cut-offs, of which the Mixed Logit model in turn outperformed the Multinomial Logit model. This yields clear evidence for the occurrence and importance of interpersonal differences in choice behaviour strategies.

Pre-trip travel mode choice behaviour

Gärling *et al.* (2000) carried out a postal survey followed by an interactive interview among households in Göteborg, Sweden, about their car use reduction propensity. The responses of 770 households revealed that, out of 23 suggested changes in work, shopping and leisure related travel behaviour, only shopping trip chaining and choosing closer stores were considered likely by most of the 770 households. For commuting, switching to public transport was another likely measure. All other suggested measures for all trip purposes were on average considered unlikely. Gärling *et al.* referred to PT in considering that minimizing disutility differs from maximizing utility. They considered that preferences, perceived costs, constraints and inertia could have determined these findings. As inertia effects might well be explained by loss aversion (e.g. Van de Kaa 2005) the perceived costs, constraints and preferences that apparently explained the limited inclination to reduce car use might also be a

consequence of loss-aversive valuation. In a follow-up interactive home interview 113 car-owning households were first asked to fill in a diary of their expected travel over eight days and next to repeat this while attempting to reduce car use as much as possible. It appeared that the respondents believed that only a small percentage (about 10 to 15%, depending on trip purpose) of the car trips could be suppressed and that very few could be changed. The households promised to try to keep to the second diary. In the week after the interview they kept a diary for the car trips they actually made. Many reported actual car trips differed from those in the 'intended' second diary and only about half of the intended suppressions occurred. A surprising 30% of all car trips were not expected beforehand. There is no apparent reason to assume that the number of unexpected 'impulsive' car trips reported by the households in the second experiment is an exception to their common travel behaviour. The failure to suppress these additional trips and about half of the intended reductions might be explained, at least partly, by loss aversion. In view of the findings of Steg *et al.* (2001), other affective factors may also have played an important role in the apparent inability to change car-use behaviour. These observations corroborate the conclusions of Gärling *et al.* (2000) that, in addition to cost measures, a shift towards a pro-social attitude of car drivers is a necessary condition for reducing car use.

A simple Swedish mode-choice experiment is described in Gärling (2004). Subjects were told that the same product was for sale at two stores, one close to their presumed location, the other far away. At one shop the product was much cheaper than at the other. Participants could acquire the product at one store or the other, and go there on foot or by car. Obviously, many subjects walked to the shop nearby if it offered the product cheaply and drove to the shop further away if the price there was lower. However, depending on whether subjects had a positive or negative attitude to driving, many of them drove to the nearby shop or walked to the remote one. This signifies the co-occurrence of affective and utilitarian valued attributes in the choice set. Surprisingly few respondents bought the expensive product. Following Gärling, this might be caused by a hierarchical-sequential choice behaviour strategy, starting with the goal attainment decision (buy the cheap or expensive product) followed by the choice between means (travel mode). Depending on the submitted attribute levels it might also be a consequence of myopic framing and/or loss-aversive valuation. However, the reviewed information allows no inferences about these choice phenomena.

Daily departure time choice behaviour

Mahmassani and Jou (2000) compared the day-to-day departure time and route changes from the real-life travel diaries of commuters from Austin and Dallas over ten days with those observed during the first ten days of Mahmassani's (1990) third experiment as described in the previous section. The departure time and route choices found in the field were similar to the experimental results and a model based on the same explanatory variables could be used for the description. However, the real-life arrival time indifference bandwidths, as inferred by the model, were only one-third of those in the experiments, indicating a much higher propensity to change departure time. As the field survey apparently did not ask for an explanation of the day-to-day changes, many observed violations of indifference bands followed by a change in departure time might be due to hidden attributes like 'the morning after the night before', an early morning staff meeting, bad weather forecasted or the expected free flow of traffic like in the Dutch Friday-morning rush-hour. Such attributes and expectations might explain the observed differences between real-life indifference bandwidths and those found from experiments in a stable context. EPT might be more able to accommodate such differences as context-dependent operational adjustments of a script followed to implement a tactical choice. Anyway, following the re-examination of

Mahmassani (1990) in the previous section, the overall similarity of experimental and real-life departure-time choices supports the observations on the descriptive ability of the assumptions of EPT compared to UT.

In the late 1990s, several experiments were carried out on an improved version of the traffic simulator described in Mahmassani (1990). Commuters could choose a route within a corridor of three highways with several crossover links, and were provided with several regimes of pre-trip and en-route travel time information. An overview of design and findings was presented by Mahmassani and Srinivasan (2004). They tested several choice strategies to explain the observed day-to-day departure time choices. A first finding was that these are better described as adjustments (changes) relative to the previous departure time than as 'reference-independent' choices of the best departure time. Next, they found that models that started with the decision 'to switch departure time or not to switch' and successively assessed the extent (if any) of the adjustment outperformed a model in conformity with UT. Individuals appeared more inclined to adjust their departure time after late arrivals[97] compared to early arrivals. From the perspective of EPT these results are obvious demonstrations of reference-dependent framing, the loss-aversive valuation and operational adjustments of tactical choices as a consequence of differences from the 'usual' context (travel conditions or activities at origin or destination). This may also explain why respondents made smaller adjustments than might be expected in view of the experienced or expected schedule delays. Within the paradigm of choice under certainty, the authors' models based on the indifference bands concept combined with a sequential evaluation process drawing on satisficing rules might yield the best description of this observed behaviour. If their experimental subjects, who were experienced drivers, considered the choice context as one under uncertainty they might just as well have conceived the travel time information in a probabilistic rather than deterministic manner. The available information did not allow inferences to be made about the weights that the subjects might then have attributed to those probabilities.

In 1998 Singapore's Area License Scheme was replaced by a fully automated Electronic Road Pricing system that allowed the toll fare to be varied over fifteen-minute periods of the day (Menon 2000). The recurrent transactions of travellers passing particular Electronic Road Pricing gantries were used by Olszewski and Xie (2005; 2006) to test several discrete departure time choice models against the observed responses to fare adjustments. They followed Small's (1982) interpretation of arrival time at the workplace and thus disregarded the consequences of departure time for the activities at the origin side of the trip. In agreement with utility maximization principles this enables the arrival time at the trip destination to be replaced by that at the Electronic Road Pricing gantry. Instead of a stepwise penalty function for arrivals after the preferred arrival time they specified a positively valued constant for arrival at the preferred arrival time or, more precisely, within an indifference band around it. Their second article in particular, which analyses recurrent gantry passages by the same individuals, offers an interesting link between individual departure time choice and traffic flow prediction. All the models revealed a strong preference for travellers to keep to their preferred arrival time and an overall larger reluctance to postpone arrival times than to advance them. These findings offer weak indications for reference-dependent framing and loss-aversive valuation.

[97] Note that before the simulations the participants were informed that they had a fixed work start time in which lateness is not permitted (Mahmassani and Srinivasan 2004: 106).

Explicitly starting from the framing principle of PT, Fujii and Kitamura (2004: 247, their emphasis) hypothesized '*that a commuting driver frames a departure time choice problem in terms of the dichotomy of being* ***on time*** *and* ***being late***'. They assumed that travellers conceive deterministic rather than probabilistic outcomes of alternatives and founded this on the posit that an individual cannot deal with probability distributions[98] but conceives uncertainty as an interval. They asked commuters who used a particular highway about the time they had to arrive at work (say TAW), their usual home departure time and the least (T_{min}) and highest time (T_{max}) that it took them to drive from home to office. Assuming a fixed arrival time at the office, the authors hypothesized that two departure times might act as references, TAW minus the least and minus the highest reported travel time. They observed that 15% of the respondents indeed left home at the 'early reference' (TAW – T_{max}) and 7% at the late one (TAW – T_{min}), and considered this as support for their hypothesis. Assuming that individuals conceived travel time uncertainty as a 'certain' interval width one would expect that most participants would leave at the early reference and the remaining at least before the late reference. However, about 54% of the respondents left before (TAW – T_{max}) and 8% after (TAW – T_{min}), both of which seem irrational when they considered the interval as 'certain'. This behaviour makes more sense if the travellers had framed the (T_{max} – T_{min}) interval as a confidence interval of a probability distribution, with interpersonal differences in the cumulative frequencies attributed to T_{max} and T_{min}. In addition to the convincing demonstration of reference-dependent framing the article demonstrates interesting differences in the departure time versus arrival time planning, depending on differences in the individual's contexts like flexible work start time or age-related attitudes towards arriving on time or late.

Jou and Kitamura (2002) examined the applicability of several elements of PT to the commuters' choice of daily departure time. They defined a decision frame consisting of a preferred arrival time flanked by two reference points: the earliest acceptable arrival time and the official work start time. When the actual arrival time is in between these reference points the chosen departure time is considered as a gain, beyond this range it is valued, also more highly, as a loss. The value function of arrival time increases with travel time on the 'early-side' of the preferred arrival time and decreases at a stronger rate on the 'late-side'. Thus they assumed a four-segmented value function, kinked at both reference points and at the preferred arrival time. Commuters are supposed to switch their morning departure to work only if the considered new departure time yields a gain. The authors used recent (2002) commuting car drivers' trip diaries from Japan and Taiwan as an input for the model they developed. The paper contains no data that allows a comparison of simulated and observed choices.

Senbil and Kitamura (2004) considered the frame of Jou and Kitamura (2002) and developed another decision frame in which the preferred arrival time is defined as a pseudo-reference point in the gain domain, flanked by two genuine reference points, the earliest acceptable arrival time and work start time defined above, separating the gain domain from very early arrivals on one side and very late arrivals on the other. Arrivals after work start time are considered unacceptable and are not incorporated in the decision frame. Arrivals between the preferred arrival time and work start time are considered as gains. All arrivals before the preferred arrival time are considered as losses with respect to the preferred arrival time. The rationale is that these 'quasi-gains' could be considered as a loss of time spent at home due to an unnecessary early departure time. For both decision frames Senbil and Kitamura (2004)

[98] Except for the survey described in their article they presented no clear empirical support for this posit, that rejects the premises of Expected Utility Theory as well as PT in its probabilistic guises.

substituted the value functions for 'certain' gains and losses according to PT, including the diminishing sensitivity principle, for the deterministic utility terms in probit-type Random Utility Maximization models. They estimated their models using a database containing all the required information (actual home departure times, etcetera) of 210 Japanese commuters on three consecutive days. This yielded indications for the applicability of PT in both frames, and in particular the second one. This is quite promising in view of the presupposed highly myopic framing of day-to-day changing departure times dependent on a one-day experience, the mono-attribute (only arrival time) valuation, and the disregarding of stochastic variations.

The studies of Jou and Kitamura (2002) and Senbil and Kitamura (2004) were meant as initial attempts to apply PT to commuter departure time choice behaviour. They indicate that the assumptions of PT (and EPT) might be well suited to improving the understanding of the departure time decisions of travellers. A further step might be to test interpersonal differences, multi-attribute decision frames with a 'common' departure time as reference state and some earlier and later departure times as alternatives.

Pre-trip route choice behaviour

Avineri and Prashker (2004) repeated some of the choice experiments of Kahneman and Tversky (1979) in a route choice context. By submitting four choice sets of two route alternatives, characterized by different probability-travel time combinations, to experimental subjects, these experiments explicitly tested the existence of loss aversion and non-linear weighted probabilities. The 71 experimental subjects were familiar with Expected Utility Theory and the instructions explicitly allowed them to use calculation aids. The authors observed that between 60 and 70% of the choices complied with the assumptions of PT and violated transitivity. One might observe that the remaining 30 to 40% of the respondents thus complied with UT. Thus this experiment supports the assumptions of loss aversion, weighted probabilities and within-context interpersonal differences in choice behaviour strategies. The authors state a caveat with respect to the unconditional application of PT to route choice behaviour research: contrary to the submitted once-only choice sets, travellers may update their travel time expectations dynamically, depending on previous experiences following their recurrent daily route choices.

In another experiment, Avineri and Prashker (2005) largely replicated the feedback-based experiments of Barron and Erev (2003) in a route choice setting, to study the effect of travel time reliability on route choice behaviour. Experienced Israeli car drivers were asked to choose between two routes for their simulated daily work-to-home trip: Route A (mean travel time 33 minutes) and B (30 minutes). The actual travel times submitted to the respondents were drawn from a probability distribution. In scenario 1 the variance in travel times for route A (standard deviation one minute) was very small compared to B (7.5 minutes). In scenario 2 the variance in travel time on route B remained the same but the range of travel times on route A was increased, though it remained well below that for B. In scenario 3 the travel times variance on route A was equal to that in scenario 1, but the range of travel times on B was increased compared to the previous scenarios. After equal distribution of the 70 experimental subjects over these three scenarios, each of them had to make the same route choice a hundred times. At the end of each individual trip they were informed of its duration.

In all the scenarios a significant part of the subjects chose the, on average, more time-consuming, route A and thus violated UT. In scenario 1, on average 36% of the choices were for the 'certain' but also, on average, more time-consuming Route A. In scenario 2, which had a larger dispersion of the trip duration on route A compared to scenario 1 though it was much

smaller than the dispersion on route B, this was approximately 41%. In scenario 3, which only differed from scenario 1 in an increased dispersion of travel time on route B, route A was preferred in 55% of all choices. The propensity to choose route A declined in all scenarios as the choice sequences progressed, particularly in scenario 1: from 45 to 30%; in the other scenarios it remained almost unchanged.

Avineri and Prashker (2005) compared the observed choices with several predictions of Multinomial Logit models. In one model the Subjective Expected Utility formula was substituted for the weighted additive utility calculation, in another the decision rule of cumulative PT (Tversky and Kahneman 1992). The Subjective Expected Utility and PT rules were applied to the probability density distributions from which the travel times in the experiments were generated. The average of the travel time on both routes (i.e. 31.5 minutes) was chosen as the reference state in the PT model. Of course, neither Subjective Expected Utility nor PT predicted a change in preference during the choice sequences.. In addition to these Subjective Expected Utility and PT models two learning models were tested. These latter models predicted a decline in the preference for route A during the choice sequences. The Subjective Expected Utility model yielded for all scenarios the same prediction for the preference for route A (44%). The PT model yielded the best overall fit; it predicted almost the same values as the averages for the first stages of the choice sequences: 45 vs. 45% (scenario 1), 40 vs. 43% (scenario 2) and 59 vs. 57% (scenario 3). The learning models predicted the decline in the preference for route A during the choice experiments correctly but their overall fit was lower than for the PT model. The results clearly demonstrate the performance of the assumptions of weighted probabilities and loss aversion in recurrent operational choices with probabilistic outcomes. They also confirm the findings of Barron and Erev (2003) that the feedback of previous outcomes in such a context induces a shift in preference compared to the once-only choice from uncertain alternatives described in a probabilistic way.

Avineri and Prashker (2005) discussed only averages of the choices. They evaluated the descriptive performance of PT by applying its deterministic decision rule in a probabilistic Multinomial Logit concept and arbitrarily fixed the reference state at 31.5 minutes of travel time, which appeared fair as a first approximation. Interpersonal differences in choice behaviour were not reported. Considering the salience of the 'instant endowment' phenomenon (e.g. Tversky and Kahneman 1991) it seems highly likely that the experienced outcomes of successive choices caused reference shifts (e.g. Kahneman and Tversky 1979). One might consider these shifts as 'learning effects', as actually modelled by Arentze and Timmermans (2005). It might be worthwhile examining the 'peak-end heuristic' (Kahneman 1999) as a 'fast and frugal' learning routine for recurrent route choice decisions. Following the assumptions of EPT, the consistency of intrapersonal choice behaviour in such recurrent choice contexts could be studied by presuming idiosyncratic reference state updating 'rules' in connection with updating routines for the expected travel time 'distributions' of the route alternatives being considered. In fact, the 'Value Assessment model' as tried out by Barron and Erev (2003) might be considered as a simplified implementation of these suggestions that as such falls completely within the premises of EPT.

One more study was reported by Avineri and Prashker (2006) in conjunction with the one described above. Here the experiments following the experimental design of scenario 1 as described above were compared to a scenario with the same travel time distributions for route A as well as route B. Just before this 'scenario 1+' started, the drivers were informed about the mean travel times (Route A 33 minutes and Route B 30 minutes), and no information

about the difference in standard deviation was forwarded. Surprisingly, the frequency of the choices for Route A increased in scenario 1+ from about 37% in the first 20 choices to almost 50% in the last round, resulting in an on average higher frequency to choose it (almost 50%) than in scenario 1 (36%). This definitely is contrary to what one might expect under the assumptions of UT. Avineri and Prashker (2006: 402) presented an elegant explanation for this finding: '*In this simple binary route-choice problem, the more risky choice (Route B) is likely to be more rewarding, which translates into a propensity to choose it. The joint probability of choosing Route A and being rewarded for it becomes smaller and smaller. But in the domain of losses (as in travel times), sampling is more self-correcting. Many choices of Route A result in a smaller loss than most choices of the route B, which reduces the learning process rate to prefer Route B*'. It once more indicates the importance of loss-aversive valuation in daily recurring choice behaviour. In addition to these observations, which are based on the choices aggregated over the survey population, the authors provide some additional information based on the behaviour of individuals. This shows that after they had made 80 choices a significant part of the respondents systematically chose one of the routes while only a minority of so-called 'indecisive' travellers chose both routes with the same frequency[99]. This finding suggests interpersonal differences in choice behaviour strategies but the personalized information about the submitted sequences of travel times and the corresponding sequence of route choices that would be required to elicit such strategies is lacking.

Similar choice experiments to those of Avineri and Prashker were reported by Bogers *et al.* (2005) and, preliminarily, by Viti and Van Zuylen (2004). During two experiments on the Delft University travel simulator subjects had to make 25 successive choices from two routes over the Dutch motorway network. Route 1 was shorter than Route 2 and consequently had a smaller free-flow travel time. The actual queue lengths on both routes were presented to them before the subjects stated their choice. Afterwards they were informed about the outcome of their choice as calculated by a traffic simulation model. In experiment 1 both routes had an almost equally, relatively small, overall congestion level. In this experiment the participants initially seemed to follow the queue length information but after some ten choices about 60 to 80% of the choices were in favour of the 'faster' Route 1. In experiment 2 the mean and variance in travel time on Route 2 were the same as in experiment 1 but the variance on Route 1 was greatly increased whilst keeping the average smaller than on Route 2. Within five successive choices about 70% of the choices now concerned the 'reliable' Route 2. This percentage rose to 75% when the queue length information suggested only small differences in expected travel time, but 25% nevertheless chose the less reliable route. This 'preference shift' between experiment 1 and 2 obviously violates the assumptions of the Expected Utility version of UT.

To explain the observed behaviour Bogers *et al*. suggested some probabilistic approaches, including PT and the related expected opportunity loss concept of Game Theory, in connection with a learning algorithm, but they did not test these assumptions against their empirical findings. They analysed the results with a Mixed Logit model in view of the expected interpersonal differences in choice behaviour. Refraining from route-specific constants it appeared that the presented queue length was by far the most important explanatory variable, followed by recently experienced late arrivals (first experiment) and travel time (second experiment). Including recently experienced early arrivals did not improve the model fit. From the preference shift between experiment 1 and 2, in connection with the

[99] Though definite information is lacking the average propensity to choose either of the routes as depicted by Avineri and Prashker (2006: 401) in Figure 1 suggests that most of this behaviour had already developed after twenty choice sequences, as one would expect based on the findings of Mahmassani (1990).

significance of late arrivals and/or travel time that may be considered as 'losses', one might conclude that at least a part of the subjects in this study exhibited context and reference-dependent framing and loss aversion, and presumably also non-linear probability weights. Particularly in view of the frequency of apparently risk-seeking choices in experiment 2 one might infer that sub-samples of the survey population exhibited different decision rules.

Recently Bogers *et al.* (2006) published the results of another, large-scale travel simulator experiment in which participants provided with different types of predicted and feedback travel time information choose between three routes. They found similar violations of Expected Utility Theory and their findings yield similar support for the corresponding assumptions of EPT. Their conclusion that '*both worst experience and expected variance of travel time are negatively valued*' agree with the findings of the value of travel time unreliability studies that were extensively discussed in the section on tactical choice behaviour.

6.4.2 Choice behaviour of drivers en-route

All the choice contexts re-examined above concerned processes in which the decision-makers were able to concentrate on the choice task at hand. Thus, their cognitive load was less than if they had to choose while carrying out another task concurrently. The latter choice context can be simulated by observation of choices of experimental subjects whilst driving a car, either in a driving or travel simulator. The effectiveness of this travel choice behaviour research tool might become increasingly popular as travellers become subject to an ever increasing variety of signs and messages about the actual traffic conditions that they should expect on different routes. Figure 12 illustrates this trend with respect to variable message signs as may be encountered on the Dutch motorway network.

Figure 12: Different kinds of actual traffic information displayed on different kinds of variable message signs

Route choice

A driving simulator was used by Katsikopoulos *et al.* (2000; 2002) to investigate route choice while underway. They describe two experiments in their first article and a third one in the second. In each experiment 30 participants simulated being on their way to downtown Boston on a particular road ('Interstate 93') while they were presented with the remaining travel time to their destination along this road as well as along an alternative route ('Route 28'). Each participant made many once-only choices. In the first and second experiments, where the predicted travel time over interstate 93 was kept at 100 minutes, the average and range of travel times were varied along with the work task following arrival and the positive or negative margin in their time schedule. In the third experiment the work task and amount of slack in the time schedule was not varied but the range of predicted travel times over interstate 93 was. The first experiment was a paper-and-pencil stated choice setting, whereas in the second and third experiments the participants were driving in a simulator. Based on a statistical treatment of aggregate results the authors observed risk aversion for gains and risk seeking for losses when the reference range was smaller than the alternative range, but the reverse pattern when the reference range was larger than the alternative range. One might however wonder whether an analysis drawing on intrapersonal consistency in the framing of reference states and the expected probability distributions of travel times, depending on the idiosyncratic interpretation of the presented travel time ranges, would not approach the observed behaviour more closely. The significance of framing, loss aversion and weighted probabilities is clearly demonstrated in both articles.

Hester *et al.* (2002) used driving simulator experiments to clarify the impact of information about the occupation of parking lots on destination choice. Experimental subjects were provided with pre-trip information about the driving time to different parking lots, the waiting time when a parking lot was full and the walking times from the different parking lots to the building of their destination. En route to a particular building the subjects passed a variable message sign showing information about the actual number of unoccupied places in the lots. Thus the total travel time could be calculated for conditions in which either no or at least one place was available in the relevant parking lots. From a first experiment it appeared that the participants tried to minimize their overall travel time rather than their walking time or parking unavailability. In a second experiment it was tested whether the subjects always chose the parking lot with the lowest expected overall travel time, including waiting time in the case of a full parking lot. As an alternative to this UT-conformable compensatory rule the authors assumed that a subject might as well use a non-compensatory rule, by choosing the next parking lot with ample empty places in case the place closest to the destination was almost full. Six choice sets were devised in which the application of the compensatory and the non-compensatory rule were mutually exclusive. Two of the twenty subjects chose according to the compensatory rule from all these six choice sets, and seven did not. The others followed either the compensatory or non-compensatory rule, depending on the number of open places in the parking lot closest to the destination and the distance to the next 'free' parking lot. The majority of the subjects apparently avoided parking lots where they considered the chance that they had to wait too high. As the potential waiting time at a full parking lot is less than the additional walking time for the alternative it seems very plausible that most test subjects framed this as a loss, maybe largely determined by affects associated with regret avoidance.

A similar parking behaviour study was reported in Bonsall and Palmer (2004). Car drivers made five successive journeys in a travel simulator to the city centre. Each participant could park at five different lots that varied in the probability of having to wait for a place, walking distance to the final destination and parking fee. Before each trip each participant was asked

to state to which car park she intended to go. Next, she made her definite destination choice during her simulated journey. Each participant thus actually made a pre-trip and an en-route parking lot destination choice. These choices were analysed with a Nested Logit model, with the actual available information pertinent for the choice (e.g. price, walking distance, car parks occupation pattern) as attributes. The authors added the car park chosen during the last preceding simulator run as an additional attribute for the pre-trip choice, and the intended destination stated during that pre-trip choice for the second pre-trip en-route choice. It appeared that the added attribute yielded the largest contribution to the explanation of the choices. This apparent dependency of the choice behaviour from previous choices is at odds with UT's concept of a context-independent preference order. It offers plausible evidence for reference-dependent framing and loss-aversive valuation. A similar impact of pre-trip route choices on route choices by travellers who were on the way was convincingly demonstrated by Mahmassani and Srinivasan (2004) for commuters who moved through a highway network. From the perspective of EPT these studies support the notion that preceding choices of individuals may act as a reference state in subsequent choice behaviour. The latter study also demonstrated substantial heterogeneity in the extent to which different travellers followed the supplied travel time information, which might be conceived as differences in the individuals' choice behaviour strategies as conceived in EPT.

Finally, Chen and Mahmassani (2006) simulated the route choice of travellers in a 12-link network by assuming that individuals chose according to PT (value function concave for gains and convex for losses, weighted probabilities) combined with three different learning models. As a departure from PT they presumed that individuals were either risk seekers or avoiders, rather than assuming that individuals always over-weight low probabilities and under-weight high probabilities. As the reported simulation results were not compared with empirical data the descriptive ability of the EPT assumptions in question could neither be rejected nor supported.

Mode choice

Yamamoto *et al.* (2002) re-analysed a 1997 stated preference survey concerning the effect of travel information on the decision to switch to transit instead of driving to the central business district of Nagoya, Japan. They compared the predictive ability of a binary Logit model drawing on the Weighted-additive decision rule with models based on: the Lexicographic Semi-order rule; production rules; and decision trees that used different rules for different socio-economic segments within the survey population. The Lexicographic Semi-order rule performed slightly better than the other rules. Each of the rules explained almost 70% of the choices, and all the rules together could explain about 80%. Yamamoto *et al.* did not mention reference-dependent framing or loss aversion that might also explain the choices of parts of the survey population but they convincingly demonstrated the use of different decision rules by different segments within this survey population.

Lane switching

Stern (1999) submitted twelve non-recurrent congestion situations on a dual carriageway to 147 students in three groups. Subjects had to mark their propensity to stay in their traffic lane or switch to the adjacent lane on a 10-point scale. Members of each group were allowed either 5, ten or 25 seconds for each choice decision. From the responses to some additional questions Stern concluded that the subjects experienced increasing time pressure with decreasing response time. Using the relative speed of the traffic in both lanes, the relative traffic density and the relative frequency of obstacles ahead as attributes for lane switching propensity, he found that relative density, thus just the opportunity to switch lane, was the

most important attribute in the high time-pressure conditions. The analysis of the stated inclinations with respect to lane changing revealed that a compensatory decision rule might explain the lane switching probability the best, but where it could explain as much as 84% under no time pressure this dropped to 75% under high time pressure. At the same time, the share of the stated inclinations that could be explained from the use of different non-compensatory rules increased. The explanation of observed lane-changing propensity from the four tested decision rules accumulates to about 200% in both the experiments with and without time pressure, so there is a large overlap. All these results are in accordance with the elicited use of decision rules reported from other domains (Chapter 4). Though there is a marked increase in the use of non-compensatory decision rules in the groups with increasing time pressure, it seems very likely that several respondents of the no-time pressure group used such a strategy as well. Stern's findings leave little doubt about the co-occurrence of compensatory and non-compensatory rules in driver's lane-changing choices.

6.4.3 Summary of findings from operational travel choice behaviour

In Table 7 the 22 re-examined studies of operational travel choice behaviour are juxtaposed. In two references the applicability of reference-dependent framing and loss aversion was presupposed but no empirical supporting information was shown. The other studies contained sufficient information for a comparison of the adherence to at least one assumption of EPT or the corresponding one of UT. None of the reviewed studies contained information demonstrating that one or more of the assumptions of EPT should be rejected because the corresponding PT or UT assumption explained the observed choices better.

After re-examination nine studies showed convincingly that most respondents framed their alternatives as gains and losses relative to some reference state and valued the attributes loss aversely, and in doing so violated the UT assumptions of context-independent preferences and state-dependent, loss-neutral valuation. Seven more studies plausibly indicated the same pattern. The remaining studies contained no empirical information suited for the assessment of the descriptive ability of these assumptions. These included two mathematical model studies in which the descriptive ability of reference dependency was assumed. Most studies investigated daily recurrent departure time and/or route choices. None of these analysed the intrapersonal consistency of choice sequences. A further step might be to test decision frames with an idiosyncratic 'common' departure time, route and VTTS as reference state, some earlier and later departure times and routes as alternatives, and changes in departure times, in travel time and its distribution, and where appropriate in working hours, as attributes. The consistency of intrapersonal choice behaviour in such recurrent choice contexts could then be tested by assuming idiosyncratic reference state updating in connection with updating routines for the expected travel time distributions of the route alternatives being considered. It might be worthwhile considering the 'peak-end heuristic' (Kahneman 1999) in such a learning routine, as several studies revealed the large impact of the previous day's and/or the 'worst' travel experience.

The diminishing sensitivity hypothesis was mentioned in four studies but only one of these provided empirical choice information that supported the concavity of the value function in the gain domain and its convexity when there are losses.

The appraisal of probabilistic outcomes of alternatives was considered in eleven of the 22 studies. Five of these showed convincingly that individuals violate the principles of Expected Utility Theory and attached some subjective, non-linear weights to the probabilities. Re-examination of four more studies provided circumstantial evidence in support of these

observations. Two other studies considered that individuals might weight the expected probabilistic outcomes of alternatives subjectively but did not examine this empirically.

Table 7: Evidence for the descriptive ability of EPT in operational travel choice behaviour

Operational travel choice behaviour domain	**Evidence[1] supporting the descriptive ability of EPT assumption:**				
Main reference to research description (in order of survey year)	Reference-dependent framing and loss aversion	Diminishing sensitivity	Non-linear weighted probabilities	Mixed affective-utilitarian valuation	Heterogen. in choice behaviour strategies
Daily trip planning					
Mahmassani and Jou 2000	CD	-	PD	-	PD
Fujii and Kitamura 2004	ES, PD	-	ES, PD	-	ES, CD
Gärling 2004	-	-	-	ES, CD	PD
Swait 2001	-	-	-	-	ES, CD
Gärling *et al.* 2000	ES, PD	-	-	PD	-
Mahmassani and Sriniv. 2004	CD	-	-	-	PD
Olszewski and Xie 2005	PD	-	-	-	-
Jou and Kitamura 2002	ES, NS	ES, NS	-	-	-
Senbil and Kitamura 2004	ES, PD	ES, PD	ES, NS	-	-
Avineri and Prashker 2005	ES, CD	ES, NS	ES, CD	-	PD
Avineri and Prashker 2006	ES, CD	ES, NS	ES, CD	-	PD
Olszewski and Xie 2006	PD	-	-	-	-
Avineri and Prashker 2004	ES, CD	-	ES, CD	-	PD
Bogers *et al.* 2005	ES, CD	-	PD	-	PD
Bogers *et al.* 2006	ES, CD	-	PD	-	PD
En-route choice behaviour					
Yamamoto *et al*. 2002	-	-	-	-	ES, CD
Stern 1999	-	-	-	-	ES, CD
Bonsall and Palmer 2004	PD	-	-	-	-
Hester *et al*. 2002	PD	-	-	-	ES, CD
Katsikopoulos *et al*. 2000	ES, CD	-	ES, CD	-	-
Katsikopoulos *et al*. 2002	ES, CD	-	ES, CD	-	PD
Chen and Mahmassani 2006	ES, NS	-	ES, NS	-	-

[1] -: no information that confirmed or rejected the assumptions; CR: Clearly rejected; ES: Explicit statement in reference; CD: Convincingly demonstrated; PD: Presumably demonstrable; NS: Neither supported nor rejected. See Section 'Search and selection of appropriate travel behaviour studies' for a more extensive explanation.

Just one study confirmed that individuals might value alternatives as a mixture of affective and instrumental attributes and another study provided plausible evidence for it. This supports the observation in the previous sections that the importance of affective valuation in strategic decision making might dwindle when the character of travel choice behaviour moves to operational contexts. However, the attributes discussed in the references were predominantly of a utilitarian character.

A majority of the studies provided evidence for interpersonal differences in choice behaviour strategies. Several revealed differences in the framing of the reference while many more demonstrated the co-existence of non-compensatory and compensatory choice processes within survey populations.

Overall these findings show that for operational travel choice behaviour at least three of the evaluated assumptions of UT are too restrictive. They corroborate the descriptive ability of the corresponding, less restrictive EPT assumptions. However, the diminishing sensitivity principle and the co-occurrence of affective and utilitarian valuation were not demonstrated in more than a single operational travel choice behaviour study, though in the other consulted references no evidence was found for their rejection.

6.5 Summary and discussion

Chapter 4 presented much evidence in publications from social sciences that the majority of individuals in many domains of decision making demonstrate choice behaviour that violates the corresponding assumptions of UT and, to a lesser extent, PT. Based on these findings, EPT was founded in Chapter 5, as a more generic choice theory. The extensive review of travel research literature in this chapter has yielded many empirical findings for which the descriptive performance of EPT could be assessed. The results of these assessments are recapitulated below, followed by a discussion of the potential benefits that the application of EPT to travel behaviour research might offer for science and society.

6.5.1 Descriptive performance of EPT in travel behaviour contexts

The present research of the travel behaviour literature revealed all-in 85 studies from which sufficient information could be retrieved to assess the adherence of travellers to at least one of the five most discriminating assumptions of EPT. Of these, 43 dated from the present century. The five assumptions against which the recovered findings were re-examined are:

i. **Reference-dependent framing and loss aversion**: each individual frames alternatives and attributes context-dependent as changes (gains and losses) relative to an updated reference state, and most individuals value losses higher than gains of equivalent size.

ii. **Diminishing sensitivity**: the value function is concave for gains, convex for losses, and concave for states of assets.

iii. **Non-linear weighted probabilities**: most individuals weight the expected probabilities of probabilistic and uncertain outcomes with a subjective non-linear probability weight factor.

iv. **Mixed affective-utilitarian valuation**: affectively salient attributes will generally be valued on a qualitative affect dimension, other attributes of the same alternative might be valued on a monetary or medium scale.

v. **Heterogeneity in choice behaviour strategies**: interpersonal differences in choice behaviour strategies may occur within the same choice context, like satisficing next to maximizing aspiration levels and compensatory as well as non-compensatory decision rules.

The findings from the re-examinations are recapitulated in Table 8. It shows the number of re-examinations that revealed a better descriptive ability of a particular EPT assumption compared to the corresponding UT assumption.

Only one of the reviewed studies contained information demonstrating that one or more of the assumptions of EPT should be rejected because the corresponding UT assumption[100] explained the observed choices better. This is conspicuous, as the search terms used to select these studies were neutral with respect to the applicability of EPT and/or UT. Thus any published analysis of choice behaviour from which e.g. UT's reference-independent attribute valuation appeared to explain observed choices better than PT's loss aversion would have had the same chance of being recovered as studies which found the reverse.

Evidence for the better descriptive ability of one or more assumptions of EPT compared to UT was found in almost all the countries considered, survey and publication years, choice process types, elicitation task characters, research environments and report modes. Actually, only four considered mathematical model simulations yielded no empirical information that supported or rejected any of the considered assumptions.

Reference-dependent framing and loss-aversive valuation

Framing of alternatives relative to a reference state was demonstrated in 70 studies of travel behaviour, 38 of which were scientifically convincing. Another 32 studies showed that adherence to this assumption was plausible. These studies were quite equally distributed over all discernable real-life and elicitation contexts. It illustrates the importance of a context-dependent description of idiosyncratic preferences or, more appropriately, intrapersonal consistent choice behaviour strategies. The corresponding UT assumption, that all individuals frame the alternatives context-independent as post-decisional states, was consequently violated in the choice behaviour contexts of these studies. Loss aversion can be considered as the most prominent deviation from UT. Over the whole range of real-life and experimental choice contexts, evidence for loss aversion was observed in connection with reference-dependent framing. In some cases where loss aversion was not explicitly demonstrated, at least some of the respondents used a non-compensatory decision rule that might to some extent draw on a loss-aversive valuation. Some studies indicate that car drivers might value their running costs loss neutrally while they may attribute a very high value to toll expenses (e.g. Hess *et al*. 2006). The loss aversion factors for the most common travel time and cost attributes appeared in the 1.4 to 2.8 range, which yields the 'average' value of 2.0 as found from observations in behavioural sciences as a useful first estimate for applications in travel behaviour, if more specific information is lacking.

The high value attributed to late arrivals as elicited in studies that follow the schedule-delay approach (e.g. Small 1982; Bates *et al*. 2001) can also be considered as the consequence of adoption of the preferred arrival time as an element of the reference state. Increases in the time spent travelling after the preferred arrival time might be valued as losses and decreases in travel time before as gains. When such a frame is considered the loss aversion factors with respect to travel time changes may attain very high values. This may definitely be expected if travel time is considered as uncertain, following some probability distribution. Even if the

[100] De Palma *et al*. (2003) found a higher VTTS for very late arrivals compared to less late arrivals, indicating a concave utility function in the loss domain. This observation was counterbalanced by seven studies that confirmed or suggested a convex value function in the loss domain and many more studies in which no deviation was found from a linear value and/or utility function.

Table 8: Descriptive ability of EPT assumptions in travel contexts

Traveller's choice behaviour context	Re-examined studies according to evidence [1] for descriptive ability of EPT assumptions [2]: Total	i.	ii.	iii.	iv.	v.
Real-life context: Subject's country						
Different countries	**22**	21	6	9	7	12
Real-life context: Survey year						
1972-1989	**10**	9	2	2	2	7
1990-1999	**32**	26	1	11	6	17
2000-2006	**43**	35	4 [3]	14	9	19
Real-life context: Choice process						
Strategic decision making	**19**	16	0	0	10	11
Tactical choice behaviour	**44**	38	6 [3]	18	5	23
Operational choice behaviour	**22**	16	1	9	2	9
Elicitation context: First publication of study						
1978-1999	**17**	14	2	4	3	11
2000-2007	**68**	56	5 [3]	23	14	33
Elicitation context: Task character						
Aggregated travel behaviour	**6**	6	0	1	0	1
Subjects' self reports	**21**	20	3	7	4	11
Customized Stated Preference	**32**	28	4 [3]	10	5	14
Choice or judgment experiment	**18**	14	0	9	5	15
Expert opinion	**8**	2	0	0	3	2
Elicitation context: Research environment						
Real-life experience	**29**	26	3	8	7	14
Travel or driving simulator	**9**	9	0	6	0	7
Imaginary, framed in real-life	**29**	26	4 [3]	7	3	14
Imaginary, fictitious	**14**	9	0	6	7	8
Mathematical model	**4**	0	0	0	0	0
Elicitation context: Report mode						
Oral interview, verbal protocol	**24**	23	2 [3]	10	7	12
Postal survey	**17**	15	3	3	3	10
Paper and pencil	**19**	15	1	6	4	8
Internet survey	**5**	3	1	2	1	4
Computer logging	**13**	12	0	6	1	8
Published report	**7**	2	0	0	1	1
Total	**85**	**70**	**7** [3]	**27**	**17**	**43**

[1] Either convincingly demonstrated or presumably demonstrable. [2] i. Reference-dependent framing and loss aversion; ii. Diminishing sensitivity; iii. Non-linear weighted probabilities; iv. Mixed affective-utilitarian valuation; v. Heterogeneity in choice behaviour strategies. [3] plus one study in which diminishing sensitivity in the loss domain was violated. See under 'Considered choice behaviour theories and paradigms' and 'Search and selection of appropriate travel behaviour studies' for more extensive explanations.

loss aversion factors are corrected for the effect of non-linear probability weighting they may remain higher than found for the values of increases and decreases in travel time. One might, however, doubt if a choice frame that only considers alternatives characterized by trip time and expenses and trip schedule delay attributes is appropriate for the assessment of the values of travel time and its uncertainty. A more appropriate elicitation process might consider at least two choice processes. In the highest tactical process an individual might trade-off the consequences of late arrival, in connection with the employment contract and the atmosphere at work, and of early home departure in connection with domestic duties. Such a tactical choice process might yield an idiosyncratic threshold for the frequencies and extents of late arrivals that, once violated due to changes in the traffic conditions, result in adjustment of the actual tactical trip planning. In the new tactical choice process the travel time uncertainty might be considered again, but the outcome of the 'higher' tactical choice would be treated as a constraint. Though the behavioural explanations for such behaviour are quite different it is functionally equivalent to the 'arrival time indifference band' concept of Mahmassani (1990).

Diminishing sensitivity

The re-examination of 13 studies enabled the diminishing sensitivity principle to be considered. Two of these tested a power function with exponent below unity, in agreement with PT. De Borger and Fosgerau (2006) elicited the VTTS from 'choice under certainty' and Michea and Polak (2006) explained trip planning under uncertainty. Both studies offered good matches with the observed behaviour. The inferences from studies in which the utility function was approached with a second order Taylor series expansion were less straightforward. While two such studies supported the principle and some others offered no clear-cut evidence to support or reject it, the analyses of De Palma *et al*. (2003) contradict it. The overall picture seems to be that diminishing sensitivity may only play a prominent role when the considered changes in attribute levels are large. As with the diminishing marginal utility principle, a kinked-linear approximation of the value function may commonly suffice.

Subjective non-linear probability weighting

The attribution of subjective non-linear probability weight factors to the probabilistic outcomes of travellers' choices was convincingly observed in thirteen and plausibly in another fourteen studies. A thorough treatment of the theory is given by Avineri and Prashker (2004; 2005). Most of the research designs that were re-examined did not consider probabilistic outcomes and thus did not allow validation of this EPT assumption. Evidence for its application is remarkably absent in the recovered studies dealing with strategic decision making related to accessibility and travel, particularly as the long-term effects of such decisions are notably uncertain. One explanation might be that individuals take myopic decisions and/or disregard long-term uncertainties, and/or that researchers are not particularly interested in the way individual people deal with it. Convincing observations are almost exclusively observed in operational choice behaviour. For tactical choice settings the principle may largely determine the assessment of an acceptable probability of late arrival and/or early departure as discussed above under reference-dependent framing and loss aversion. In successive tactical and operational trip planning the outcome might act as an idiosyncratic constraint, making further assessments drawing on this principle superfluous.

Mixed affective-utilitarian valuation

An important role of the affective valuation of some attributes in addition to the utilitarian valuation of others was found in 17 studies. Convincing demonstrations were almost completely confined to strategic decision making. Most observations in tactical choice

contexts were characterized by explicitly submitted affectively and ethically salient attributes, more specifically traffic safety in terms of number of casualties (e.g. Rizzi and Ortúzar 2003; De Blaeij and Van Vuuren 2003). The stated preference context in which these were submitted allowed the subjects sufficient time to follow a deliberate decision making process. This mixture of the affective and utilitarian valuation of attributes was not observed in most studies of tactical and operational travel choice behaviour contexts. Evidence from other disciplines suggests that these differences might be attributed to the character of the choice situation and its importance in real life (Zajonc 1980; Slovic *et al.* 2002; Dijksterhuis 2004).

Interpersonal heterogeneity in applied choice behaviour strategies

The evidence assembled under this heading covers differences in the framing of objectively the same travel situations, differences between the loss-aversive and loss-neutral valuation of the same attributes, and the co-occurrence of compensatory and non-compensatory decision rules within a survey population. Such interpersonal differences in choice strategy were retrieved from 43 studies. The evidence from 23 of these studies was very convincing. The studies that supported the co-occurrence of different decision rules often showed that one population segment employed a first-stage elimination rule that might draw on loss aversion followed by a compensatory second stage, while another segment followed a weighted-additive compensatory decision rule. Overall, most studies suggested that a majority of the survey population exhibited loss aversion for all attributes while a minority valued at least a part of these loss neutral.

Conclusions

The re-examinations of travel behaviour studies so far have demonstrated the descriptive ability of the individual assumptions of EPT and the violation of those of UT in all travel-choice behaviour domains and contexts where individuals can adhere to them. Reference-dependent framing and loss-aversive valuation should be expected in any travel-related choice process, just as interpersonal differences in the applied choice behaviour strategies. Though the diminishing sensitivity principle was supported in several studies – and rejected in one – its relevance for travel behaviour research seems small as in most contexts a kinked-linear approximation of the value function will suffice. The application of non-linear probability weights was supported where it was tested. It would be better to consider it in such contexts as the assessment of scripts for late arrival at work. In most situations an individual may rely on the outcomes of such incidental assessments and consider her outcomes as constraints. A mixture of affective and utilitarian appraisals might complicate human choice behaviour in strategic choice contexts. These might, again, yield constraints in tactical and operational settings but few indications were found that they might play a prominent role in the actual tactical and operational choice behaviour.

6.5.2 Potential benefits of EPT applications to travel behaviour research

In transport sciences Random Utility Maximization Theory appears to be the dominant model for the description and understanding of travellers' choice behaviour. From the findings from behavioural sciences one might expect EPT to offer a tool for a better description of travel behaviour. This is supported by the occurrence of travel choice related phenomena that may be explained by assumptions of EPT rather than UT. If this expectation is true the application of EPT might be relevant for travel behaviour research in several respects.

First and foremost the strict functional-descriptive nature of EPT might improve the understanding of what kind of choices travellers make. Foerster (1979: 26) elaborated this

subject thoroughly with respect to decision rules and mode choice: '*If mode choice decisions are compensatory, planning activities should concentrate on the analysis of incremental changes and tradeoffs: it could be assumed that cost-savings associated with car pooling can compensate travellers for increased travel time and loss of privacy…Strong Lexicographic processes preclude any marginal trade-off behaviour…If conjunctive processes are involved in mode choice, planners need to determine what levels of the attributes of travel modes constitute the threshold conditions or minimal criteria for conjunctive acceptability.*'

EPT enables for a better elicitation and anticipation of the choice behaviour strategies and valuation principles that travellers employ in different domains and contexts. The elicitation of different choice behaviour strategies within populations might offer a better understanding of the interests that incite the behaviour of public and private actors in the governance networks that in the highly individualized Western societies determine the further development of the transport systems.

The inclusion of the elicited frequency of the use of different choice behaviour strategies might improve the credibility and quality of modelling and forecasting of travel behaviour. For that purpose EPT might well be incorporated in a discrete choice model structure. It might also provide the answer to several questions regarding the simulation of choice processes in such environments with agent-based models (e.g. Hunt 2002).

Modelling the assumptions of EPT might improve the prognosis of the public support for transport policy objectives and measures. It might underpin a transport policy primarily aimed at the prevention of 'losses' (e.g. an increase in delays) at the cost of 'gains' (e.g. improvement in the actual experienced circulation).

EPT seems even more promising for a proper assessment of the external effects of infrastructure and transport. It substantiates the often-chosen approach of governments to implement stricter environmental measures primarily for new infrastructures instead of for existing ones. Thus it might promote the use of scarce budgets initially to reduce the anticipated highly valued 'losses' of citizens to be confronted with these new infrastructures, at the expense of donating environmental 'gains' that are considered of low value to the individuals that may be adapted to it.

The loss aversion concept in particular may turn out to be a powerful instrument for providing an improved understanding of the reactions of travellers to changes in the transport system. Individuals might e.g. hardly value a few minutes decrease in their daily commute but may be very upset by 'new' delays, even if these are less frequent. Thus with respect to delays such as due to road reconstruction and maintenance, particularly when these are unannounced, AMR (1999: 35) suggests that '*the value of travel time for time losses seems more appropriate than the average "long-run" value*'. Loss aversion in connection with the weighted probability concept also explains context-dependent differences in risk seeking or risk avoiding behaviour of the same travellers that are confronted with uncertainties in, for example, travel time.

Taking this type of reaction into account might improve cost-benefit analyses as well. For example, most *ex-ante* transport project appraisals value small travel time gains and losses independent of size and sign at the same unit cost level and assume a compensatory evaluation by the travellers. However, with respect to the predicted demand for a new road scheme, for example, AMR (1999:35) remarks that '*if unexpected time gains are less valuable than expected ones, the demand for such schemes could be depressed in the early years*'.

6.5.3 Summary

The re-examinations of travel behaviour studies in this chapter by and large confirm similar findings from a host of studies in other fields of behavioural sciences as discussed in Chapter 4. They have demonstrated the descriptive ability of the five most discriminating assumptions of EPT, as founded in Chapter 5, and the violation of those of UT and, where relevant, PT in all travel choice behaviour domains and contexts where the available information allowed for a comparison. The joint application of the examined assumptions to travel behaviour research within the framework of EPT thus appears a promising way to arrive at a better understanding of travellers' choice behaviour. This, in turn, may boost the opportunities of private and public actors to improve their policy and operations with respect to different elements of the transport system. Such a joint application will be tested in the next Chapter. It will describe the development and calibration of an EPT-based model of tactical travel behaviour and compare its prediction of the responses of car drivers to the introduction of road pricing in Singapore with a similar model drawing on the UT assumptions.

Chapter 7
Travel Choice Prediction: Singapore's Road-pricing Experience

Remember that TIME is MONEY

Benjamin Franklin (1748)

This piece of conventional wisdom was originally formulated by Franklin in his '*Advice to a Young Tradesman.*' It might also be the best advice to travel behaviour scientists and policy makers trying to understand the tactical travel choice behaviour of Singapore's commuters

7.1 Introduction

7.1.1 Background and purpose

The previous chapter revealed support for the *descriptive* ability of EPT similar to the review of notions and observations from the behavioural sciences in Chapter 4. It demonstrated the better descriptive potential of the five assumptions of EPT compared to the corresponding assumptions of UT, in all kinds of travel behaviour domains and contexts. Most of the re-examinations drew on parameters estimated from the observed behaviour with models that adhered to the UT paradigm, in which incidentally one or two EPT assumptions were substituted for those according to UT. Hardly any studies were retrieved in which such estimated or calibrated models were validated by a comparison of predictions and observations in a different context[101]. The re-examinations of travel behaviour studies in Chapter 6 did thus not allow inferences to be made about the *predictive* abilities of the EPT paradigm compared to UT. This Chapter aims to provide such a comparison of these predictive abilities in a range of similar real-life travel choice contexts, for implementations of both paradigms in which all their relevant assumptions are considered together.

[101] A conspicuous exception is a paper by Olszewski and Xie (2006) who predicted trip timing adjustments following a change in road-pricing fares with a model calibrated on the observed trip timing before the fare adjustment. The published information did not allow a comparison of the predictive ability of models following UT and EPT principles.

7.1.2 Considered travel-choice contexts

The range of real-life travel contexts[102] chosen for the comparison of the predictive abilities was the response of car owners in Singapore to road-pricing measures during their morning commute. Four interrelated considerations led to this choice. First, the morning commute is still the main cause of congestion all over the world and road pricing seems nowadays to be the most popular policy to relieve these problematic travel conditions. If the prediction of the responses of the travellers differs significantly between EPT and UT this difference might thus be of the utmost importance for the development of effective road pricing policies. Secondly, Chapter 6 revealed large differences in the elicited values of travel time savings (VTTS) and/or schedule delays depending on the applied model that, in turn, might give rise to similar differences in the predicted responses to the changes in travel costs. The Singapore road pricing experience offers several contexts in which VTTS concepts for calibration and the prediction of behaviour can be tested. Thirdly, the introduction and adjustments of road pricing in Singapore were extensively examined, analysed and reported in the literature. In particular the large-scale real-life travel behaviour surveys before and after the introduction and the corresponding changes in travel flows as reported and analysed by Watson and Holland (1978) may allow for calibration of a predictive choice model to the *ex-ante* context and comparison of the predicted with the *ex-post* observed behaviour. Fourthly, there is also a host of articles available with descriptions of the successive changes in the travel context in connection with the observed changes in travel behaviour of the considered target group of car drivers which spans a quarter of a century. This allows the consideration of both short-term and long-term responses to changes in travel conditions. A drawback of the Singapore case is that no information about the travel circumstances and choices at the individual's level could be retrieved, which prevents, for example, the incorporation of idiosyncratic probability weighting in the predictions. However, the wealth of published information allows the segmentation of the travelling population into several narrow target groups that each might be considered to be represented by a characteristic traveller.

7.1.3 Methodology

The methodological challenge that has to be tackled in this chapter is how to assess and compare the predictive ability of two theories that both rely on a description of the choice behaviour of individuals but differ in the character of their behavioural assumptions and the considered rules of conduct, against reference material consisting of responses by segments of the travelling population to different road pricing measures across over 30 years.

The obvious first step in coping with this challenge is to consider the general socio-economic and travel contexts in which the road pricing measures were made. Next, the available reference material is established. This is done by considering the individual's choice set formation process, inventoring the available data about observed responses to road pricing measures, estimating which attributes might have been considered to arrive at them and establishing the attribute levels that apply to the different categories of travellers. This effort will curtail the responses for which predictions can be made.

[102] Obviously, the complete set of ambient conditions in each choice process of any individual is unique. The individual contexts in the range of similar tactical travel choices considered in this chapter are assumed to be sufficiently similar to be able to be described by the same model. This enables the model to be calibrated using the observed choices in one set of contexts and then applied to predict choices in any other context of the same range. Hereafter, following common language use, the designation 'context' is also used for such a 'range of similar contexts' or subdivisions of it.

The models for the prediction of the responses to changes in road pricing are developed as implementations of a more generic covering model. The approach followed is deductive, starting with the development of the covering model from the constituent assumptions about the individual's choice behaviour according to EPT. For reasons of parsimony the number of independent variables and parameters discerned to model the attribute dimensions is kept to the bare minimum. As the algorithms of the covering model comply with EPT and largely cover the assumptions of UT as well (see Section 5.3) this allows implementations of EPT and UT to be derived that can be customized to the range of contexts and responses considered. To enhance a fair comparison of the predictive ability of the theories with these implementations an *a priori* boundary condition is that the considered attributes, or independent variables, are the same. Another precondition is that the parameters that have to be calibrated to the considered Singapore travel contexts are the same for both the UT and EPT implementations. As the EPT implementation includes some parameters that are redundant in the UT implementation, like the loss aversion factor and the distribution of its use over attributes and individuals, these are estimated beforehand from observations in other contexts than the range to which the calibrations and predictions in this chapter apply. These preconditions ensure that the comparison of the predictive ability of the UT and EPT assumptions is not biased by a better tuning of the EPT implementation to the considered contexts as a consequence of its larger number of parameters compared to the UT model.

Once the material for comparison has been assessed and the model implementations have been developed the prediction and comparison process is straightforward. For both models the travel mode choices, as observed before the introduction of road pricing, are used for the calibration of the relevant parameters. Next, the frequency of the different responses to that introduction, by means of the Area License Scheme that was enforced in June 1975, are predicted with the calibrated models and the predictions will be compared to the observed frequencies. The same procedure is followed for the comparison of the predictive ability of both theories with respect to a sudden rise in the road pricing fees just seven months after the original introduction. A less detailed and in some respects more qualitative approach will be followed to predict the long-term development in the frequencies of the different responses to road pricing measures. This chapter finishes with a summary, discussion and covering conclusions concerning the predictive abilities of UT and EPT.

All the inferences in this chapter about the predictive abilities of the model implementations and corresponding theories are based on a qualitative, narrative discourse. This is considered more appropriate for a comparison of theories that are meant to be approximative descriptions of actual behaviour, rather than hypothesizing and statistical testing followed by rejection or acceptance of one or both theories as this latter approach requires a disputable acceptability criterion for the degree of approximation.

7.1.4 Chapter outline

Road pricing started in 1975 with the Area License Scheme (ALS) that charged car drivers who entered a Restricted Zone in Singapore City during the morning rush-hour. Since then several changes in the scope, fares and implementation have occurred. An overview of these road-pricing measures is provided in Section 7.2, preceded by an overview of the developments between 1975 and 2005 in Singapore's transport system and the socio-economic context in which these developments took place.

The responses to road pricing are published in terms of the numbers of travellers who chose a certain travel mode or trip schedule. The aim of section 7.3 is to transform these aggregated

responses and the concurrent changes in travel circumstances into material that can be used to compare the predictive ability of the UT and EPT theories. This results in an overview of the alternatives and attributes/independent variables that should be considered in the choice models used for the comparison.

The model development is extensively described in Section 7.4. The resulting covering discrete choice model allows implementations that are useful for calibrations and predictions in agreement with the UT or the EPT paradigm, depending on the assumed choice behaviour strategies and loss aversion factors that are substituted. By specifying a linear-additive utility function with the monetary Value of Travel Time Savings (VTTS) as coefficient of the travel time attributes a simplified version of the UT implementation is derived that leaves just this parameter to be calibrated. After substitution of estimated loss aversion factors that are not the result of calibrations in the Singapore travel contexts a simplified implementation of the EPT paradigm emerges that requires the calibration of the same VTTS parameter as its UT opponent.

The assessment of the reference states for the pre-road pricing conditions in Singapore is the backbone of the model calibration in Section 7.5. In view of the aggregated nature of the available observations of behaviour it focuses on the calibration of the VTTS and its distribution over the population.

In the following Sections 7.6 to 7.7 the responses of car owners to the introduction of road pricing and to a fare increase shortly thereafter are predicted and compared with the observations. Section 7.8 investigates the responses to successive sudden changes in road pricing as well as to the travellers' long-term responses to changes in their travel conditions and welfare. In view of the large deviations between the observed responses to the 1975 and 1976 road pricing measures and the corresponding predictions with the UT model implementation the section starts with a re-calibration of the relevant parameters to these observations, again following the same procedure as for the EPT implementation. A discussion and conclusions section finalizes this chapter.

7.2 Singapore: Socio-economic and travel context

The present section describes the general context in which Singapore's car owners responded to road pricing and other policy measures aimed to influence the travel conditions. Most facts and figures were found in Watson and Holland (1978), Spencer and Sien (1985), Phang and Toh (1997), LTA (1997), Willoughby (2000; 2001) and the Website of Singapore's Land and Transport Authority (LTA 2007) and Singapore Statistics (2007). The references to these sources are further omitted from this section to improve the readability. Information derived from other sources is acknowledged as usual. Readers who are familiar with or not interested in the context in which travellers in Singapore make their choices may skip this section and move directly to Section 7.3.

The section starts with a generic overview of the development of the socio-economic situation. It is followed by a description of the development of the transport system, including the government transport policies and individual's travel circumstances in general. Next the road-pricing policies and the responses of car owning commuters measures are listed briefly. It is concluded with a brief discussion about the effectiveness of different types of transport policies as applied in Singapore and the relative contribution of road pricing to it.

7.2.1 An eye-catching socio-economic development

Singapore is a relatively small island state in Southeast Asia. Information from Singapore Statistics (2007) shows that in 1975 it had 2,250,000 inhabitants and in 2005 4,400,000. The largest ethnic groups are Chinese (74%), Malays (14%) and Indians (8%). In 2005 the most frequently spoken language at home was Mandarin (36%), followed by English (28%), Chinese dialects (18%) and Malay (13%). The use of English at home is increasing while use of the Chinese dialects is decreasing at the same pace. About 50% of the residents are Buddhists or Taoists while Christians, Muslims and people with no religious affiliation each account for about 15%. In the 1960s about 40% of the population was below the age of 15 and less than 2% over 65. By 2005 these percentages were less than 20% and almost 10%, and the fertility rate was amongst the lowest in the world. Between those years the household size dwindled from an average of 5.2 to 3.5 persons and the average number of workers per household, which peaked at about 2.1 in the 1970s, declined to 1.7. While the proportion of the population in their active years was still high in 2005 compared to most other highly developed societies the rapid ageing of the population will continue.

Large-scale land reclamation increased Singapore's land surface area from 580 km^2 in 1975 to 700 km^2 in 2005. The creation of immense harbour works and vast industrial areas supported the development of manufacturing, particularly in oil refining, petrochemical and electronic products, and made it the busiest harbour in the world. Simultaneously the tertiary sector was boosted while the office space multiplied and the poor housing situation from the colonial period was improved by the development of residential areas all over the island. The drastic changes in the face of the island state are prominently illustrated in Figure 13.

When Singapore became independent in 1965 it was a poor developing country. Since then it has seen remarkably strong economic growth reflected by the increasing strength of the Singapore dollar (S$), the value of which doubled between 1960 and 2005, from 0.32 US$/S$ to 0.6 US$/S$. In 1975 the per capita income (in purchasing power parity) had doubled to 7,000 US$, about half the Western European level. It increased further to about 30,000 in 2005, approximately 90% of the concurrent level in Western Europe. The welfare of the population grew with Singapore's economy. Taking inflation into account the average real household income in 2005 was over four times as high as in 1966. Unemployment, which in the early 1960s was well above 10%, fell below 5% from the mid-1970s onwards. By 1975 the number of households living in extreme poverty, which was more than 10% in the early 1960s, had fallen below 2% and soon disappeared entirely. Income inequality, as indicated by the GINI index[103] for household income, initially decreased from 46 at independence to 41 in 1975 and since then has gradually climbed back to the original level. Table 9 offers some more data on the income changes in Singapore since its independence. The increase in welfare included health and educational matters, housing and so on. This is reflected in the United Nation's human development index which rated Singapore amongst the 30 most developed countries in 2006.

[103] A higher Gini-index indicates an increasing inequality in wealth or income in a country. In the Netherlands, for example, it remained within the 30.5 to 31.1 range between 1974 and 2000. Around the year 2000 it ranged from below 30 in Japan, most Scandinavian and several other European countries to well over 55 in most Latin American and many African counties, according to the World Bank's World Development Indicators 2006. The index for Singapore was above the average, slightly above the USA (40.8) and below China (44.7).

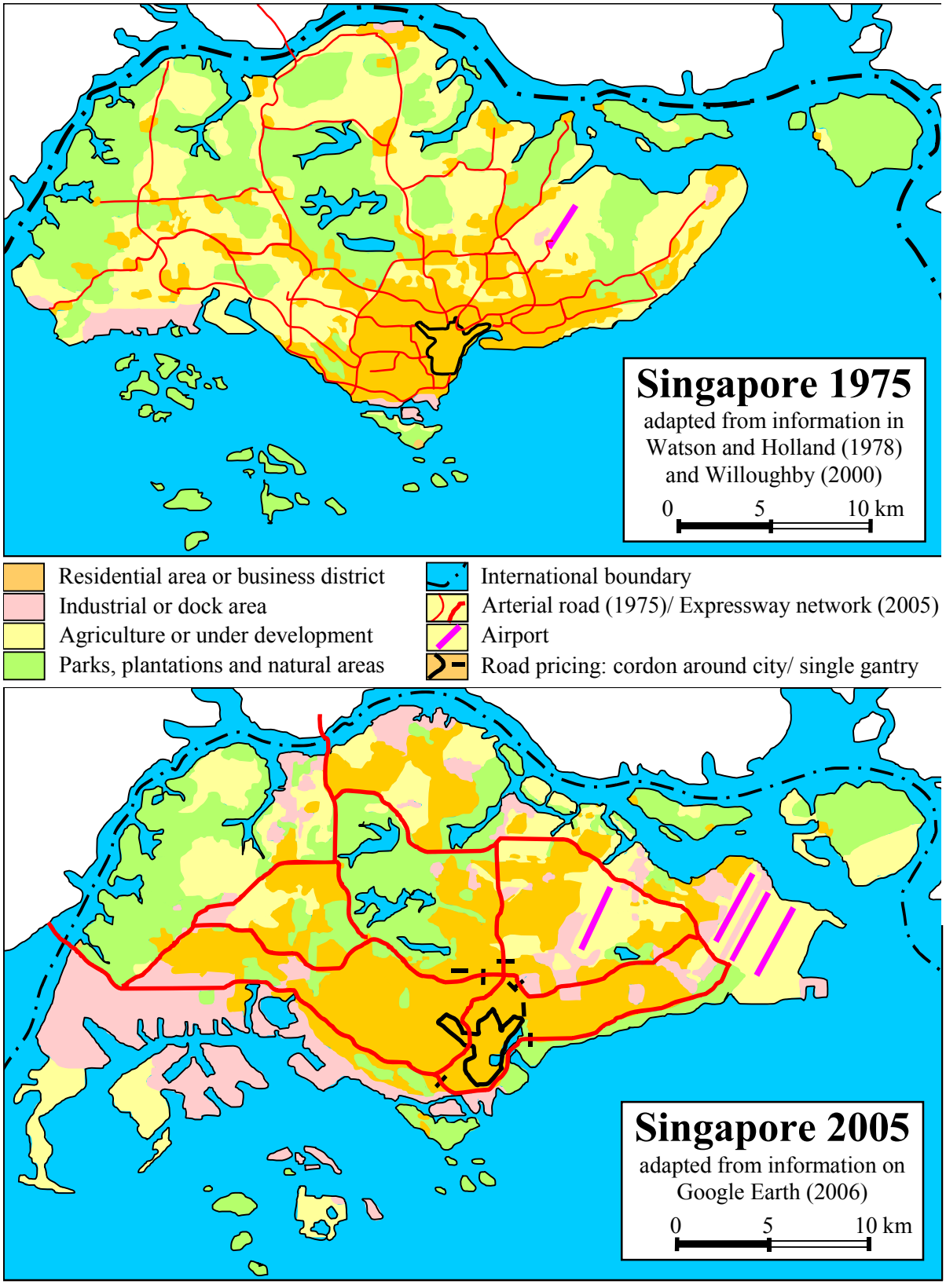


Figure 13: Land use in Singapore

The distribution of economic activities over the country was uneven. In 1975, 70% of the population lived within eight kilometres of the Central Business District, which housed 10% of the nation's inhabitants, 24% of its jobs and more than two-thirds of its office and retail spaces. Between 1975 and 1996 the population of Singapore's Central Business District

dropped to 45% of the 1975 level, only 3% of the population. Meanwhile its employment grew by 57% to 315,000 jobs, and the area occupied by offices and retail spaces increased there by 330 and 460% respectively. As employment grew even more strongly elsewhere, the CBD's share in the nation's employment decreased to 19% in 1996. In 1975 the most common office hours[104] were from 9:00 a.m. to 5:00 p.m. while shops typically opened at 10:00 a.m. These hours have remained virtually the same to date.

Table 9: Core figures of Singapore's socio-economic development

	1966	1975	1990	2005
Population (1,000 inhabitants)	1,950	2,250	3,050	4,400
Labour force (1,000 employees)	600	850	1,550	2,350
Unemployment rate (% of labour force)	9.0	4.5	1.5	3.0
Per capita Gross National Income (S$, current market prices)	1,800	6,000	22,500	43,000
Per capita Gross National Income (2005 = 100)	4	14	52	100
Consumer Price Index (2005 = 100)	34	55	82	100
Average nominal wage rate per worker (S$/h)	1.3	2.0	7.6	16.7
Average nominal household income (S$/month)	430	820	3,080	6,000
Real household income (2005 = 100)	20	25	65	100
GINI index of nominal household income	46	41	44	47

7.2.2 The development of the transport system

At independence Singapore's road infrastructure was poor and expressways were absent. The supply of public transport was essentially limited to bus services that were provided by several companies along an inefficient, incoherent route system serviced with insufficient, partly obsolete rolling stock. Between 1969 and 1975 the bus companies were merged, a coherent route network was brought into operation and the rolling stock was improved through additions and replacements (Spencer 1988). In 1975, therefore, the public transport situation, though far from perfect, was much better than five years before. In addition, in the first ten years after Singapore's independence the number of private cars almost doubled. In 1975 15% of the labour force either owned a car or had a company car at their disposal. Meanwhile, the road infrastructure remained almost unchanged. Particularly during the morning and afternoon rush hours the roads became heavily congested, with over 74,000 motorized vehicles entering the core of the Central Business District during the morning peak hours. Commuting by the fast growing fleet of private cars was the most important cause of this development. The worsening accessibility of the Central Business District provoked several government measures to discourage car ownership and use, for example through the introduction of road pricing (see next subsection). Also several new express bus services were started in 1975 to mitigate the effects of road pricing. Annex C reviews the use of private cars for commutes to and through downtown Singapore before and after these measures. An extensive overview of the travel conditions that prevailed around the introduction road pricing is given in Annex D. As a consequence of the road pricing a significant proportion of car owners left their car at home and changed to public transport or car-pooling.

[104] More specifically, in 1975 work started at 9:00 a.m. (over 30% of the jobs), 8:30 or 8:00 a.m. (each about 20%), 9:30 or10:00 a.m. (each about five percent) or further dispersed over the morning (about 20%, mostly between 7:30 and 10:00), according to Wilson (1988a).

The introduction of road pricing occurred during the economic recession that struck Singapore in 1975 and 1976, during which time the private car population dropped by five percent to 133,000. It then started to grow again and reached 250,000 in 1989 and 430,000 in 2005 when the rate was one car for every 10 inhabitants, still only 20% of the average in the European Union. This growth occurred despite very high increases in vehicle acquisition taxes, which amounted to three times the car-plus-insurance costs in the 1980s. Between 1982 and 2005 the share of workers who commuted by car (either as a passenger or driver) increased faster than the car population, from 14% to 23%. Despite the astounding increase in car mobility and the increased dispersion of residences over the island, the average one-way commute time remained 27 minutes. The increase in investment in the road network from 1975 onwards may be responsible for this continuing smooth flow of road traffic. Between 1980 and 2005 a nationwide expressway network was built that extended over 150 km (see Figure 13) while in the same period the length of arterial roads doubled to 600 km and the collector road length tripled to 450 km. In that year the average speed during the peak hours was 63 km/h on the expressways and 27 km/h on the arterial roads. The density of the expressway network was 0.21 km/km^2 and the availability was 33 km/10^6 inhabitants. This is, for example, 1.5 times the density and 0.4 times the availability of expressways in the main Dutch metropolitan districts. Taking the arterial and collector roads into account the availability of the Singapore trunk road network is also higher than in Dutch urban areas.

In 1982 Singapore decided to build a metro network, the Mass Rapid Transit system. Five years later the first section came into operation and in 2005 the network comprised 110 km, with an additional 30 km of local feeder rail services. The network connects all the large residential areas developed since 1975 with each other and, of course, with the Central Business District. Though competing long-distance bus services were ended MRT ridership fell initially short of expectations. There are no indications that its opening caused a considerable modal shift from private to public transport or even that it mitigated the growth of car traffic. In the 1980 census public buses accounted for 56% of all commutes whereas in 2005 its share had fallen to 22% , when 15% used the bus as well as MRT and 10% MRT alone. The share of all the public transport modes together, including taxi and local rail feeder lines was 52% in 2005. A notable development is that the average commute duration for public transport users was 43 minutes in 2005 compared to 39 minutes in 1982. In addition to the spreading of residential areas over the island the greater distances between MRT stations compared to bus stops and the time for bus-metro transfers might be responsible for this increase. Even though investments in the rail network were greater than those in the expansion of the road network this could not prevent the advantage in travel time for car driving over transit increasing.

The introduction of the Area License Scheme (ALS) was accompanied by several large-scale surveys, carried out by the World Bank. In the spring and fall of 1975, many Singapore households were interviewed about travel mode choice, trip schedules and other travel-related matters which revealed their responses to the introduction of the ALS. Watson and Holland summarized aggregated results of these studies – further referred to as the World Bank survey – while some additional results may be found elsewhere (Wilson 1988a; 1988b; 1989).

7.2.3 Road-pricing measures

Singapore was the first country to introduce location-specific road charging. From its beginning in 1975 the fare policy aimed primarily to the control of traffic flows. However, over the almost thirty years of its existence to date many drastic changes in fares, operating

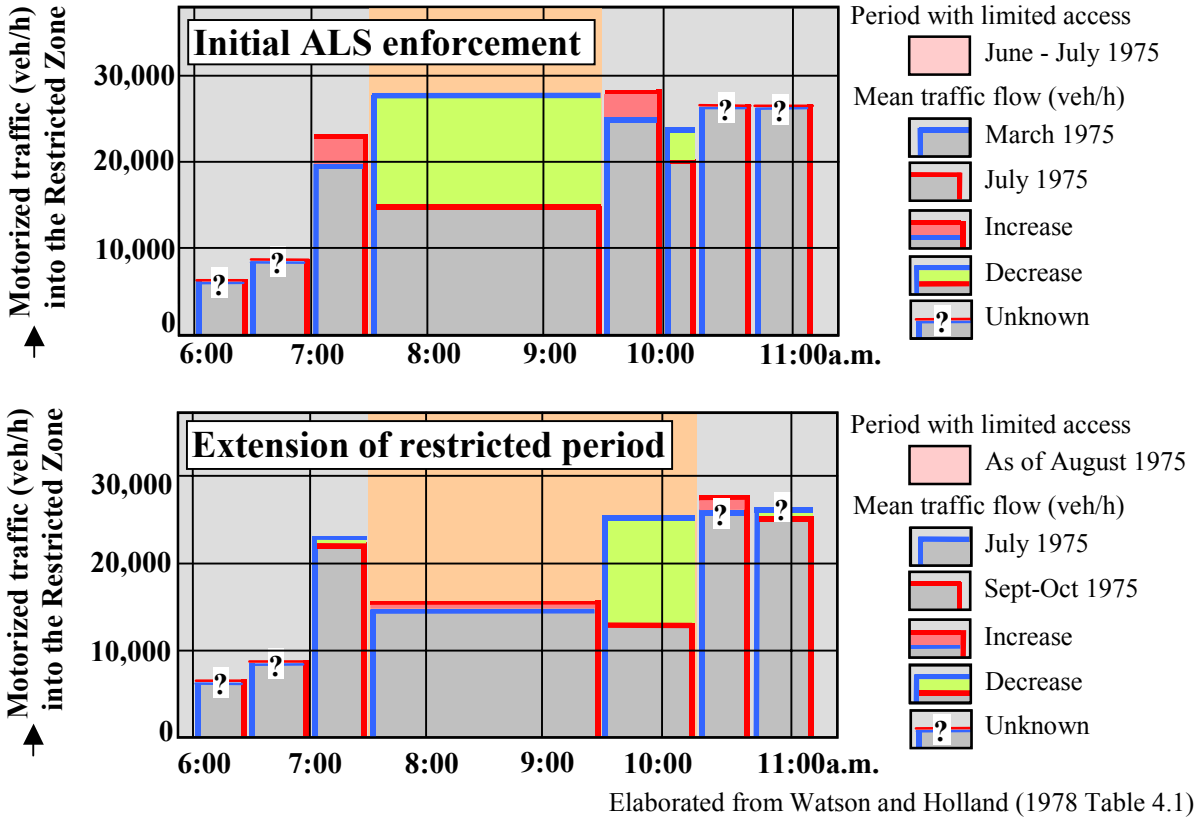
hours, tollgate locations, scope of application and mode of operation of the system have occurred. These are summarized briefly here.

Road pricing started in June 1975 with the introduction of the Area License Scheme (ALS). Its aim was to control access to the Central Business District during the morning-rush hour. From 7:30 to 9:30 a.m., cars with less than 4 occupants were not allowed to pass a cordon around the Restricted Zone that coincided with the core of the Central Business District, unless they bought a monthly or daily ticket that allowed unlimited access. The license fare was set at S$3.00 per day or S$60.00 per month. The ALS was manually operated. The introduction was combined with an increase in parking fees in the Central Business District. Initially there was a strong increase in traffic with taxis, which caused the government to also bring these under the license obligation within the first three weeks.

The most obvious alternative options for car drivers who could not afford the license fee was either to join a carpool or make a modal shift to bus transit, which, as mentioned above, had significantly improved in the previous years. To facilitate such a shift to public transport, express 'Blue Arrow' bus services were launched on several routes, and a few high comfort Air-Conditioned Coach services were provided during the morning commute. The most expensive mitigating measure was the provision of a park-and-ride alternative. The government had constructed several parking lots with 10,000 spaces just outside the Restricted Zone and arranged shuttle buses to bring commuters from there to the Central Business District, originally at a price of S$30.00 per month but this was soon reduced to conventional bus fares. Another mitigating measure was that '*employers in the Central Business District were encouraged to allow staggering of work hours*' (Wilson 1988b: 193), to spread the travel demand across the day. In the end, the introduction of the Area License Scheme (ALS) resulted in a drastic reduction of downtown traffic during the restricted hours whilst outside this period the traffic flows to the Central Business District did not decrease significantly. The 45% reduction in traffic was much greater than the 25 to 30% that was expected. Figure 14 illustrates the changes in inbound traffic flows over the day. Private cars accounted for 95% of the reduction during the restricted period. Annex C gives an extensive analysis of the responses to the introduction of the Area License Scheme by car owners with a destination in or beyond the Restricted Zone.

Government revenues from the Area License Scheme exceeded the current costs many times, but the return on investment for the involved capital expenses got stuck at 77%. Though the official policy aim of the ALS was a reduction in congestion, this may have been one of the reasons why the license fee was raised just seven months after the enforcement of the ALS regime. The price rise was drastic: 33% for private cars and 267% for company cars. It increased the rate of return on the ALS investment for the government from 77% to 95%. The effect on inbound private car traffic was negligible but the fare adjustment presumably contributed to a significant reduction in company car traffic during the restricted period, though simultaneous drastic increases in acquisition and road taxes and the concurrent economic recession may explain at least a part of this reduction as well. In March 1980 the license fares were raised by another 25%, to S$5.00 per day for private cars and S$10.00 per day for company cars. The growth in the number of licenses sold[105] after the economic recession ended in 1978 dropped by a few percent that year but resumed the pre-1980 level until a new recession struck Singapore in 1985.

[105] Inferred here from the government revenues from the Area License Sceme as listed by Willoughby (2000), taking the changes in fares into account and calibrated to the actual number of licenses sold in 1975 and 1976 as reported by Watson and Holland (1978).



Elaborated from Watson and Holland (1978 Table 4.1)

Figure 14: Impact of the ALS introduction on all motorized traffic to the Restricted Zone

In early 1989 the number of licenses sold reached twice the 1976 level. In June of that year commercial vehicles, car pools and motorcycles, which had had free access till then, were brought under the ALS regime. At the same time the ALS was extended to cover the afternoon rush-hour (4:30 to 7:00 p.m.) while the whole day license fares were reduced to S$6.00 per day for company cars and S$3.00 per day for other charged cars. McCarthy and Tay (1993) reported a 30% increase in car traffic and a significant decrease in commercial vehicle trips during the restricted period in the morning. The motorized traffic that entered the Restricted Zone during the new afternoon restricted period diminished by 44%.

Over subsequent years the number of licenses sold kept on increasing and between the morning and afternoon restricted period peak traffic intensities of above 30,000 vehicles per hour were reached, well above the highest intensities that gave rise to the introduction of the ALS in 1975. In January 1994 the intervening 10:15 to 16:30 period was also brought under the license obligation. In addition to the whole-day licenses, cheaper tickets (2/3 of the whole-day price) could also be bought which were only valid during the intervening period. On balance the extension reduced the total inbound traffic considerably. It also caused a strong increase in traffic intensities during the morning restricted hours. The traffic intensity during the new 8:30-9:00 peak half hour was only slightly below the pre-1975 peak half hour intensity. Better round-trip planning was presumably the most important response to this change in the ALS.

In 1998 the manually operated ALS was replaced by a fully automated Electronic Road Pricing system, which allowed the toll fare to be varied over 15-minute periods across the whole day. Even though the fares were set lower than under the ALS regime the inbound

traffic volumes fell by over 15%. One should consider, however, that the ALS fare allowed any number of gantry passages per day while any passage of an Electronic Road Pricing gantry involved payment. Menon (2000) considered that the reduction in observed Restricted Zone entries was caused by route adjustments, such that on each trip only one gantry was passed, and by reduction of the number of trips per day. The advent of Electronic Road Pricing might have stopped the habit of going home for lunch, for example, which was still widespread in the 1970s. Since its introduction the coverage of Electronic Road Pricing was extended to several expressways and arterial roads (Figure 13 on page 190). The flexible, time-of-day dependent pricing appeared a better tool for traffic flow control than the ALS-regime with fares that did not vary continuously during the priced period (Olszewski and Xie 2005; 2006).

7.2.4 Discussion

Road pricing and the investment in rail transport are often cited as the policies responsible for the relatively smooth road traffic in Singapore. The overview in this section suggests that these were supportive rather than the dominant success factors. The most important government policy that resulted in the present travel conditions might have been the measures to deter car ownership, such as imposing acquisition quotas, road taxes, parking fares and extremely high acquisition taxes (see Willoughby 2001). This resulted in one car per ten inhabitants in 2005, a ratio of car ownership which is about 20% of that in comparatively equally-developed countries. After the introduction of road pricing in 1975 large investments in expressways and other trunk roads yielded a road capacity per inhabitant that is equivalent to that of the Dutch metropolitan districts, for example. The even larger investments in a metro network were not able to prevent a deterioration in the competitiveness of transit compared to the car, at least with respect to commute travel times. The most significant contributions of road pricing to the present travel conditions may have been that many car owners started to leave their car at home and changed to ridesharing or transit in response to the 1975 introduction of the Area License Scheme. In the following sections the observations of responses to road pricing that could be retrieved will be analysed from several perspectives.

7.3 Alternatives and attributes for comparison

The aim of this section is to retrieve information about actual responses and changes in the travel circumstances that may be used as material to compare the predictive ability of the UT and EPT theories. Most responses to road pricing that could be retrieved, in combination with the concurrent changes in travel conditions, concerned the introduction of the ALS in June 1975 and the first fare increase in January 1976, as described in Watson and Holland (1978). In Annex C the published information about changes in traffic flows and the aggregated data from travel diaries and travel surveys, in terms of numbers of travellers who chose a certain travel mode or trip schedule, is analysed. The aggregated findings are considered here as the outcomes of the tactical choice behaviour of individuals who are confronted with the measures. The retrieved information about the travel conditions concerns public transport service frequencies, average vehicle speed and aggregated travel time and cost data. In Annex D these are analysed to assess the average travel time and cost attribute levels of the alternatives that are deemed relevant for several groups of travellers.

This section starts with an exploration of the alternatives of the subjective consideration choice set that an individual might consider when she is confronted with the introduction of road pricing during her morning commute. These are compared with the aggregated responses

that are retrieved in Annex C. This is followed by a summary of the relevant changes in attribute levels for those alternatives for which sufficient information could be recovered in Annex D. The outcomes of this latter effort curtails the responses for which predictions can be made. The section results in a segmentation of the travellers into different groups with similar choice sets and attribute levels for which predictions can be made of their responses to the ALS introduction.

7.3.1 Consideration choice sets

Dependent on their socio-economic situation and the context of their daily commutes different individuals may consider different alternatives to cope with the introduction of ALS. In this subsection the considerations that play a role in the individual's choice set formation process are explored. It offers preliminary suggestions for a useful segmentation of the pre-ALS car drivers in groups for which the same choice set composition might be assumed.

The introduction of the ALS implied that car drivers who passed a cordon around a Restricted Zone of Singapore City between 7:30 and 10:15[106] a.m. had to pay a license fee of S$3 per day. Drivers of a 4^+ carpool, i.e. carrying three or more passengers, were exempted from this obligation. The following discussion considers the alternative courses of action that the other individual car drivers who usually passed the cordon between 7:30 and 10:15 a.m. might have considered to cope with the imminent travel cost increase.

The EPT paradigm considers human choice behaviour as a goal-oriented selection process, embedded in a strategic-operational choice hierarchy and aiming to cope with a change in the subject's circumstances that affects her interests. One possible response is the cancellation of the trip. Though this behaviour was actually observed in 1975 the analyses by Watson and Holland (1978) showed that this was not in response to the ALS enforcement. In Annex C these were attributed proportionally to solo and rideshare drivers before the actual choice frequency of the different alternatives was assessed. This behaviour is not considered any further in this subsection.

In the presently considered tactical travel choice contexts the change obviously regards the payment of the license fee: to pay or not to pay, that is the question. From the perspective of the Cognitivist's paradigm (Figure 1 on page 13) one may take it for granted that all car drivers for whom it was going to matter perceived this looming, structural change long before it was enforced. Each individual's choice process, initiated by this perception, would have been aimed at dealing with this challenge. It might start with a context-dependent information search leaning on recognitions from earlier travel choice processes and their experienced outcomes to establish the individual's subjective consideration set as defined by, e.g., Bovy (2008). All alternatives that make no difference to the 'going concern' in the current context will not be added to this set. Courses of action that address higher levels of the choice hierarchy, like quitting the job, moving home or even reducing the probability of a timely arrival at work will thus be disregarded, unless incidentally no satisficing alternative is found at the tactical choice level. At that level only alternatives that prevent payment of the license fee will be added to the default option of payment to allow continuation of the pre-ALS travel mode, route and schedule. Thus, as all alternative routes into the Restricted Zone pass the cordon they will not be considered, as they do not answer the 'payment' question, even though they might promote the subject's interests. Likewise, an individual may use the

[106] Initially (in June and July) 9:30 a.m. The introduction was accompanied by a sudden average S$0.75 increase in the fare for whole-day parking. For expository reasons these adjustments are disregarded in this subsection.

recognition principle to restrain the continua of departure and work start time alternatives to one discrete moment that meets her idiosyncratic limiting conditions and is appropriate to prevent payment. This frugal choice set formation process limits the cognitive and emotional burden of the choice process and might allow 'utility maximization' in the evaluation of the considered choice set but may imply that only a 'satisficing' alternative is chosen from the complete set.

Focussing on the looming ALS introduction, a 'keep-to-your-mode-and-schedule' (KYMS) alternative can be conceived as the default alternative for all pre-ALS car drivers who could afford to pay the license fee. It only differs from their pre-ALS reference state by the higher monetary travel costs. The conventional buses, which operated on many lines that stopped in the Restricted Zone and had a high frequency during the restricted period, offered the default alternative for those who could not afford the cost increases. During the whole restricted period there was also a high fequency of Restricted Zone-bound Blue Arrow express buses and of shuttle buses that served the park-and-ride facilities. However, for many if not most car drivers the access and/or egress of the Blue Arrow service and the park-and-ride option in connection with the offered service frequency might have been too poor for them to be added to their subjective consideration set. Such accessibility constraints were also true, to an even larger extent, for the Air Conditioned Coach service. Joining a carpool required fellow travellers who lived nearby and worked at or close to the driver's job location. The carpool members must also agree to attune their working hours which would have needed the consent of employers. Due to these constraints carpooling, too, will have been in the consideration choice set of only some of the car drivers. Even more constrained were the alternatives in which the home departure time had to be adjusted. Advancement without adjustment of the work start time might only have been considered seriously by commuters with an official work start time of 8:00 a.m. or earlier. Each traveller may have only evaluated the advancement that was just sufficient for her to avoid the license fee. Car drivers with a work start time of 8:00 might have considered an advancement of work start time of half an hour. Those with a work start time of 8:30 who were used to arriving at 8:00 might also have contemplated an advancement of half an hour, but those who commonly arrived from 8:10 onwards may have disregarded any work start time adjustment. Postponements of home departure to pass the ALS cordon after the restricted period requires postponement of the work start time and might only have been considered by drivers who had an official work start time of about 10:00 a.m. Any adjustments in the work start time may further have been considered only if the employer had made it clear that he was also willing to do so. This was presumed to be generally the case, except for postponements until after 10:15 a.m. The most extensive consideration choice sets might therefore have contained less than 10 alternatives and might have been adopted by a few constrained segments of the pre-ALS car driving population only.

Car drivers who worked beyond the Restricted Zone will not have considered the express bus services and the park-and-ride option as serious alternatives. In addition to KYMS and a shift to bus riding, a detour over the ring road might have constituted the core of all subjective consideration sets. For the carpool and departure time adjustments the same observations apply as discussed above for the Restricted Zone-bound commuters.

7.3.2 Observed responses of car drivers

Watson and Holland (1978) presented an overview of the responses of car drivers who were confronted with the ALS enforcement by comparing the traffic counts and household survey

waves for the Spring and Fall of 1975. Disregarding a small number of drivers[107] who went to the Restricted Zone for reasons other than commuting, they distinguish trips with destinations inside and beyond the Restricted Zone. For the first destination they estimated the number of drivers who changed to the bus, changed to a non-driving mode (i.e. most often became car passenger), became 4+ carpool driver or rescheduled their trip to pass the cordon during the toll-free hours. For the second destination they also estimated the number of drivers who detoured the Restricted Zone. For both destinations they also estimated a decrease in trips that was attributed to reasons other than the introduction of the ALS.

These numbers concerned an extrapolation of the observed pre-ALS car traffic proportionate to the changes in trip planning between the pre and post-ALS waves of the household survey. In annex C these extrapolations are refined. Recovered data about car ownership, express bus ridership, occupancy of the new park-and-ride facilities and so on, found in Watson and Holland and several other publications, enabled the driving mode to be split up into 4+ carpool, rideshare, solo driving and park-and-ride and the bus ridership into conventional buses and the new Blue Arrow and Air Conditioned Coach express services. Home departure time, arrival and work start times found in Watson and Holland and Wilson (1988a,b; 1989) were used to attribute changes in the trip schedule into advancements of the home departure time without the adjustment of the work start time, advancements of the home departure time combined with advancements of the work start time and postponement of departure, arrival and work start time. These data also enabled the assessment of cumulative frequency distributions of the arrival and work start times from which the distribution of the sizes of the schedule changes could be estimated. These findings, extrapolated from the pre-ALS traffic counts, are also compared with the post-ALS traffic flow observations as documented by Watson and Holland. It revealed a large overestimation of post-ALS car traffic. Therefore, an alternative assessment of the responses to the ALS was made that drew on retracing the post-ALS travel flows. This yielded a better agreement between the changes in car traffic flows and the changes in the individual's trip planning as followed from the household survey. The adopted 'retraced' observed responses are listed in Table 10. An extensive overview of the assessments is given in Annex C.

One might consider that the introduction of the ALS also changed the travel context of non-driving commuters. Actually, Watson and Holland found a significant shift by members of vehicle-owning families from bus to carpool ridership. The changes from rideshare passenger to car driving were about equally frequent as the reverse, suggesting continued alternative driving arrangements (see Annex D). Watson and Holland (:81) also found that '*there is no reason to believe that the Area License Scheme affected the trip-making behavior of people from non-vehicle-owning households.*' This is confirmed by the virtually zero shift from bus ridership to car or 4+ carpool passengership by members of these households, who accounted for about 60 % of all the commutes to the Restricted Zone (see Annex C). As these observed non-responses to the ALS do not offer material for comparison of the predictive ability of the UT and EPT paradigms they are disregarded here.

7.3.3 Considered attributes and their levels

From the preceding subsections it is evident that the level of the ALS fee is a crucial attribute of the different alternatives from which the individual commuter can choose to cope with the

[107] This concerned trips for shopping, social, recreational and personal business purposes that amounted to 2 % of all pre-ALS trips between 7:30 and 10:15, of which 90 % were either cancelled or rescheduled to the license-free parts of the day.

ALS enforcement. Other obvious monetary attributes are the expenses for parking, park-and-ride facilities, bus trips and the running costs of car trips. As the duration of trips by transit and car differs strongly in Singapore, like elsewhere, travel time is the other main determinant for the individual's travel choice behaviour. In annex D the available information about trip cost and times before and after the ALS introduction is reviewed and re-examined. They are largely based on information about personal characteristics and travel choices from the World Bank household survey and speed and traffic measurements as reported by Watson and Holland (1978). These are supplemented with additional analyses to arrive at realistic estimates of the attribute levels of the groups of travellers considered here. In agreement with the adopted perspective on the individual's choice behaviour only the levels of time and monetary cost attributes are assessed there. It is assumed that attributes like comfort or alternative-specific hidden factors can be approximated by stochastic interpersonal variations in the VTTS.

Table 10: Retraced actual responses to the ALS enforcement

Car drivers' responses to ALS	**Retraced from post-ALS traffic**	
	Solo driver	Drivers with passenger
Commuters on their way to work within the Restricted Zone		
Pre-ALS total	10,200	10,000
Cancelled trip or shifted to non-driving mode	3,500	4,700
Shifted to conventional bus	700	2,300
Shifted to Blue Arrow or ACC service	400	300
Accepted Park-and-Ride	600	-
Advanced home departure, same WST	600	300
Advanced home departure and WST	400	200
Postponed home departure and WST	300	200
KYMS (Kept to pre-ALS mode and schedule)	3,700	2,000
Commuters on their way to work beyond the Restricted Zone		
Pre-ALS total	9,600	3,900
Cancelled trip or shifted to non-driving mode	3,700	2,100
Shifted to conventional bus	-	-
Detour via ring road	3,900	1,200
Advanced home departure, same WST	500	100
Advanced home departure and WST	200	100
Postponed home departure and WST	100	100
KYMS (Kept to pre-ALS mode and schedule)	1,200	300

Numbers relate to pre-ALS non-carpool drivers who entered the future Restricted Zone between 7:30 and 10:15a.m., rounded off to multiples of 100. Empty cells indicate that less than 100 car drivers chose the option. WST = work start time. ACC = Air Conditioned Coach

The attribute levels for the travel alternatives that were relevant before and during the ALS enforcement are assembled in Table 11. They can be considered as averages across the groups of travellers for whom the alternatives to which they apply are feasible options. Car users who changed to carpooling after ALS enforcement appeared to have the same travel time as before. As they escaped the ALS fee and at most kept the same expenses as before the change,

this was clearly the dominant alternative for them. No information was retrieved about the 'would-be' travel time for the drivers who kept on driving alone or with one passenger if they had joined a carpool.

Table 11: Adopted attribute levels for the pre-ALS travel alternatives

Pre-ALS trip attribute (averaged over all concerned travellers)	Post-ALS trip attribute(averaged over all concerned travellers)	Spring 1975	Fall 1975
Trips to the Restricted Zone (RZ)			
Fee for car entering RZ	Fee for car entering during RP [1]	S$0.00	S$3.00 [2]
Fee for whole-day parking	Fee for whole-day parking	S$2.50 [2]	S$3.25 [2]
	Fee for park-and-ride services		S$1.50 [2]
Fare for one-way common bus trip	Fare for one-way common bus trip	S$0.40	S$0.40 [3]
Running costs, car trip	Running costs, car trip	S$0.85 [2]	S$0.85 [2]
Running costs, 8 km car trip [4]	Running costs, 8 km car trip [4]	S$0.70 [2]	S$0.70 [2]
Travel time, car trip during RP	Travel time, car trip during RP	28 min [5]	27 min [5]
	Travel time, park-and-ride trip	29 min [5]	36-44m [5]
Travel time, car trip before RP	Travel time, car trip before RP	26 min [5]	31 min [5]
Travel time, 8 km car trip during RP [4]	Travel time, 8 km trip during RP [4]	25 min [5]	24 min [5]
Travel time, average bus trip	Travel time, average bus trip	41 min [6]	40 min [6]
	Travel time, Blue Arrow/ACC trip [7]	41 min [6]	≥ 35mn [6]
Travel time, 10 km bus trip [6]	Travel time, 10 km bus trip [8]	47 min [6]	46 min [6]
Trips to and beyond the Restricted Zone (RZ)			
Fee for car traversing RZ	Fee for car traversing during RP	S$0.00	S$3.00 [2]
Fee for whole-day parking	Fee for whole-day parking	S$1.00 [2]	S$1.30 [2]
Fare for one-way common bus trip	Fare for one-way common bus trip	S$0.50	S$0.50
Running costs, average car trip	Running costs, average car trip	S$1.00 [2]	S$1.00 [2]
	Running costs, detoured car trip		S$1.20 [2]
Running costs, 10 km car trip [4]	Running costs, 10 km car trip [4]	S$0.85 [2]	S$0.85 [2]
Travel time, average car trip	Travel time, average car trip	33 min	32 min
	Travel time, detoured car trip	33 min	40 min
Travel time, 10 km car trip [4]	Travel time, 10 km car trip [4]	30 min	29 min
Travel time, average bus trip	Travel time, average bus trip	48 min	47 min
Travel time, 12 km bus trip [7]	Travel time, 12 km bus trip [8]	52 min	51 min

[1] RP = Restricted Period from 7:30 to 10:15 a.m. [2] For rideshare drivers: 60%. [3] Blue Arrow express buses: 0.50 S$; Air Conditioned Coach service: 1.00 S$. [4] Calculated hypothetical value for a car trip with the same distance as an 'average' bus trip. [5] Drivers who carried a passenger: plus one minute. [6] Plus one minute for former solo drivers, minus two minutes for former drivers who carried a passenger. [7] ACC = Air Conditioned Coach service. [8] Calculated hypothetical value for a bus trip with the same distance as an 'average' car trip.

7.3.4 Assessment of population segments for which predictions will be made

The overview of the retraced actual responses to ALS enforcement (Table 10) is considered as the material to compare the predictive ability of the UT and EPT paradigms. Such a

comparison is only feasible for alternatives for which attribute levels are known and that allow the assessment of their value according to the different paradigms. As cancellation of trips is apparently not a consequence of the enforcement of ALS and no quantitative attributes are known that can explain this behaviour these will not be considered in the predictions. The shift from car driving to 4^+ carpool driver or passenger is definitely a major response to the ALS introduction. As the costs are lower than for solo or rideshare driving and no quantitative information about the differences in travel time or affective and/or utilitarian attributes between these alternatives could be retrieved, according to any implementation of the UT and the EPT paradigms this alternative will be dominant to other driving modes. This prevents a comparison of the predictive ability of both paradigms with respect to this mode-shift to 4+ carpools. This change is therefore left out of the comparison of actual and predicted responses to the ALS scheme.

Disregarding the pre-ALS car drivers who cancelled their trip or joined a carpool, 21,200 drivers had to choose how they were going to cope with the ALS enforcement. Based on the observations above different consideration choice sets can be conceived, dependent on the individual's travel contexts. As only averages of attribute levels across groups of travellers are available, prediction requires a deliberate segmentation of this remaining driving population into segments in which all drivers may have had the same consideration set. For example, commuters who worked within the Restricted Zone and had a work start time of 7:45 a.m. or 8:00 a.m. may have had the largest subjective consideration choice set. It may have contained the KYMS and shift-to-transit defaults, the Blue Arrow or Air Conditioned Coach express bus services, the park-and-ride alternative and advancement of the home departure, whether or not combined with advancement of the work start time. Commuters with a work start time between 8:31 and 9:30 a.m. might have disregarded any schedule adjustment, leaving the other four options.

The two main distinctions that are applied for the segmentation are:

i. Destinations within and beyond the Restricted Zone; and

ii. Solo car drivers and rideshare drivers.

To approach the interpersonal differences in trip scheduling and accessibility constraints a further subdivision will be applied in six work start time categories: at 7:45, 8:00, 8:15, 8:30, 8:31-9:30 and 9:31-10:15 a.m. For the 7:45 and 8:00 a.m. work start time classes, subsegments of five-minute pre-ALS arrival time bands allow for a more balanced reference-dependent assessment. The differences in the accessibility of alternative services as discussed in Annex D will also be approximated by further subdivisions. Five subsegments approach the supposed normal distribution over the population of the expected travel time increases if the park-and-ride alternative was chosen. For destinations beyond the Restricted Zone a similar sub-segmentation will be applied for the time required for detours over the ringroad. The limited accessibility to the express bus services will be simulated by assuming that 10% of the car drivers had access to a Blue Arrow or Air Conditioned Coach line that reduced their equivalent conventional bus trip by at least five minutes while the corresponding travel time difference for the remaining car drivers is considered to be negligable.

7.4 An operational model for trip planning prediction

This section describes the development of an operational model that specifies all the assumptions of EPT and UT in a way suited to predicting the tactical travel choices of

commuters. As the outcome of such choice processes is considered to act as a script for operational travel choices, the model developed hereafter should also offer an appropriate description for the travellers' 'default' choices from the feasible alternatives for the daily recurrent operational trips. Readers who are not interested in the theoretical underpinning of the model can move on directly to the model description in Subsection 7.4.9.

The approach followed in this section is deductive, starting from the constituent assumptions according to EPT as listed in Table 2 (page 96). First, the framing principles as they might be applied in the tactical commute choice context are elaborated in Subsection 7.4.1. In the following subsection the commensurability of time and money attributes is discussed. The levels of these attributes are considered to be the decisive factors for travel options with differences in fares and/or road pricing. Next, a way to cope with different travel time components and the experience of different travel circumstances is discussed. The following subsections elaborate the loss aversion, weighted probability and diminishing sensitivity assumptions for tactical travel choices and derive approximations for them that are sensible for the commute contexts considered in this chapter. As information about attribute levels, reference states and alternatives, and the preferences among them is missing at the individual level, subsection 7.4.8 focuses on how to deal with interpersonal differences in the valuation of time and money attributes. At the end of all these subsections the corresponding model assumptions are adopted according to the UT paradigm, wherever the building blocks which agree with EPT differ from those that are commonly employed in travel behaviour research. In the penultimate subsection the building blocks are united in a conceptual model for the prediction of the tactical travel choices of individuals as a response to changes in their choice context. Further simplifications are added that allow calibration and prediction based on the aggregated information about the travel contexts considered in this chapter, in agreement with the EPT and/or the UT paradigms. The section ends with a discussion and conclusions.

7.4.1 Framing of the choice process in the travellers' actual context

The trigger to starting any of the different choice-behaviour processes of car-owning travellers that are described in this chapter is the perception of a concrete change in their travel circumstances, in this chapter most often a change in road user fares. This change is considered to demand a choice between several alternative courses of action that coincide with different changes in the reference state. This subsection explores the approaches that can be followed to model the general assumptions of EPT about the individual's framing of reference state, choice set, needs and aspiration levels for their gratification (see Table 2 on page 96) in the tactical travel choice contexts considered in this chapter. At the end of the subsection the equivalent approaches in agreement with the UT paradigm are examined.

The reference state for each choice process is considered to apply to the travellers' circumstances, possessions, constraints, patterns of behaviour, expectations, etcetera, as far as they may influence a response to a concrete change, and at the time when the coming change in travel conditions is perceived. In agreement with the strategic-operational choice hierarchy of EPT this reference state is conceived as the outcome of her previous strategic and tactical choices. Once a concrete choice is made and put into operation for some time, the reference state is 'updated' and this updated reference state is considered when the next change in the travellers' context demands the initiation of a new choice-behaviour process. For car owners making daily recurrent trips to or through the Restricted Zone, the reference state includes at least their out-of-pocket trip expenses for the day, their usual home departure time, their commonly experienced probability distributions of travel time and corresponding arrival time. The latter will include some exceeding frequency of lateness compared to some discrete

arrival constraint. The reference state also includes geographic and socio-economic characteristics, like the location of the travellers' residence and workplace, the accessibility of these locations to and from parking and bus stops, car ownership, income/wealth, employment, etcetera. Many of these may remain unchanged during several of the successive tactical and operational travel choice processes discussed here but may, for example, largely determine a traveller's value of travel time as applied in these processes.

The available choice alternatives that are relevant in this chapter are combinations of destination, travel mode including different rideshare arrangements, route and departure time, of which mode and departure time will be the main considerations hereafter. In addition to several alternatives that merit serious consideration by specific segments of the car-owning population, two alternatives are considered to be feasible in any context: switching to bus transport, and keeping to the previous travel mode, route and daily activity time schedule by paying the license fee/road price. The attributes of all the feasible alternatives are conceived as differences compared to the traveller's actual reference state. They may comprise deterministic changes in running costs, out-of-pocket expenses for fares and fees, travel time, departure and arrival times, work start and finishing times, discretionary time spent at home or elsewhere, and probabilistic changes in travel time and arrival time. Within the EPT paradigm attributes like ownership taxes and depreciation costs for cars and the average daily working hours of commuters are a consequence of earlier strategic decisions. As changes in them are not feasible alternatives in the tactical and operational travel choice context at stake they are disregarded here. This yields subjective consideration choice sets that predominantly consist of adjustments of the reference trip with respect to route, departure time, and travel mode and ride share arrangements. The alternatives and attributes in these sets are presumed to be traced by the travellers' recognition from earlier travel choice appraisals. Many of these alternatives are only feasible for a limited number of travellers who may treat several ranges of attribute levels as unacceptable.

With respect to the travellers' needs it is assumed that the outcomes of previous strategic choices with respect to employment, including daily working hours, residence location, family ties have priority and that these act as constraints that impose restrictions on the feasible alternative departure times, routes and time schedules. Where these constraints limit the range of attribute levels they might be described with an Attribute-Based Elimination rule. In the analysis of stated choice games this is a logical step, as people are inclined to consider all the submitted alternatives seriously. For the prediction of real-life behaviour, discussed in this chapter, it seems more appropriate to leave such 'unfeasible' alternatives out of the subjective consideration set. The recognition-driven framing of the consideration choice set as conceived above is in agreement with a satisficing rather than maximizing aspiration level. Within the above-mentioned constraints, a maximizing aspiration level is assumed for evaluation and choice. There is ample evidence that majorities of survey populations use this routine in experiments and most real-life contexts, at least when the number of considered alternatives is small (see Section 4.4). Though minorities may even then have satisficing aspirations, no convincing evidence was found that proves its significance as an explanation for the application of non-compensatory rules, which may derive their rationale as well from the need to comply with constraints. As furthermore the aggregated character of the retrieved information on travel-choice behaviour does not allow for the assessment of the character and the extent of occurrence of satisficing decision rules among Singapore's travellers these are disregarded here.

Unless it is one of the feasible choice alternatives, the reference state is principally irrelevant for the context-independent and reference-independent valuation and choice processes as assumed under the UT paradigm. The real levels of the attributes are assumed to be compared with each other, instead of their differences with those of a reference state that has been updated since the last choice in the current context. Though according to the UT paradigm all the theoretically feasible alternatives and associated attributes should be evaluated, only those that are considered relevant from the EPT perspective are considered in this chapter. This reduction to a consideration set and the disregard of attributes like depreciation costs is in agreement with most practical travel choice assessments in the tactical domain that claim to follow the UT paradigm. For evaluation-and-choice only maximizing aspiration levels and compensatory decision rules are considered.

7.4.2 Valuation and commensurability of attributes

In agreement with EPT it is assumed that individuals value attributes, chances and alternatives according to hedonic principles and that they are consistent in their successive choice behaviour within similar contexts. In the previous subsection it was argued that travellers might have maximizing aspiration levels for the choices from their limited, 'satisficing' subjective consideration sets. This requires commensurability of attributes. The most important attributes considered in the present chapter are travel time and expenses, which have different dimensions. These may also be the most common attribute dimensions of human choice processes. Following the 'weighted additive value' concept of behavioural Decision Theory (Section 4.4) it is assumed here that each individual attributes idiosyncratic importance weights to these attributes, to compound these in the considered context. These weights are influenced by the subject's earlier experiences and actual needs and can be considered as an important element of the reference state. In a concrete tactical choice context the previous reasoning is equivalent to the assumption that each traveller has an idiosyncratic value of travel time savings (VTTS) that holds within similar successive travel choice contexts and allows for the commensurability of attributes with a money and a time dimension. This subsection explores how this assumption can be quantified in the tactical travel choice contexts considered in this chapter.

Following hedonic principles the VTTS is defined as:

VTTS = Monetary value of travel time (S$/h) =
Psychological value of a unit decrease in travel time (-/h) /
Psychological value of a unit decrease in monetary travel expenses (-/S$)

The psychological values are considered to encompass hedonic experiences as well as motivational factors (see Higgins 2006), which makes them equivalent to Kahneman and Tversky's (1984) decision values and Kahneman's (1999) decision utilities. Substitution of utility for psychological value in the definition above yields the common definition followed in Random Utility Maximization models, which makes it equal to the ratio of the coefficients of travel time and cost as found in discrete choice models with a linear utility specification. Mackie et al. (2001b) reported that this VTTS concept is the same as the one DeSerpa (1972) derived by following a rigorous neoclassical UT treatment of the valuation of time. Both travel time and cost are formulated here as positive changes. This enables the 'marginal substitution of time for money' concept behind it to be illustrated with the common shape of an indifference map in agreement with Neoclassical Utility Theory. The left-hand side map of Figure 5 (page 55) does so from the perspective of the reference-independent UT paradigm. Within the PT/EPT paradigm this definition applies to the first or 'equivalent gain' quadrant

of the right-hand side map of Figure 5. Similar definitions as for VTTS might be considered for the indifference relations in the second or 'Willingness to pay', the third or 'equivalent loss' and the fourth or 'Willingness to Accept' quadrant. Here, attribute-specific loss aversion factors are used instead, to catch the differences in the valuation of travel time between the quadrants.

As, within the tactical and operational contexts considered here, time spent daily for work is conceived to be fixed, travel time can only be exchanged for discretionary available time, which in the actual context will most often be time spent at home. Likewise, money spent for travel in the tactical and operational contexts considered here concerns out-of-pocket expenses that can be exchanged for discretionary spending (see also Van de Kaa 2005). As stated in the previous subsection the consequences of an earlier strategic decision, like capital expenses for buying a vehicle, are not considered in the subsequent tactical and operational choice behaviour discussed in this chapter. This means for the actual travel choice contexts:

VTTS (S$/h) =

Psychological value of a unit increase in time for discretionary activities (-/h) / Psychological value of a unit increase in money disposable for discretionary expenses (-/S$)

This concept of the value of travel time and money expenses as equivalent to the value of discretionary expenses conjoins elements of the value-of-travel-time and value-of-schedule-delay approaches in trip planning and in modelling that is trip, tour and activity-based, but only those elements that are relevant in the actual choice context of the individual. This concept is based on the straightforward application of hedonic valuation principles. However, by assuming fixed work duration it can also easily be derived from the value of travel time savings that DeSerpa (1971) found from an elaboration of the principles of Neoclassical Utility Theory. In a strategic context, like a choice between different employers and/or jobs, the same individual might consider travel time, for example, as exchangeable for time spent earning money, in which setting she may value VTTS equal to her hourly wage rate.

In the contexts discussed in this chapter, the value per unit of travel time reduction is thus considered to be equal to the value per unit of discretionary time increase, whether gained by a later home departure time, an earlier home arrival time or any additional time spent for discretionary purposes elsewhere. The duration of the time spent working is considered to be the consequence of the individual's strategic decisions and to act as a rigid constraint on tactical trip and activity planning. In case of fixed start and finishing times for work these are conceived in the same manner[108]. From this perspective there is no need to believe that each individual attaches a specific monetary value to late arrivals or early departures at the workplace, as in the actual context the only feasible possibility for the commuter to cope with changes in travel time is to adjust her earlier tactical departure time-mode-route choice. If the work start time is a discretionary option for the choice subject, there is no need to assume another value of time for early or late arrivals than the value attached to time spent on discretionary activities. Travellers may choose to advance or postpone their home departure

[108] Note that the consequences of actual violations of the nominal working hours are considered to affect a higher level of the strategic-operational choice hierarchy than the operational commute choice context in which they are generated. People with very strong constraints at home will be forced to pass through such a strategic choice process once they cannot accommodate increased travel time unreliability within their operational choice context, but this will most often be exceptional. Therefore the chance of formal work hour violations is conceived here as an idiosyncratic constraint for the operational choice context.

time to cope with their idiosyncratic constraints at home and/or away from home and thus, for a fixed duration of working hours and other activities away from home, find the best match of travel and discretionary expenses (time and money) in their daily schedule. There is thus no need to assume a trade-off of late arrivals versus money, at least in the tactical and operational travel contexts. In other words, it is conceived that most individuals choose as if they apply an Attribute-Based Elimination rule to reject alternatives that violate their idiosyncratic arrival time constraint. Obviously, when in a stated choice game such an individual is confronted with such a violation of her arrival constraint and if her statements are analysed with a model assuming compensatory, utility-maximizing choice behaviour one might elicit any value for late arrivals, depending on the design of the stated choice game and the adopted formula for the utility function.

The definition of VTTS according to UT leads to descriptively the same result as the one in agreement with EPT that was elaborated above. The equalization of the values of travel time and discretionary time follows from the elimination of alternatives from the consideration set that were rejected in earlier strategic trade-offs. If the UT assumption is followed to consider an exhaustive, complete set of possible alternatives, including the strategic choices of employers and working hours, one would be better off following the treatment in, for example, DeSerpa (1971). However, as the limited consideration set that is evaluated here does not contain changes in the time spent working, the reasoning above satisfies the premises of UT as applied within this constraint context. Clearly, contrary to EPT the definition according to UT holds for increases as well as decreases in the relevant attribute levels.

7.4.3 Valuation of time components and experienced travel circumstances

Though the value that travellers attach to changes in travel time and the corresponding consequences for their daily activity program is presumably the single most important factor, several other attributes of the alternatives may influence their tactical and operational travel choices as well. There is, for example, no doubt that an individual, if requested, values different travel time components differently, depending on her appreciation of the travel circumstances. A well documented finding is that public transport users value the time required for walking and waiting about twice as highly as their in-vehicle time, and car drivers value time spent in congestion, particularly if unusual, much higher than their free flow time (see Section 6.3 for an overview). Some studies (e.g. Caussade *et al*. 2005) have even revealed subadditivity: the value attributed to the total duration of a trip was lower than the sum of the values attributed to the constituent time components. This subsection elaborates a modelling concept that circumvents this anomaly by considering that these studies elicited the combined effect of the valuation of the travel time duration *per se* and the appraisal of the affective experience during that time. It proposes that the duration *per se* of different time components may be compounded with one idiosyncratic VTTS while the affective experiences during the different travel episodes may be considered in connection with the other attributes that are not naturally valued in a time or money dimension.

Reasoning from first principles, the value-of-travel-time *per se* is not considered to differ between different episodes of the same trip. Even if such differences could be elicited in stated choice surveys designed to reveal them, adhering to the EPT principles they may not have an important impact on the real-life travel choices between alternatives with different overall travel times. For example, the in-vehicle travel time in public transport and the equivalent ‘average’ travel time of car drivers are most often quite similar and in a mode choice context the walking and waiting components of public transport and any extra congested travel time of car trips may be considered as time losses relative to a reference.

From this perspective the higher values found for these time components might to a large extent be driven by loss aversion and could do the same as a reference-dependent, loss aversive valuation of the resulting overall difference in travel times. Under the EPT-paradigm, as conceived here, it is assumed that in a real-life choice setting the values per unit time are the same for the different episodes of a trip, apart from the loss aversive appraisal of differences between the overall travel times of the considered alternative and the reference trip.

This leaves an idiosyncratic affective appraisal for the characteristics of the trip components other than their duration. The values attached to it are similar and to some extent form part of the alleged 'comfort' attributes and/or alternative-specific constants of travel alternatives as commonly considered in analyses that adhere to the UT paradigm. Note that these appraisals will be influenced strongly by the travellers' experiences with the consequences of their previous travel choices and the co-occurring hedonic adaptation. For example, many train passengers may appreciate the opportunity to read at ease and enjoy their stroll to the station but despise the loud mobile phone conversations, while others might like the lively conversations in the compartment but utterly dislike the non-smoking regime and the strenuous walk to the office. Similar positive and negative affective appraisals might be elicited at will from other transit users, car drivers and bicycle riders. Within the EPT paradigm these appraisals might be considered as 'experienced values' following a previous choice. These might, as 'remembered values', definitely influence the 'decision values' in successive choice contexts. There they will strengthen the reference dependency of the choice behaviour process. On balance positive experiences might result in an additional inclination to continue to travel by the same mode as in the reference state while negative experiences may do the opposite. The extension neglect as observed for affective or hedonic appraisals (e.g. Kahneman and Frederick 2002) suggests that this inclination does not preponderantly depend on the duration of the experiences.

A more or less exhaustive elicitation of the many characteristics of trips and the different affective appraisals attached to them seems unfeasible, even disregarding that these affective values may change with the choice context. As most affective appraisals are related to the most commonly-used travel mode, including the required access and egress modes, one might consider adding a reference-mode-specific dummy parameter to the value function to catch the overall impact of these effects under the premises of EPT. This should apply to all the alternatives considered that have the same mode as the reference state. In an analysis of travel mode choice according to the UT paradigm this parameter may do approximately the same job as a mode-specific and/or a 'comfort' attribute.

A stochastic assessment of this 'reference-mode' dummy might be appropriate. One could also consider attributing the effect of interpersonal differences in the choice context on VTTS to this parameter. Actually, in Random Utility Maximization Theory, which assumes the context independency of preferences, this heterogeneity in unobserved actual choice contexts and preferences is implicitly treated as one random 'taste' attribute that does not relate to the size of travel time differences or to total travel time. Another approach might be to conceive VTTS itself as a stochastic quantity that takes care of the interpersonal heterogeneity in contexts and tastes. Fosgerau (2005: Sect.2.1) called the former concept '*Pure optimisation error, utility space*' and the second '*Pure preference variation, Willingness-to-Pay space*' and found that the second approach yielded a much better description of the observed choices in the Danish national VTTS survey than the former. He found an even better description when the stochastic variation in the VTTS was considered as proportionate to the trip duration. This

finding might be expected if the duration of pleasant and unpleasant experiences that are 'tasted' on a trip play a role in the subject's choice, even if it may not be preponderant. Such a specification may have the additional advantage that it might cover, to some extent, estimation errors of individuals in the conversion of time attribute levels. Therefore, following Fosgerau, the stochastic contribution to VTTS is presumed to be proportionate to the travel time and is considered to cover individuals' VTTS estimation errors and a part of the interpersonal taste heterogeneity. Another part of the interpersonal taste heterogeneity is considered to be covered by treating the reference-mode-specific dummy introduced above as a stochastic variable. To a certain extent this approaches Fosgerau's combination of '*preference variation and optimisation error*'. A further improvement may be to consider the changes in travel time and costs as relative to the total travel time and travel expenses, by assuming it as inversely proportional to it. This latter improvement is not considered here, as the aggregated nature of the available data means that it cannot be tested.

7.4.4 Loss-aversive attribute valuation

In agreement with EPT it is assumed that in most contexts the majority of people value losses much higher than gains of equivalent size. Application of this assumption in a model that predicts tactical choices requires information about interpersonal differences in the size of loss aversion factors and the attributes to which they are applied. This subsection examines the available information about loss-aversive valuation to arrive at quantitative estimates for the employed sizes of loss aversion factors in connection with the attributes to which they are applied and their distribution amongst Singapore's commuters.

The size of the loss aversion factor attached by an individual may differ between attributes. The size of the loss aversion factor attached by different individuals to the same attribute may also differ. Although a clear majority of travellers will value all relevant attributes loss aversively, different segments within the population may follow other choice behaviour strategies to exhibit it. For example, many travellers who value travel time increases much higher than equally sized decreases may consider monetary travel expenses as routine market expenses and will attach no additional value to these cost increases compared to the equivalent savings. Another population segment may use an elimination rule to cover the difference in appraisal between gains and losses, and a small but significant minority may not exhibit loss aversion at all. The aggregated nature of the information about Singapore's travellers and their travel-related contexts prevents their use for the assessment of the distributions of such choice behaviour strategies and the corresponding loss aversion factors over the population.

For the prediction of loss aversive travel choices according to the EPT paradigm the loss aversion factors are considered as random parameters in the value function that may differ between the time and money parameters. This may cover the interpersonal heterogeneity in loss aversion factors to a certain extent. In most appraisals in this chapter the 'average' behaviour of large groups of travellers is predicted and compared with observations. For these appraisals the random interpersonal variation as assumed in the value function will be considered to be 'averaged' and submerged in the overall dispersion of interpersonal VTTS. However, following the intrapersonal consistency principle of EPT it is assumed that within a certain choice context individuals keep to their choice behaviour strategy, including once adopted loss aversion factors.

Where appropriate, following the findings from behavioural sciences and travel behaviour assessments, $\lambda = 2.0$ is adopted as a rough estimate for the 'average' loss aversion factor for

time, money and affective attributes (see Sections 4.3 and 6.3 for an overview of findings and references). These include the 'certain' attribute levels, like advancement of home departure time, as well as probabilistic attribute outcomes like the different travel time increases that are expected when different expected probabilities come true. It is assumed that the most prominent interpersonal differences in choice behaviour strategies lie in whether individuals apply loss aversion to time changes, to changes in money expenses, to both or to none. These choice behaviour strategies are hereafter denoted as LA(2,2), LA(2,1) and LA(1,1). LA(2,2) stands for a strategy in which both time and money losses are valued twice as high as gains of equivalent size ($\lambda_{time} = \lambda_{money} = 2$). LA(2,1) assumes an average loss aversion factor 2 with respect to time changes ($\lambda_{time} = 2$) and a loss-neutral appraisal of money attributes ($\lambda_{money} = 1$). LA(1,1) assumes a loss-neutral valuation of all attributes, in agreement with UT ($\lambda_{time} = \lambda_{money} = 1$). As the survey of observed choices from behavioural sciences in Chapter 4 revealed no substantial occurrence of a LA (1,2) strategy this combination is not included.

In the absence of survey data that allow for a more tailored assessment of the distribution of these choice behaviour strategies over the population, the data from the Dutch stated choice surveys as published in Van de Kaa (2006) are followed here. These showed that application of LA (1,1) could explain the successive choice behaviour of 35% of the respondents. Most of the answering sequences of these respondents were also found if the same individuals were presumed to have valued in agreement with LA (2,2) or LA (2,1). These latter strategies explained 62% of the sequences of all responses. Only an intermediate range of the sequences that would follow from LA(1,1), indicating 'average' VTTS values, could not be predicted by application of the loss-aversive strategies. These covered just 3% of all that could be explained by LA(1,1) while 30% of the sequences that followed from the application of LA(2,2) as well as LA(2,1) could be explained from this intermediate range of VTTS values. When the 'overlapping' choice sequences are attributed to LA(2,2), LA(2,1) and LA(1,1), according to the ratio of the frequency of the non-overlapping sequences, this yields approximately a 70-30-0 distribution. In addition to LA(2,2) and LA(2,1) strategies, several others were identified that drew on similar loss-aversive principles by applying attribute cut-offs and two-stage appraisals. These revealed similar VTTS values as the PT-based strategies. These additional strategies covered about 30% of all respondents. For current prediction purposes under the EPT paradigm the 70-30-0 distribution of the LA(2,2), LA(2,1) and LA(1,1) choice behaviour strategies is considered an acceptable approach, in view of the highly aggregated nature of the choice data as discussed elsewhere in this chapter. Obviously, under the UT paradigm individuals are conceived to exhibit no reference-dependent loss aversion. This can simple be effectuated by applying LA(1,1) where appropriate.

7.4.5 Values of travel time reliability and probabilities of late arrival

This subsection considers how to deal with probabilistic variations in the travel time of commuters when information about the travel context and choice behaviour is only available at the population level.

Under the premises of EPT commuters are considered to be well acquainted with the frequency distributions of their travel times and the corresponding chances of late and early arrivals. This seems a plausible assumption, as they experience similar trips every day and also observe the consequences of the travel conditions of similar trips by their colleagues. It should be underlined that their knowledge is not assumed to be at the conscious level, let alone in terms of formal mathematical representations of frequencies. To account for interpersonal differences in the valuation of uncertainty in travel time it is assumed that

people choose their trip schedule each day such that they limit the chance of late work start times. They do so to such an extent that, in the longer term, their career prospects and/or employment status are not endangered. The same process is assumed for violations of the nominal work finishing time. This implies that the individual will primarily adjust the 'discretionary' or 'home' side of her journey when she is confronted with changes in the frequency distribution of travel times.

Within their operational context, it is assumed that people employ covert 'System 1' mental reasoning processes to value changes in the probability distribution of travel times (see Section 2.3). EPT assumes that these processes yield choices that are equivalent to those found according to Cumulative Prospect Theory (Tversky and Kahneman 1992). This assumes that the subject applies the same value to probabilistic travel time decreases as to an equal 'certain' decrease in it, but she is considered to attach a non-linear weight factor to the corresponding chances or expected frequencies. As no information was retrieved about frequency distributions of arrival, departure, work-start and work-finishing times on the individual level, this assumption could not be tested in this chapter. The previous reasoning implies that large interpersonal differences in the acceptable chance of late arrivals at work have to be expected, depending on employment status and/or position in the work place hierarchy.

According to UT people do not attach weights to probabilities or attribute the same values to probabilistic travel time decreases as to equally sized 'certain' decreases in it. The same lack of information prevents the test of this principle in this chapter. For the sake of convenience the same constraint with respect to arrival time is assumed as under the EPT paradigm.

7.4.6 Diminishing sensitivity in concrete tactical choice processes

The diminishing sensitivity principle as conceived in EPT relates to the valuation of states of assets as well as to that of changes in it. The diminishing marginal utility and 'diminishing marginal rate of substitution' principles of UT are state-related. This subsection considers how these principles may be used to model the values attributed to travel cost and time attributes, particularly by deriving an appropriate expression for the VTTS used for their compounding in concrete tactical choice processes.

With respect to the valuation of changes in attributes relative to a reference state EPT adheres to the diminishing sensitivity principle as conceived in PT. Kahneman and Tversky (1989) founded this assumption on findings from psychophysics. Since Weber (1834) established the just noticeable difference principle and Fechner (1860) proposed that mental perceptions are a logarithmic function of physical stimuli this field has given a firm scientific underpinning of the concave character of that relationship. In combination with reference-dependent change-oriented framing Kahneman and Tversky (1979) derived a concave value function for monetary gains and a convex function for monetary losses, both of which could be described by a power function. In their presentation of cumulative Prospect Theory Tversky and Kahneman (1992) suggested a value 0.88 for the exponent, based on observed choices between prospects with monetary outcomes in which the extension of the gains and losses amounted to a few hundred dollars. UT's concave utility function with respect to the state of the attribute can be conceived as a consequence of the same psychophysical phenomenon. It may be approached by a logarithmic function as originally proposed by Bernoulli (1738) or by a power function with an exponent of about 0.225, as suggested by Camerer and Ho (1994).

Within the concrete tactical choice contexts considered here a person's psychological value of a change in daily travel time might be related to the total discretionary time available, including time spent for travelling. According to EPT that total time is conceived to be framed as a reference state and the alternative travel times as gains or losses relative to that reference. Under the UT paradigm the alternative times are considered as reference-independent. This latter approach agrees with the 'diminishing marginal rate of substitution' concept of UT as well. Of course, the total available time per day is fixed. In the tactical contexts at hand the number of hours allocated to working are also considered to be fixed. Though large interpersonal differences may occur in the daily chores and needs that are considered as non-discretionary activities, as well as in the time required for them, this leaves for most people at least a few hours that can be considered as discretionary. The individual's changes in travel time as a consequence of a mode change, for example, may only incidentally amount to half an hour in Singapore. Following the logarithmic or power function for UT's state-dependent diminishing sensitivity principle discussed above, the maximal difference between the values of this half hour change and those assessed with the best linear approximation in the considered interval is below one percent[109]. Kahneman and Tversky's power function relates to the changes from the reference state, which in Singapore's situation holds for an interval from one to about 30 minutes (see Annex D). In this range the value of the best fitting linear approximation differs at most five percent from the values according to a power function with exponent 0.88, except for small travel time changes. For changes of one to a few minutes this relative difference is higher but the value of misestimation is smaller than would be caused by a one-minute misestimation of travel time, which is the nearest level to which the aggregated travel times are rounded off. This means that in the choice contexts considered in this chapter it is justified to approximate the psychological value of travel time changes with linear value functions.

Both the real incomes and the price index, and thus the nominal incomes, will not change significantly during a concrete tactical or operational choice process. The changes that are a consequence of travel choices are completely insignificant compared to total income or wealth, and this implies that the individual's psychological value of money may be considered to be constant during such processes. Considering the change-related diminishing sensitivity principle according to PT it appears that the range of feasible changes in travel costs as discussed in this chapter is smaller than the range of considered travel time changes. Thus here, too, a linear approximation is well founded for the purposes of this chapter.

The preceding reasoning showed that for the concrete tactical choice contexts in Singapore it is justified to approach the psychological value of both monetary and temporal attributes with a linear function of their size. This was found starting from the relevant assumptions of EPT as well as UT. Within the concrete tactical choice contexts considered here, VTTS is defined above as proportionate to a person's marginal psychological value of discretionary time available divided by her marginal value of money for spending. According to both paradigms it is thus sound to assume that the idiosyncratic VTTS remains constant during the concrete tactical choice processes considered in this chapter.

7.4.7 Diminishing sensitivity of the reference state

The state-dependent concave utility function and corresponding diminishing marginal utility concepts of UT are commonly considered to apply to both short and long-term changes in the

[109] If travel time changes were valued as marginal changes in total travel time instead of in total discretionary time the maximal differences in the Singapore commute situation may increase to a few percent.

considered states. When they proposed PT, Kahneman and Tversky (1979: 277) posited that '*value should be treated as a fuction of two arguments: the asset position that serves as reference point, and the magnitude of the change (positive or negative) from that reference point*'. In their explanation they apparently conceived the '*attitude to money*' as the value of the monetary asset position and assumed it to be a concave function of wealth that in most choice contexts may be approximated by a linear function, in agreement with the conclusions drawn in the previous subsection. No references were found in which the authors or other researchers elaborated this 'diminishing sensitivity' of the reference state any further. EPT adopted the concept of a concave function for the attribute values of the reference state (see Table 2 on page 96). In agreement with the hedonic valuation approach this subsection explores how this principle might be made operational in travel choice modelling. It focuses on the modelling of long-term changes in idiosyncratic values for VTTS and its constituents.

No publications could be recovered which examined the long-term development of the psychological value that individuals attribute to the discretionary time available. More information might be recovered about changes in the amount of it. For Singapore, Wilson (1979) assumed an average working week of 48 hours in 1975 while Li (1999) mentioned 44 hours for 1990. The 2005 household survey revealed a 44 hours median and a 48 hours average. This suggests a small increase in discretionary time, and thus its marginal psychological value might have diminished slightly. Also the average age of the working population increased, which might have had a similar effect. However, the increasingly hectic struggle for life world-wide did not leave Singapore untouched, as can be seen, for example, from the 10% of the working population who worked more than 65 hours per week in 2005. This might just as well have caused a slight increase in the marginal psychological value of discretionary time. On balance it is clear that changes in activity patterns over the years have not had a significant effect on the marginal psychological value of time for Singapore's commuters.

Travel behaviour literature adheres to the neoclassical micro-economic theory of the valuation of time as developed from the 1960s onwards (e.g. DeSerpa 1971; Mackie *et al*. 2001b). This conceives that the subject balances the benefits of the time spent each day for working, for intermediate and for leisure or discretionary activities. From his theoretical considerations DeSerpa (1971: 838) concludes that '*there is likely to be a high positive correlation between the two*' (i.e. VTTS and wage rate) but '*it is unlikely that there exists any common proportionality constant for any significant proportion of the population*'. In the travel behaviour literature most authors nevertheless assume that the VTTS develops proportionate to the wage rate (e.g. Li 1999). This suggests an inverse proportionality of the marginal utility of money with the hourly wage rate. From a hedonic valuation perspective this is not the most obvious indicator for the individual's appraisal of wealth. The jobs offered on the labour markets of most developed societies usually have a fixed number of hours required per week and provide a monthly salary. The overall benefits experienced from the income will thus co-vary with the real income development. If, for example, the number of working hours per week decreased more quickly than the hourly wage rate increases, the monthly income and thus the experienced wealth would decrease, resulting in an increasing marginal utility of money at an increasing wage rate. As the spending of income is commonly organized at the household level a traveller might also experience a decline in wealth if the income of her partner is lost, for example following a dismissal. In the current implementation of EPT the real household income is therefore considered as the most appropriate approach for the traveller's overall wealth.

The constancy of the marginal psychological value of time over time implies a simple inversely proportional relationship between VTTS and the marginal psychological value of money. A quick look at Table 9 (page 191) shows that in Singapore the long-term relative changes in nominal and real income and in the Consumer Price Index are of a completely different size than the changes in discretionary time. Clearly the psychological value of money, as a medium of exchange, is inversely proportional to inflation. This means that, as long as the long-term nominal income and discretionary and travel money spending of a traveller co-develop with the Consumer Price Index, the psychological value of changes in monetary travel expenses will be inversely proportional to these nominal changes. The VTTS co-develops then with the Consumer Price Index. What is more interesting is what happens when real income growth differs from the development of the consumer price index and/or the discretionary or travel expenses in real money. Four different hedonic valuation approaches might be considered for an individual's psychological value of discretionary and travel expenses:

i. It follows a **linear function of real income**. This superseded concept[110] is discussed here for expository reasons only. It implies a constant marginal psychological value of real money and a VTTS that develops proportionate to the Consumer Price Index only.

ii. It follows a **concave function of real income**. This is the prevailing view according to the UT paradigm. When for reasons of mathematical convenience Bernoulli's logarithmic approximation is followed this yields an inverse dependency of the marginal psychological value on real income increases. It implies that VTTS co-develops with the nominal monetary value of income.

iii. It follows a **concave function of increases in the real day-to-day costs**. This is what might be expected when the traveller follows choice bracketing (Subsection 4.2.3) by assigning the income to different mental accounts and budgets (e.g. Thaler 1999). Suppose a simple division in two budgets, one for 'spending' and one for 'savings' which are in equilibrium, i.e. have the same marginal psychological values for budget exchanges. The first mental account might contain the budget required for running expenses, such as lunch, cinema attendance, transit tickets, drinks, petrol etcetera. The second might contain capital expenses and savings for the mortgage, the highly desired acquisition of a new car, pensions and so on. Supposing that the real income increases significantly while the subject keeps the running expenses the same, after accounting for the Consumer Price Index and thus persisting in the same consumption level, the additional income increase would be placed entirely in the savings account and soon hedonic adaptation would adjust the marginal psychological value for changes in the savings budget to that of the spending budget, which remained the same after the real income increase. This implies that VTTS develops at the same rate as the Consumer Price Index, just as was found under i. but as the consequence of a completely different choice behaviour strategy.

iv. It follows a **concave function of increases in the real running costs for travel**. This is what might be expected when the traveller follows another assignment of income to mental accounts, in particular by discerning a budget for the running costs for travel. Suppose that a transit passenger's real income remains the same but that over a long period her day-to-day travel expenses lag slightly behind the Consumer Price Index. At any arbitrary moment it makes no sense to allocate the resulting savings to the daily travel budget thus the subject may use it for other discretionary spending or savings. Again, hedonic adaptation will level out the marginal values of money for both budgets.

[110] This valuation approach follows the expected value concept of Pascal (1670) as discussed in Annex A.

> VTTS will now follow the development of the real costs for transit[111] or, more generally, the price index for the running costs for travel.

Under the EPT paradigm VTTS might thus follow the household income, for those travellers who organize their travel choices within a comprehensive account (Section 4.3) or who continue the same distribution over the considered accounts or budgets when their income changes. This latter implies, for example, the '*constant relative monetary travel budget*' as posited by Zahavi (1979). In actual practice, interpersonal differences in mental accounting and budgeting abound, even in very similar contexts (e.g. Kahneman and Tversky 1984; Thaler 1999). Applied to the tactical travel choice contexts, some conceivable budgeting strategies would result in a propensity of VTTS to follow the long-term development of the Consumer Price Index or of real travel costs, at least when drastic hedonic adaptation is assumed. From the perspective of EPT one might thus expect that, at the level of a population, the development of VTTS over the years follows either the nominal household income or the Consumer Price Index.

As mentioned above most travel behaviour researchers implicitly assume that the VTTS develops proportionate to the wage rate, often by defining it as a fraction of the nominal wage rate and positing that this fraction remains the same over the years (e.g. Li 1999). As an explanation for observations from UK stated choice studies, which indicated that VTTS lagged behind nominal wage increases (e.g. Gunn 2001), Mackie *et al*. (2001b) suggested that it might follow the per capita Gross Domestic Product, which they considered to grow less fast than the average real wage. Consultation of the UK National Statistics website showed that between 1960 and 1980 the average annual growth of real wages was indeed 2% above that of the real per capita Gross Domestic Product growth but between 1980 and 2000 the annual growth of the Gross Domestic Product exceeded that of the wages by 0.7%. The differences between both indicators might to a large extent be caused by differences in the average working hours and in the labour participation of households. These differences might be removed if the household income is considered instead of the wage rate. Between 1975 and 2005 the increase in real household income in Singapore, for example, followed the fourfold increase in per capita Gross Domestic Product while the average hourly wage rate increased by a factor five. This supports the earlier conclusion to adopt the household income as the most realistic approximation of 'wealth'.

Few empirical observations of the long-term development of VTTS were retrieved. Most conspicuous is the observation by Gunn (2001) that in the Netherlands the VTTS hardly changed at all between 1988 and 1997, despite real income growth. However, Gunn apparently overestimated the real household income growth, which was actually very small over that period. The final report of the 1997 survey confirmed an increase that was slightly faster than the increase in the Consumer Price Index and thus might have followed the small real income growth (HCG 1997).

For Singapore, published information about the VTTS could be recovered for the years 1975, 1990 and 2001. Wilson (1988b, 1989) analysed 1975 World Bank survey data of vehicle-owning family members who commuted with public and private modes. He used a

[111] This reasoning also shows that mode shifts following strategic choices by a number of individuals may soon be followed by a drastic change in the individual's VTTS. These will effect the VTTS distribution over the population of all travellers if these are predominantly in one direction, for example from car driving to transit. Even then they may hardly affect the VTTS distributions of the subpopulations of car drivers and transit passengers.

Multinomial Logit model with several utility specifications that contained different schedule-delay components. If these latter components had been disregarded in his models[112] he would have found a VTTS of S$3.50/h in his 1988 article and a S$4.10/h to S$4.70/h range from the three unrestricted specifications in his 1989 article. The average monthly personal income for the survey samples considered were S$709 per month in the first article and S$730 per month in the second. Taking the 1.94 ratio between the 1975 averages of household and personal income into account and after division of the monthly income over 712 hours this yields VTTS/household income ratios of between 1.8 and 2.3. For the VTTS of 1990 car owners in Singapore Li (1999) mentions that Png *et al*. (1994) estimated this at 67% of their wage rate. The concurrent average wage rate of car owners as assessed by Li yields a VTTS of S$10.30/h. Taking into account the mean household income of car owners as found from the 1990 Population Census a 1.53 VTTS/household income ratio is calculated. Finally, from a stated choice survey held in 2001 Richardson (2003) found a VTTS of S$3.10/h for public transport passengers and S$7.90/h for car drivers and taxi passengers. The average household incomes according to the 2000 Population Census were S$4,500 per month for public transport users and S$7,500 per month for car drivers and taxi passengers. Taking into account that real income growth stagnated in 2001 because of a recession, the respective VTTS/household income ratios were 0.5 and 0.75, respectively. Since 1975 the VTTS had thus lagged behind the development of the average nominal household incomes. This held to an even stronger degree for the average wage rates, as these increased faster than the household incomes. If the VTTS had followed the Consumer Price Index, extrapolation of Wilson's findings gives VTTS/household income ratios between 0.7 and 0.9 in 1990 and between 0.5 and 0.7 in 2001. The agreement between the 2001 extrapolation and Richardson's results might be caused by an underestimation of the actual VTTS as stated preference surveys analysed with a conventional discrete choice model might easily underestimate these with about 50% (e.g. Hensher 2001a; Brownstone and Small 2005). If Richardson's VTTS values were doubled the VTTS-household income ratio would have followed the household income growth but would not have kept pace with the wage increase.

Following the ordinal utility principle of neoclassical economics one might expect an individual's VTTS to approximately co-vary with the wage rate[113], but both the theoretical observations above and the scarcely available empirical information indicates that its real growth is slower. Starting from a hedonic valuation perspective the VTTS as 'constant proportion of household income' initially seems very plausible. Taking mental accounting into consideration its long-term increase with inflation or the running costs of travel might be just as plausible. The available empirical evidence yields no definite conclusions. Where appropriate all three hypotheses will be considered in this chapter. As a population might exhibit a mixture of mental accounting and budgeting strategies it might be expected that the average growth of VTTS over time lies somewhere between the growths of Consumer Price Index and the wage rate, as was actually found from the comparison of the findings from several earlier VTTS assessments in Singapore.

[112] From the model coefficients in Wilson's 1988 article follows a VTTS of S$1.40/h and from the three unrestricted specifications in his 1989 article S$1.70/h. This would have yielded a VTTS/household income ratio of 0.70 to 0.85.The schedule delay parameters attracted a high proportion of the travel costs in all considered specifications. As these were presumably disregarded in the analyses by Png (1994) and definitely in those by Richardson (2003) these are incorporated in the VTTS.

[113] At least, if a fixed duration of the working hours is assumed, which would minimize the substitution effect.

7.4.8 Interpersonal differences in VTTS

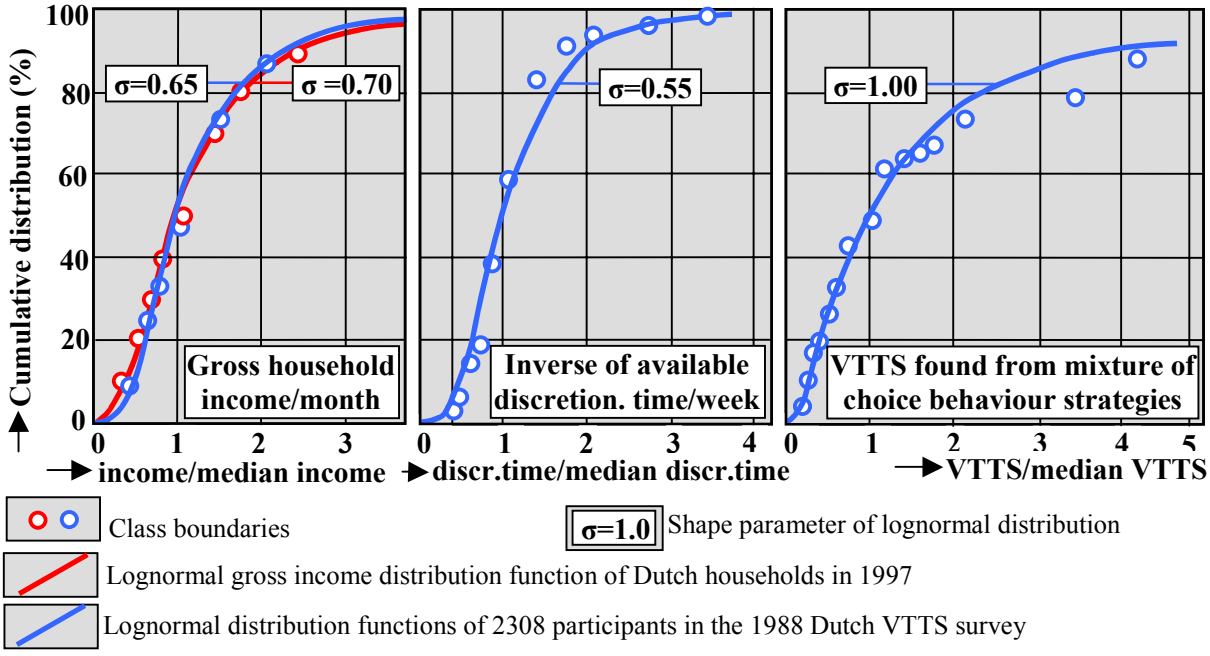
The information about travel alternatives and the choices that Singapore's commuters made between them that are considered in this chapter consists of aggregations over populations. The model that is developed in this section draws on an approximation of the choice behaviour of individual travellers. This subsection explores the characteristics of interpersonal differences in behaviour that have to be considered in the model estimation process.

To date, little information has been published about the interpersonal distribution of VTTS values over populations. In addition to some congress papers dealing with provisional findings from the present research (Van de Kaa 2005; 2006) the only source found thus far was the 2001 adaptive stated choice survey in Singapore (Richardson 2003). The observations in this subsection draw strongly on the results from these surveys. As large interpersonal differences in wealth and in the daily activity patterns and associated discretionary available time have to be taken for granted, the same will hold for the idiosyncratic VTTS. Elicitation and prediction according to both the EPT and UT paradigms have to consider these differences in the individuals' choice context as well as in their preferences. To grasp an idea about the range of these idiosyncratic differences in VTTS within a population one may once more consider that these are proportionate to the ratio between the individual's marginal psychological value of discretionary time and the individual's marginal psychological value of household income. As a first approximation of the distribution of VTTS over a population one might thus hypothesize that it is the product of the distributions of the individual's household incomes and the inverse of their discretionary time.

Over the years 1972, 1990 and 2005 household income distributions for Singapore's population were available, and similar distributions were accessible at Statistics Netherlands (2007). The raw data revealed a positive skewness, implying a distribution tailed to the right. Some scientists found that with respect to income distributions the lognormal distribution '*may facilitate comparisons among societies and generations*' (Limpert *et al*. 2001: 349). A lognormal function appeared indeed to fit all these distributions nicely indeed, as follows from the less than 3% difference between the arithmetic means according to the lognormal approximations and the averages of the data points. For the household incomes in Singapore, the shape parameters[114] were $\sigma_{\text{income distrib.}} = 0.72$ in 1972, 0.75 in 1990 and 0.85 in 2005, reflecting the increase in income inequality as indicated in Section 7.2. The lognormal distribution appeared to fit equally well to the Dutch disposable and gross personal and household income distributions (see left hand chart in Figure 15). The shape parameters for the Dutch gross household income ($\sigma = 0.70$) were lower than in Singapore, which agrees with a lower Gini index. For the disposable household income in 1997 an even lower $\sigma = 0.6$ was found, reflecting the Dutch progressive tax system. Application of the same procedure to the distribution of the 1988 and 1997 Dutch national VTTS survey populations (HCG 1990; 1998) over the distinguished income classes showed $\sigma = 0.65$ and 0.6, respectively. Segmentation of the populations with respect to trip purpose yielded $\sigma = 0.5$ for commuting and business and $\sigma = 0.7$ for the 'other' purposes. With respect to travel modes there were hardly significant differences: the shape parameter ranged from 0.6 for car drivers to 0.65 for bus and tram passengers. For these and several further segmentations of the Dutch surveys that were tested, the difference between the arithmetic means of the samples and their

[114] The standard deviation σ of the natural logarithm of the values of a lognormally distributed stochastic variable lays down the skewness and kurtosis (curvature) of the density function as well. Both increase with an increase in σ, which is commonly denoted as the shape parameter. This custom is followed here. Note that elsewhere occasionally $\exp(\sigma)$ is denoted as such (e.g. Limpert *et al*. 2001).

lognormal approximations remained within 3%. Apparently, the shape parameter[115] of the lognormal function is very useful to indicate the income distribution within these populations and random samples from them. For the late 20th Century, σ = 0.6 (the Netherlands) and σ = 0.8 (Singapore) might be considered appropriate estimates.



Based on data from Van de Kaa (2006), Statistics Netherlands (2007) and HCG (1990)

Figure 15: Lognormal distribution functions for income, discretionary time and VTTS in the Netherlands

Though quite some information is available about the way in which people allocate their available time over obligatory commitments, basic needs fulfilment like sleeping and eating and discretionary activities, the easily accessible information is restricted to averages over populations and socio-economic segments of it (e.g. Van de Broek *et al*. 2004). In the Dutch national VTTS surveys the travellers were also interviewed about the time spent weekly for paid labour and for household duties. After attributing the average time required for sleeping, eating, personal care and study to the members of the relevant socio-economic categories discerned in the 1988 survey, these and the other obligatory activity times were subtracted from the 168 hours per week. The work-related travel times should also be considered as obligatory as well. The survey also elicited the individual's total daily travel times, but these included business trips that were also included in the reported working hours and commutes that were not. The reported single-direction commutes of workers and students were converted to weekly travel times. For other respondents, where this was not possible by lack of data, averages reported by Van de Broek *et al*. were applied. Of course the combination of self-reported times for some activities with averages for other activities yielded some negative discretionary times. As in actual circumstances these times should be zero or positive they were replaced by low positive values of 1% of the total time per week. A lognormal function fitted reasonably well to the definitely skewed distribution of the inverse of the discretionary times revealed in this manner, with the mean of the lognormal approximation 5% below the

[115] Obviously, one needs to know the median or scale parameter of the sample to get a correct impression of the differences in income between the samples. These ranged from 75% to 120% of the median for the Dutch survey population as a whole.

average of the raw data and a shape parameter $\sigma_{\text{inverse discr.time}} = 0.55$ (see the chart in the middle of Figure 15). The shape parameter increased when the discretionary time was defined as part of a working day instead of a whole week, but this did not improve the agreement between the data and the inferred lognormal distribution. The use of population averages for several time spending categories might have underestimated the dispersion in discretionary time available and thus also in its inverse. As the share of people in Singapore who work more than 60 hours per week, for example, is almost twice as many as observed in the Dutch VTTS surveys, the skewness of the inverse discretionary time function will be higher there. This implies that the corresponding shape parameter for Singapore's travellers might be considerably higher.

Based on the previous assessments one might expect that VTTS is also lognormal distributed over populations. The product of two lognormal distributed random variables yields a lognormal distributed variable with $\sigma = \sqrt{(\sigma_1^2 + \sigma_2^2)}$, provided that the variables are independent (e.g. Limpert *et al*. 2001). Following the definition of VTTS in terms of available discretionary time and money this implies:

$$\sigma_{\text{VTTS}} = \sqrt{(\sigma_{\text{distribution of inverse discretionary time}}^2 + \sigma_{\text{distribution of income}}^2)}$$

For the participants of the Dutch national VTTS surveys this yields a shape parameter in the range of 0.8 to 1.0, depending on the definition of discretionary time. Following the same reasoning, shape parameters in the 1.0 to 1.2 ranges might be expected for the VTTS dispersion in Singapore. If one considers the other sources of dispersion like differences in tastes and in applied choice behaviour strategies, the actual shape parameter might be slightly above the upper limits of these ranges.

For the Dutch stated choice VTTS surveys, Van de Kaa (2006) inferred the distribution of choice sequences over VTTS intervals. These were revealed from a loss-aversive choice behaviour strategy by most of the interviewees and loss neutral and mixed lexicographic-elimination strategies by most other respondents. When these distributions are approximated by a lognormal function this yields average VTTS values that are less than 5% above the average of the raw data, for the combined database as well as for the separate 1988 and 1997 distributions. The shape parameter σ_{VTTS} varies between 1.0 and 1.05 (see right hand chart of Figure 15). A range of shape parameters from 1.0 to 1.1 is found for sub-samples of the combined survey populations whose choices could be attributed to a consistent loss-aversive valuation of the alternatives with $\lambda_{\text{money}} = \lambda_{\text{time}} = 2.0$. Within this group, the differences between the shape parameters inferred for the separate survey years were at most a few percent. The shape parameter for train passengers was about 1.0 while σ_{VTTS} for car drivers as well as bus and tram passengers[116] was about 1.1. For the smaller and largely overlapping sub-sample of travellers that might have applied loss-neutral valuation of the travel time and cost changes, the corresponding values of the shape parameter ranged from 1.2 to 1.4.

The large differences in σ_{VTTS} between the sub-samples that might have followed different choice behaviour strategies and the smaller differences between travel modes and survey years might be the consequence of differences in the share of lexicographic answerers in the samples. This may also explain the differences in the ratio between the means of the raw data and as calculated from the lognormal distribution. These ranged between 1.0 and 1.1 for the 'mixture sub-sample' of all the explained choice behaviour strategies, between 1.05 and 1.2

[116] Though the shape of the distributions was similar, the average VTTS inferred for car drivers was more than twice that for the tram and bus passengers, with train passengers in an intermediate position.

for the 'loss-avoiders sub-sample' of interviewees that might have applied $\lambda_{money} = \lambda_{time} = 2.0$, and between 1.1 and 1.4 for the 'loss-neutral sub-sample' of those who might have consistently applied a loss-neutral valuation. One should note that the interviewees who chose consistently either the alternative with the lowest travel time or that with the lowest cost from each choice set, belonged to each of these samples. Their share increased from 14% of the 'mixture sub-sample' over 22% of the 'loss-avoiders sub-sample' to 36% of the 'loss-neutral sub-sample'. Taking the VTTS-assessment for the 'mixture sub-sample' as the most realistic one there appears to be a fair agreement between the empirically determined and the expected shape of the standardized lognormal distributions, as follows from the observed $1.0 < \sigma_{VTTS} < 1.05$ range compared to the expectation of a shape parameter around or slightly above the upper limit of the $0.8 < \sigma_{VTTS} < 1.0$ range.

Richardson's (2003) analysis of the 2001 adaptive stated preference travel survey provided the only other recovered quantitative information about the interpersonal dispersion in VTTS values. Actually, he drew from a lognormal distribution to arrive at first estimates of VTTS in his adaptive algorithm (Richardson 2002) and should thus be given the credit for suggesting this type of distribution to describe the heterogeneity of VTTS over populations. Observation of his cumulative distributions of the VTTS for the survey population as a whole and of the sub-samples of public transport passengers on the one hand and car and taxi passengers on the other shows a skewness from about 0.8 for private transport to 1.0 for public transport, all in the same range as found for the 'mixture of choice behaviour strategies' samples from the Dutch surveys. Fitting lognormal functions through the data yielded shape parameters of around 1.3 for the population as a whole and for public transport and 0.6 for private mode users.

This suggests that the relatively small group of private mode users in Singapore is much more homogeneous with respect to income distribution and discretionary time available than the population as a whole. The mean of the lognormal distribution for this subgroup was about equal to the average of the raw data, but the similarity of the empirical and lognormal VTTS distributions for transit users and for the population as a whole were rather bad: the lognormal means were 20% and 30%, respectively, above the corresponding empirical averages. This was a consequence of relatively strong differences between the left and right hand tails of the lognormal functions and the corresponding empirical data. The same was found for the relatively small 'UT' sample of possibly loss neutral respondents from the Dutch surveys. Richardson chose to ignore the 'status quo' choosers (see Section 6.4.6) and so may have boosted this effect. When the lognormal distributions are 'forced' to have the same median as the empirical data, the differences between lognormal and empirical averages reduces to about 10% and the shape parameters range from 0.7 for the private to 1.0 for the public modes. Of course, a more thorough re-examination of Richardson's adaptive stated preference results would be required to arrive at firm conclusions with respect to shape parameters for particular travel modes. As a working hypothesis for this chapter it is posited that the dispersion in the VTTS of all travellers within a population is larger than within its constituent segments of travellers that commonly use one particular travel mode. For the survey population as a whole the elicited shape parameter is in line with the expectations based on the income distribution and discretionary time estimates.

Overall, these findings from Singapore and the Netherlands corroborate that the lognormal function yields a fair description of the distribution of idiosyncratic VTTS values across populations of travellers. The elicited parameters of about 1.0 for the Dutch 1988 and 1997 stated choice survey populations as a whole and of about 1.3 for the whole population of the

2001 Singapore stated choice survey appeared to agree well with the expectations based on the product of the lognormal distributions of household income and inverse discretionary time.

7.4.9 Summary: a model for the prediction of tactical travel choices

In the previous subsections the theoretical assumptions of EPT were elaborated for implementation in a tactical travel choice context and compared with a corresponding implementation of UT assumptions. This subsection unites these building blocks into an operational model for idiosyncratic tactical travel choice behaviour and provides simplifications that allow its application to the highly aggregated data of travel conditions, alternatives and choices in the Singapore commute contexts that will be examined in the following sections. The model considers many different sets and their objects. Table 12 provides an overview of their definitions and symbols as applied in this chapter.

Table 12: Definitions and symbols of the sets considered in the choice model

Symbol	Set designation	Included elements
A	Universal (objective) choice set	$A = \{A_a;\, a = 1, 2,..., y\}$
C	Set of subjective consideration choice sets	$C = \{\bigcup C_q\} = \subseteq A$
C_q	Subjectieve consideration choice set of individual Q_q	$C_q \subseteq A$
D	Choice strategy set	$D = \{D_d;\, d = 1, 2,..., n\}$.
I	Time attribute set	$I = \{I_i; I = 1, 2,..., k\}$
J	Cost attribute set	$J = \{J_j; j = 1, 2,..., m\}$
Q	Population set	$Q = \{Q_q;\, q = 1, 2,\ldots, z\}$
R_q	Set of time and cost attributes of the reference state of individual Q_q	$R_q = \{\tau_q^{ri}, \gamma_q^{rj}; i = 1, k; j = 1, m\}$

For the development of a simulation model for tactical and operational choice behaviour the subjective choice set formation concept is a crucial notion. Under the EPT paradigm the traveller is not considered to derive this from a universal set of all possible alternatives, as commonly conceived in agreement with the Random Utility Maximization model (e.g. Manski 1977). Depending on the trigger that initiates her choice process, for example a new rail service that becomes available or a sudden change in travel expenses, she will rather recollect a set of feasible adaptations of her concurrent travel behaviour that may suit her interests under the changed circumstances. This subjective consideration set is constrained by the outcomes of previous strategic and tactical choices, particularly with respect to the accessibility of home and office locations and the timing of obligatory activities. For the prediction of travel choices, the analyst has to estimate the alternatives that make up this subjective consideration set. Starting from the change in travel conditions for which the traveller's response is predicted, a concrete alternative – for example a particular home departure time – may be taken and the groups of travellers for whom this may be a feasible and effective option may be estimated, or a concrete group of travellers may be considered and their feasible and effective alternatives are estimated. In this chapter the first approach is

followed, resulting in what is termed here an estimate of the subjective consideration set C_q of subject Q_q. Though theoretically this process might be followed for each individual traveller, in practice representatives of more or less aggregated groups will be considered. The nature of this process requires that the segmentation of the population in such groups should take differences in accessibility characteristics into account.

The prediction of the response of a population of travellers to a change in their travel context requires the assessment of the probabilities that a particular alternative A_a is chosen from the union C of the subjective consideration sets C_q of all travellers Q_q within the population Q Obviously, this depends on the probability $P_q^{a\in C_q}$ that the considered alternative A_a is part of Q_q's subjective consideration set C_q. Following Cantillo and Ortúzar (2005) this probability might be elicited by estimation of an attribute-based elimination of alternatives from a more complete set. Under the EPT paradigm, micro-simulation models of traffic drawing on a geographical base with relevant land-use and travel services might be more appropriate for a refined disaggregate or even personalized approach, in view of the assumed strong dependency of the individual's accessibility options. This approach bases the consideration choice set of individual travellers on their accessibility characteristics and constraints rather than on stochastic principles. The development of such models goes far beyond the scope of this book. For the highly aggregated data examined in this chapter $P_q^{a\in C_q}$ is simply set at zero if the alternative does not come up to the mark to meet the subject's demands in the changing context or overdoes things by harming other of her interests. It is set at unity if it might cause the first effect without implying the second.

The prediction of the frequency of choice for alternative A_a within the population as a whole follows straightforward from the summation, over all individuals within that population, of the probability P_q^a that individual Q_q chooses alternative A_a from her subjective consideration set C_q. P_q^a is dependent on the probability that she selects choice behaviour strategy D_d from a set D of n feasible strategies. Following Ortúzar and Williams (1982a) this yields:

$$P_q^a = P_q^{a\in C} \sum_{D_d \in D} P_q(A_a \mid D_d) P_q(D_d \mid D)$$

$P_q(D_d \mid D)$ is the probability that choice behaviour strategy D_d is selected by Q_q and $P_q(A_a \mid D_d)$ denotes the probability that she chooses alternative A_a from set C_q if strategy D_d is applied. The only statistical information about the distribution of the employment of choice behaviour strategies over a population is based on the analysis of the Dutch national stated choice surveys in Chapter 8 and in earlier publications from the same study (Van de Kaa 2005; 2006). This offered no indications of large systematic differences in the frequency of employment of strategies between different socio-economic segments of the population. As under the assumptions of EPT the potential effects of constraint driven lexicographic and Attribute-Based Elimination rules on the prediction of choices are largely covered by the subjective choice set formation process such choice behaviour strategies are disregarded here. This leaves a distinction between travellers who value both time and money changes loss aversively, those who value time changes loss aversively and money changes loss neutrally, and those who value both time and money changes loss neutrally. These strategies will be denoted here as D_{22}, D_{21} and D_{11}, respectively. For the loss aversive valuation of time and/or money, the loss aversion factor $\lambda_{\text{time}} = \lambda_{\text{money}}$ is considered as a quantity that varies between

travellers. If almost every individual applies the strategy in which both time and money are valued loss aversively this is considered as the best match for behaviour in agreement with PT and thus indicated as such. If almost every individual values both categories of attributes loss neutrally this is likewise indicated as in agreement with UT. As discussed in Section 7.4.4, for assessments under the EPT paradigm a 70-30-0 frequency distribution over the three strategies is assumed.

$P_q(A_a \mid D_d)$ is equal to the probability that the value V_{qd}^{a} of alternative A_a, as valued by traveller Q_q who employs choice behaviour strategy D_d, is higher than any value $V_{qd}^{a'}$ of alternative $A_{a'}$ ($A_{a'} \neq A_a \wedge A_{a'} \in C_q$). In the value function V_{qd}^{a} the time and money attributes of each alternative A_a are treated as gains or losses relative to the corresponding levels of the individual's reference state R_q and the losses are multiplied by the relevant loss aversion factor. As discussed above, a linear approximation of the cost and time variables in the value functions is applied. The sum of all the time attribute values is multiplied by the value of travel time savings $VTTS_q$ that accounts for the commensurability of the time and cost atttributes as well. After completion with the stochastic parameters ξ_q^a and η_q^a discussed in the previous subsections this yields the value function:

$$V_{qd}^{a} = VTTS_q.(1+\xi_q^a).\{\lambda_{qd}^{time}.\sum_{i=1}^{k}\max(t_q^{ai}-\tau_q^{ri}),0)+\sum_{i=1}^{k}\max(\tau_q^{ri}-t_q^{ai}),0)+$$

$$+\{\lambda_{qd}^{money}.\sum_{j=1}^{m}\max(c_q^{aj}-\gamma_q^{rj}),0)+\sum_{j=1}^{m}\max(\gamma_q^{rj}-c_q^{aj}),0)+\eta_q^a.MODE_q^a$$

The variable t_q^{ai} is the level of a travel-related time attribute I_i of alternative A_a expected by traveller Q_q. It is assumed that the traveller appraises increases in these travel-related time attributes as losses and decreases as gains. The variable τ_q^{ri} is the corresponding travel-related attribute level of the traveller's reference state R_q. In this chapter the subtraction $(t_q^{ai}-\tau_q^{ri})$ concerns increases in travel time, advancements in work arrival times to cope with increased travel time unreliability, advancements of morning home departure time and postponements, following obligatory activities out-of-home, of discretionary activities in the afternoon, all relative to the corresponding time durations in traveller Q_q's reference state.

The variable c_q^{aj} is the level of a travel-related cost attribute c of alternative A_a as expected by traveller Q_q and the variable γ_q^{rj} is the corresponding attribute level of the traveller's reference state as experienced by traveller Q_q. In this chapter, the subtraction $(c_q^{aj}-\gamma_q^{rj})$ covers increases in expenses for transit tickets, the running costs of cars, park-and-ride services, parking and license fees, and electronic road-pricing tolls, all relative to traveller Q_q's expenses in her reference state.

The variable $MODE_q^a$ is a dummy parameter, which is equal to one if the travel mode of alternative A_a is the same mode as used by traveller Q_q in her reference state R_q.

The parameter $VTTS_q$ is equal to the idiosyncratic value of travel time savings for traveller Q_q. It varies between individuals according to a lognormal distribution. The shape parameter for the whole population of Singapore's travellers is assumed to be well above 1.0, with lower values for segments with a less heterogeneous income and/or discretionary time budget. The median of the distribution is conceived to be known, either from the revealed outcomes of earlier choices or from stated choice surveys.

The parameter ξ_q^a is a random term that takes care of individual Q_q's estimation errors in the VTTS-based attribute value assessment process of alternative A_a. It might also catch a part of the interpersonal taste heterogeneity. Following Fosgerau (2005) the latter source of choice heterogeneity might better be described by a stochastic contribution to VTTS that is proportionate to the total travel time. The aggregate nature of the information of the travel choices of Singapore's travellers does not allow firm conclusions to be drawn with respect to the size and distribution of ξ_q^a let alone about its dependency on total travel time. Therefore, for the concrete appraisals in this chapter this cause of choice heterogeneity is assumed to submerge under the variations in $VTTS_q$ by setting ξ_q^a at 1.0.

The parameters λ_{qd}^{time} and λ_{qd}^{money} are the loss aversion factors for time and money changes relative to the reference state, as applied by traveller Q_q exhibiting choice behaviour strategy D_d. For strategy D_{11} both parameters are equal to unity. For D_{22} both are supposed to be normally distributed. For D_{21}, λ_{qd}^{money} is equal to one and λ_{qd}^{time} is normally distributed. Using the findings from endowment experiments (Section 4.3.4) as a first estimate, 2.0 and 0.4 might be applied as rough estimates for the means and standard deviations, respectively. There are some indications that the degree of loss aversion may vary between attributes that have the same dimension. Particularly changes in running costs may be valued loss neutrally by an individual car driver who values road toll increases loss aversely. For the concrete appraisals in this chapter this refinement is not investigated. The dispersion in choice behaviour caused by the stochastic character of λ_{qd}^{time} is also considered to submerge under the lognormal distribution of $VTTS_q$.

The stochastic parameter η_q^a might be assumed to catch the part of the interpersonal taste heterogeneity that is not proportionate to the total travel time or changes in it. In view of the well-documented effects of hedonic adaptation processes one might expect a positive sign for it, and thus a contribution to the inclination of travellers to keep to the reference mode. Due to lack of information that enables a useful estimate of it in the highly aggregated travel choice contexts considered in this chapter it is disregarded in the concrete appraisals here.

One might consider that the prediction of the effects of the different stochastic parameters draws from the probability distributions that cover interpersonal heterogeneity within a population segment and aggregate the resulting probabilities P_q^a for all individuals Q that constitute the segment and/or the population. Another algorithm may be to assess the 'average' P_q^a of all travellers that make up the population segment and multiply this probability with the concerned number of travellers. The appraisals in this chapter follow in principle the second approach. They start with the elicitation of lognormal distributions of $VTTS_q$ for the 'average' individuals of the most relevant categories of travellers, based on

their observed choices before the 1975 ALS introduction and in connection with the income distribution of the category and the attribute levels of the considered alternatives. In subsequent subsections 'threshold' VTTS values are determined above or below which alternative A_a is pair-wise preferred to each other alternative $A_{a'}$ of the consideration set C_q, for each choice behaviour strategy D_{11}, D_{21} and D_{22}. This yields VTTS intervals in which A_a is preferred to all other alternatives in C_q, which holds for the 'average' traveller Q_q in the considered category. The predicted frequency of the choice for alternative A_a is estimated as the product of the number of travellers in the concerned category times the frequency distribution over D_{11}, D_{21} and D_{22} times the difference between the cdf of the lognormal distribution at the upper and lower limit of the VTTS interval. This process is followed according to the UT and EPT paradigms. A comparison between the predicted choice frequency and observed behaviour allows for qualitative conclusions about the suitability of the different paradigms for the understanding and forecasting of travel behaviour.

7.4.10 Summary, discussion and conclusion

The discrete choice model that was developed in this section allows calibrations and predictions to be performed that adhere to the UT or to the EPT paradigm, depending on the assumed choice behaviour strategies and loss aversion factors that are substituted. Assuming that all travellers follow one choice behaviour strategy in which all attributes of the available alternatives are valued independent of a reference state posits it in the UT paradigm. By accounting for interpersonal differences in the choice behaviour strategies, conceiving that the attributes of the alternatives are valued as changes relative to a continuously updated reference state, and assuming loss aversive valuation it is accommodated to the EPT paradigm. In the preceding sections a simplified version of the model was used as a deterministic model at the 'representative individual' level. The utility function discerned just one VTTS parameter that accounted for the individual's valuation of travel time components and their weight factors. The monetary attributes were devoid of coefficients. Of course, relevant attributes with other dimensions might be added to the utility specification by providing them with a similar 'value for money' parameter. This allows for their commensurability with the money attributes as well. The approach follows what Fosgerau (2005) called the 'pure preference variation, Willingness-to-Pay space' concept and is fully in agreement with the weighted additive value decision rule of behavioural decision theory.

This modelling concept might be closer to the common elaborations of Neoclassical Utility Theory than to those of Random Utility Maximization. The utility function as conceived according to the latter theory most commonly contains 'average' travel time and cost parameters that hold for the whole population segment and a random parameter that accounts for all kinds of interpersonal differences in tastes, errors etcetera. This imposes in fact the same VTTS, or the same linear indifference 'curve' of time and money, on all members of the population considered. In Mixed Logit applications random variations of the different components are also allowed. To some degree this allows interpersonal variations in preferences of time over money, though restricted to what the different specifications of randomness allow. Such models commonly yield better agreements between the observed and calculated choice frequencies than the 'classic' Multinomial Logit models. This better performance of Mixed Logit models suggests that there is indeed interpersonal variation in VTTS that cannot be caught by adding just a random parameter to the utility specification.

In the model developed in Section 7.4 interpersonal differences in the idiosyncratic VTTS values are not randomised nor disregarded by assuming them as the ratio of average travel time and cost parameters. They are considered to be caught by a stochastic variable that

follows a lognormal or similarly skewed frequency distribution. Its shape parameter is conceived to be the consequence of the interpersonal variation in idiosyncratic psychological values of discretionary time and money available that are based on hedonic appraisals, fed by experience and subject to adaptation. Each individual is assumed to have at each time a preference order for quantities of these goods that can be described with a linear indifference curve. From the assessments in the previous subsection it appears that the median of this lognormal VTTS function develops over time approximately proportionate to the ratio of the individuals' monthly household incomes. Implementations of the model that use this VTTS indexation approach thus follow UT's concept of an idiosyncratic preference order that is stable over time closely.

The choice rule of the model as applied in this chapter is deterministic instead of probabilistic and completely compatible with the UT paradigm. The subject is considered to choose the feasible alternative with the highest utility. As the time-over-money preference relation is considered to vary continuously amongst travellers, judgment errors are assumed to be levelled out from one traveller to the other. The same holds for the interpersonal variance in experienced attribute levels. The utility expression might, however, just as well be applied in a common Logit-type model by adding the appropriate stochastic factors.

An exploration of the decreasing marginal utility and diminishing sensitivity principles in connection with the psychophysical and hedonic adaptation processes that explain them showed that in the considered travel contexts a linear-additive utility and/or value function would suffice under both paradigms. The adjustment of the VTTS over time by indexing it with the experienced price or income development – and, theoretically, the inverse of the discretionary time budget development – introduces the major consequence of the just noticeable difference principle of psychophysics as well as hedonic adaptation in the model implementations, according to both paradigms. The reference updating conceived under the EPT paradigm accounts for another major effect of it. Adoption of a power instead of linear value function would hardly add any further improvement in the description of these phenomena.

Non-linear probability weighting was considered during the model development but appeared not to be essential for a proper description and prediction of the tactical travel choices considered in this chapter. Also affectively salient attributes like status and comfort were considered, resulting in a proposal to combine them in a reference-mode specific stochastic parameter. The available information about an individual's trip attributes and corresponding choices did not allow elicitation of this parameter.

Depending on the substitution of parameters by values or functions that agree with the considered assumptions, the developed discrete choice model allows calibrations and predictions with implementations that adhere to the UT or to the EPT paradigm. In the following section the loss aversion factors and the distribution of choice behaviour strategies across the population are applied that are estimated in Section 7.4 from information about choice behaviour in contexts other than Singapore's morning commute. When these are substituted into the EPT implementation of the model the only parameter that has to be calibrated to the Singapore travel context is the VTTS. This is the same parameter that remains to be calibrated according to the UT paradigm. This allows a 'ceteris paribus' comparison of the descriptive ability of these assumptions, provided that the VTTS parameters of the implementations are calibrated to the same context in a similar way.

7.5 Calibration of the VTTS parameters

The aim of this section is to calibrate the VTTS parameter as applied in the UT and EPT model implementations, as discussed in the previous paragraph, to enable the responses of Singapore's car-driving commuters to the introduction of the ALS and to successive changes in the road-pricing regime to be predicted. From the recovered information about attribute levels in Section 7.3 and the adopted value functions in Section 7.4 it follows that the calibrations require knowledge of the destination and travel mode and the corresponding set of attribute levels that characterize the considered daily trips of the pre-ALS car owners.

The present section starts with the assessment of the travel mode choice made by car owning commuters before the ALS was announced and the attribute levels of the considered alternatives. In Subsection 7.5.2 the UT and EPT implementations of the value function developed in the previous section are applied to the modal choices of commuters who had a car at their disposal, to settle intervals of feasible VTTS values. In Annex E the interpersonal distribution of household income is used to estimate the shape parameters of the VTTS distributions of the different groups of travellers, in agreement with the process developed in Section 7.4.8. These shape parameters are combined with the VTTS intervals to estimate the average VTTS for the different groups of travellers (Subsection 7.5.3). The section ends with a discussion about the plausibility of the assessed VTTS values.

7.5.1 Pre-ALS modal shifts and attribute levels

Much information about the modal shares and trip schedules of travellers was collected in the extensive World Bank household travel survey as compiled by Watson and Holland (1978). In Annex C this information is reviewed and elaborated in connection with data from other sources 'Car owner' is defined there as the person who takes care of a car that is daily at the disposal of her family, by driving to some activity location or by leaving it at home. It is assumed that this deployment may imply its use for the daily commute, as solo-driver or while carrying a family member or a paying co-worker, but also to leaving the car at home, for example to save running costs or parking fees. The topic of interest of this section is the pre-ALS mode choice and car deployment behaviour of car-owning commuters who passed the cordon during the hours that would become restricted. Table 13 lists the relevant information as estimated in Annex C. The numbers presented are not meant as exact assessments but rather indicate orders-of-magnitude. It shows that by far most car owners used their vehicle for their daily recurrent trips. The expenses might not have counterbalanced the travel time savings for only a distinct minority.

Table 13: Estimated March 1975 modal shares of car owners

Destination and purpose:	Work within future RZ	Work beyond future RZ
Mean daily number of trips entering the future RZ between 7:30 and 10:15 a.m.		
All car owners	32,600	16,200
Solo car drivers	11,700	11,400
Car driver with 1-2 passengers	11,600	4,100
Carpool driver (≥ 3 passengers)	2,300	700
Bus passengers	7,000	

RZ = Restricted Zone. Numbers are estimates based on the figures in Table C.1, adapted for supplementary information presented in the text and rounded off to multiples of 100.

The levels of the cost and time attributes of the different feasible trip alternatives for commuters, as they were before the 1975 introduction of the ALS, were assessed in Annex D. They can be considered as averages across the groups of travellers for whom the alternatives to which they apply are feasible options and are assembled in the third column of Table 11.

7.5.2 VTTS interval assessments of pre-ALS car-owning commuters

This subsection aims to settle the order-of-magnitude of the VTTS for commuters who had the use of a car well before the mid-1975 introduction of the ALS. The model developed in Section 7.4 is applied to estimate VTTS values from the 'average' choice behaviour of different groups of commuters: those who, after car acquisition, stuck to transit, drove solo or carried passengers. The assessments yield VTTS intervals bounded by 'threshold VTTS values' below or above which the 'representative' travellers should choose the considered alternative, according to the considered implementations of the UT and EPT paradigms.

The strong growth in car ownership during the 1960s and early 1970s implies that a large number of the car drivers, who in 1975 entered the Restricted Zone each morning, had had their vehicle for some time. Almost all of them had taken the bus on trips to and beyond the Restricted Zone, just as about 90% of the non-vehicle-owning household members also had in March 1975. Bus riding therefore coincided with the reference state. Before they changed to solo car driving, travellers who went each day to a destination in the Restricted Zone and back were used to paying about S$0.40 for a single trip that lasted on average 48 minutes. If they kept on travelling by bus the money and time expenses remained the same. If they travelled by car, they would save S$0.40 twice a day, but the running costs for the distance of 10 km twice daily would imply a loss of S$0.85 running costs twice. They might however need just 29 minutes for their car trip, thus saving 19 minutes twice a day. A S$2.50 parking fee should be added to the losses, and to the gain side maybe some comfort. If they took a passenger along, the parking fee and running costs expenses would be almost halved and the travel time changes would differ by a few minutes.

The range of possible idiosyncratic VTTS values of the 'average' pre-ALS solo car driver follows from the consideration that the value of solo driving is higher than for bus riding. After application of the simplifications discussed in Section 7.4 the value function reads in the present trade-off (with i and j as indices for the considered time and cost attributes and after substitution of the relevant attribute levels for the reference state) as:

$$V_{\text{solocardr.}} = VTTS_{\text{solocardr.}} * \{\lambda_{\text{time}} * \Sigma_i \max(t_{i\,\text{solocardr.}} - t_{i\,\text{bus}}, 0) + \Sigma_t \max(t_{i\,\text{bus}} - t_{i\,\text{solocardr.}}, 0)\} + \{\lambda_{\text{money}} * \Sigma_j \max(c_{j\,\text{solocardr.}} - c_{j\,\text{bus}}, 0)\} + \Sigma_j \max(c_{j\,\text{bus}} - c_{j\,\text{solocardr.}}, 0) > V_{\text{bus rider}}$$

Clearly, the value of continuing to use the bus is zero. Disregarding the differences in privacy and comfort between the car and bus and after substitution of the time and cost changes, the lower threshold of the idiosyncratic VTTS of the 'average' pre-ALS solo car driver thus follows from:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (2 * 0)[\text{min}] + 2 * (48[\text{min}] - 29[\text{min}])\} / 60[\text{min/h}] + \lambda_{\text{money}} * \{(0.00 - 2 * 0.85)[\text{S\$}] - 2.50[\text{S\$}]\} + 2 * 0.40[\text{S\$}] > 0$$

As the car-driving alternative has no attribute that contains a loss of time, the size of the loss aversion factor λ_{time} is not relevant for this assessment. For λ_{money} the value 2.0 is considered where appropriate (see Section 7.4). Following the LA(2,2) perspective, the rounded-off

threshold VTTS was S$12/h for the average solo car driver. The LA(2,1) appraisal, which coincides here with LA(1,1) and the UT model, yields a S$5/h threshold. According to the EPT model 70% of the solo drivers would exhibit the S$12/h threshold and a 30% minority that of S$5/h. The same assessment with the relevant attribute levels for drivers who take passengers (see Table 11 on page 200) yields thresholds of S$8/h and S$3/h, respectively. For their passengers these thresholds are S$5/h and S$2/h.

The average travel distance of car owners who remained bus passengers was less than the distance of those who changed to car driving. Had these bus riders changed to solo car driving, they would have had to pay the S$2.50 parking fee and twice the S$0.70 running costs and would have earned the S$0.80 bus fare. They would also gain seventeen minutes travel time twice a day. Substituting these attribute levels in the value function yields about 10% higher VTTS thresholds below which they would be better keeping to bus transit compared to those assessed for the car owners who actually switched. The same increase was found for the trade-off between bus riding and car driving with a passenger.

For individuals working beyond the Restricted Zone, the average pre-ALS travel time of bus riders was 48 minutes and the corresponding travel time they might have encountered if they had switched to car driving was estimated at an average of 30 minutes. Their average S$1.00 daily expenses for parking were much lower than for destinations within the Restricted Zone while the S$1.70 daily running costs were only slightly higher. Following similar assessments to those above, taking the bus and leaving the car at home instead of a solo drive to work would have been profitable for the 'average' car owner with a VTTS below S$8/h according to LA(2,2) or S$3/h according to LA(2,1) and LA(1,1). For car drivers carrying passengers the corresponding VTTS values were < S$4/h and < S$1/h. A similar assessment for the pre-ALS car drivers, with an equivalent travel time by bus of 52 instead of 48 minutes, yielded slightly lower VTTS thresholds. As hardly, if any, car owner left her vehicle unused for commutes through the Restricted Zone to work beyond it, these thresholds might be considered as lower limits for the VTTS of car drivers.

The threshold values were inferred under the assumption of a loss aversion factor 2.0, where appropriate, for time and monetary cost attributes. However, as observed in many psychological 'endowment' experiments and confirmed in the Dutch VTTS studies (Van de Kaa 2005), the loss aversion factor may vary between about 1.5 and 2.5. This implies a scatter of VTTS-thresholds around the medians assessed above. Obviously, the VTTS threshold values found from loss-neutral assessments are not subject to this additional scatter.

As disaggregate data were not available, the thresholds above had to be assessed from the experienced differences between car and bus travel times, averaged across all the travellers concerned. This disregards the interpersonal heterogeneity in the accessibility of home, office and other locations and in the costs associated with car use. Such differences in accessibility characteristics are apparently the main reason for the differences between the VTTS thresholds inferred for trips to work within and beyond the Restricted Zone. The much lower VTTS thresholds for car trips to work beyond the Restricted Zone follow from the relatively poor transit accessibility compared to the Restricted Zone. These are reflected by the longer travel times listed in Table 11 (page 200) and by the larger car driver-bus rider ratio among commuters who worked there. Within the three groups of travellers for which the average travel times and costs were used to elicit the VTTS thresholds, large differences in accessibility appear to exist. Though there may be some differences in in-vehicle times, mainly due to congestion, by far the largest source of heterogeneity may be in the access and

egress links of the trips. According to the household travel survey (Watson and Holland 1978) the average time spent for walking to and from the bus stops and for waiting at them was fifteen minutes more than for walking to and from the car parks. Interpersonal differences in the transit accessibility of car drivers may explain differences in the responses to the ALS measures. For example, after ALS enforcement the average travel time of the 3,500 car drivers to the Restricted Zone who switched to transit was only 39 minutes compared to an estimated 48 minutes for all car drivers (see Annex D). One might assume that an equally sized group of car drivers would experience an average 57 minutes transit time if they took the bus. This yields a standard deviation of about seven minutes as a rough estimate of the dispersal in the car versus transit difference in overall travel time, if this is conceived as normally distributed. Such a symmetrical variance around the 'average' travel time differences yields a skewed distribution of VTTS threshold values. For the S$12/h threshold for the 'average' transit accessibility of solo car drivers according to the LA(2,2) appraisal, for example, it yields S$9/h for a seven minutes larger and S$19/h for a seven minutes smaller travel time difference.

The sources of interpersonal dispersal in idiosyncratic VTTS thresholds indicate that about equal parts of the travellers may have a lower or higher VTTS threshold than the one assessed above for the 'average' traveller from the six groups with different mode choice and different destinations. These and similar thresholds will therefore be interpreted as medians of the distributions that hold for the population segments to which they apply. As such they offer, in connection with the frequencies of actual mode and destination choices (Table 13 on page 227), VTTS frequency thresholds for the estimation of approximate lognormal cumulative frequency distributions of the VTTS of car owners in the next subsection.

7.5.3 Car owners' VTTS distribution

In the previous subsection the intervals within which the VTTS of different 'representative' commuters lie were assessed. The shape parameters of the corresponding VTTS distributions across the population segments to which they belong are estimated in Annex E, following the approach developed in Section 7.4.8. This subsection considers the position of the distributions within the intervals. It results in estimates for both the average and distribution of the pre-ALS VTTS over different groups of travellers, according to the UT as well as the EPT model implementation.

Except for the commuters who worked beyond the Restricted Zone there are no indications that the VTTS values of most car drivers are far above their thresholds. On the contrary, a sizeable number of car owners took the bus to the Restricted Zone and left their car at home. Even more car owners found ride-share arrangements that kept their travel expenses at an apparently acceptable level. Thus most car owners traded off the travel costs and times of the feasible travel modes. This leaves two reasons why some of the car drivers might have had VTTS levels different to those indicated by the pre-ALS bus-car trade-offs: the changes in travel conditions and income since the year in which the modal shift was actually made, and the conditions under which individuals started to consider this modal choice. Travellers who changed from bus to car in the 1960s may have experienced a worse transit experience than the actual conditions in 1975 (Spencer 1988), suggesting a VTTS below the threshold inferred for 1975. However, their real income had increased by 25% since 1966, and thus their actual VTTS might have grown above the threshold, at least if their VTTS increased at a higher rate than the consumer price index. The latter income growth effect on VTTS would presumably predominate over the transit improvements but thus far no conclusive evidence has been

found for its actual occurrence. The idiosyncratic VTTS of the 'representative' traveller will thus not differ very much from the corresponding threshold as assessed in Subsection 7.5.2.

Upper and lower limits of the cumulative frequencies of the VTTS thresholds found in Subsection 7.5.2 were estimated by considering the shares of the solo car riders, rideshare drivers and deliberate bus riding car owners (see Table 13 on page 227) in the total population of travellers and in subdivisions of it. The actual VTTS distributions were considered to lie slightly below the most constraining upper limit and/or above the most constraining lower limit. Following the principles discussed in Subsection 7.4.8, the shape parameters of lognormal approximations of the VTTS distributions of these groups of travellers are estimated in Annex E, relying on their income distributions as found in Watson and Holland (1978). This yields $\sigma \approx 1.0$ for the VTTS distribution of all travellers and $\sigma \approx 0.75$ for the homogeneous subgroups of car owners who commuted by bus, as solo driver or rideshare driver. Additional requirements for the assessment of the frequency distributions were: subdivisions should have smaller shape parameters than the covering populations and frequency distributions of population segments should add to those of the covering populations. It was further assumed that the shape parameters for different population segments inferred according to LA(2,2), LA(2,1) and LA(1,1) were equal.

The left hand chart of Figure 16 shows the inferred cumulative distributions according to the EPT model implementation. The corresponding frequency distributions are depicted on the right hand side. As indicated in Section 7.4 they assume that 70% of the travellers of each group chose in agreement with the LA(2,2) algorithm and 30% in agreement with LA(2,1).

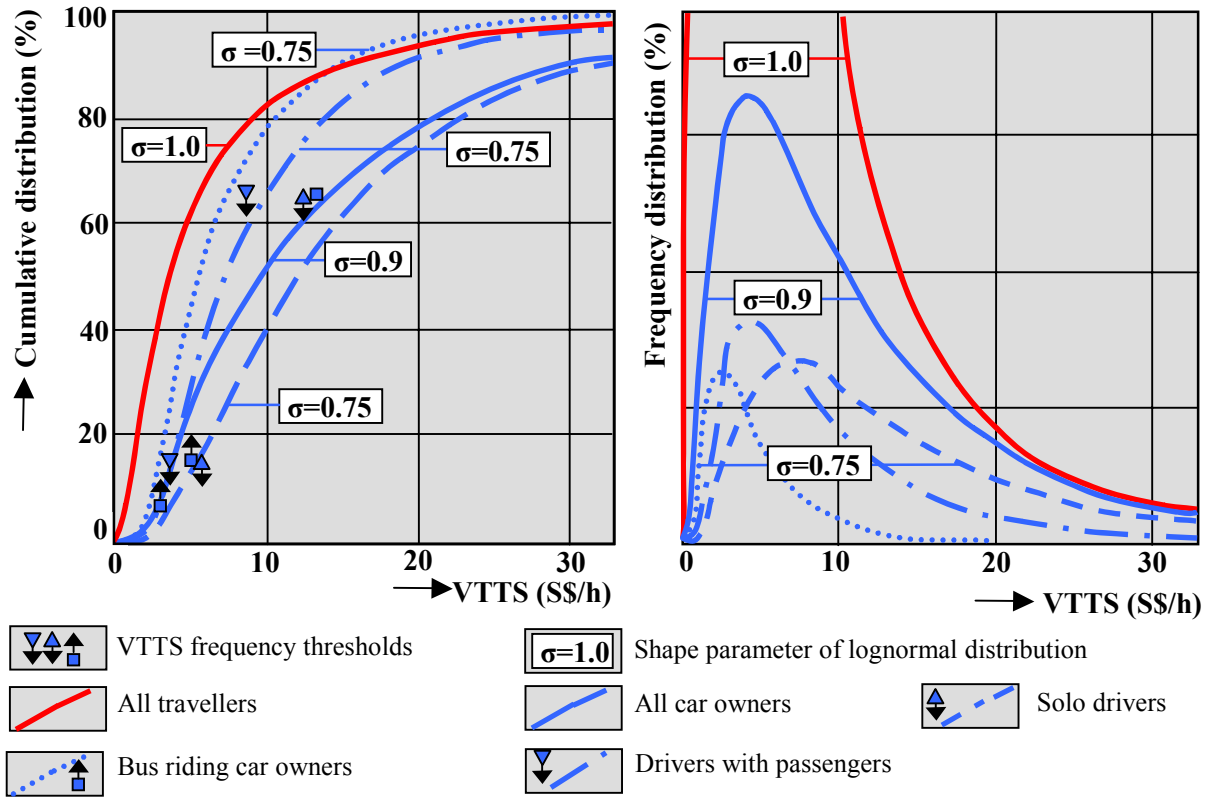


Figure 16: Lognormal VTTS distributions in Singapore, assessed in agreement with the EPT paradigm.

The average VTTS was S$7/h for all travellers and amounted to S$14/h for all car owners. That the average for car owners was twice as high agrees with the ratio of about 1.8 in average incomes discussed above, taking the differences in shape parameter into account. The inferred average VTTS for solo car drivers was S$16/h, 60% above the average of S$10/h found for car drivers who carried one or more passenger. The average VTTS for non-captive bus passengers from car-owning families was almost S$8/h, slightly above the average for all travellers. At first sight this seems low in view of the relatively high income of this group: bus riders from vehicle-owning households earn an average income of S$1,750 per month, almost 50% above the mean for all travellers (see Annex E). One should consider, however, that the majority of these bus riders had no car at their disposal as another family member used it, either as a solo driver or within a rideshare agreement with a colleague. Their average household income might have been the same as that for all solo car drivers. One might thus expect that the minority of car owners who deliberately left the car at home to save money had a lower household income than the average bus rider from vehicle-owning households. Similar reasoning explains the mean VTTS average for car passengers, which was even slightly below the average for all travellers. This once more points to income as a main determinant of the traveller's VTTS.

The average VTTS values for all travellers were 8/h according to the LA(2,2) appraisals and S$5/h following the LA(2,1) algorithm – which here were the same as according to the UT model implementation. Compared to the assessments in agreement with EPT the average VTTS values for bus riding, car driving and passenger carrying car owners were 10 to 20% higher if calculated with the LA(2,2) algorithm and ranged between 60 and 70% of them if appraised in agreement with the UT model.

7.5.4 Discussion

The assumption of a lognormal distribution of the VTTS over different groups of travellers in connection with the modal shares allowed approximate VTTS distributions to be inferred from the highly aggregated data about accessibility characteristics and travel behaviour. Obviously, a more solid VTTS assessment would be to analyse the personalized data of the World Bank survey, both with respect to income and revealed travel choices. Though the actual distribution would definitely appear to be skewed the lognormal function would not by definition offer the best fit. However, as income is a main determinant of VTTS and the lognormal function ranks as about the best approximations for actual income distributions it is plausible that this also holds for VTTS distributions.

The average VTTS values inferred from the lognormal approximations are far beyond the S$1.75/h that Wilson (1988b; 1989) found as an average, from an analysis of the pre-ALS World Bank survey with a Multinomial Logit model with a linear utility specification. Wilson treated the VTTS under the assumption that commuters could choose their work start time at will, but at a schedule cost that increased the further the work start time was, either before or after, from the most common time of 9:00 a.m. This 'working hours schedule costs' parameter attracted by far the largest share of the travel costs in his utility specification. In the present treatment, the commuters' choice of an employer and the associated work start time arrangements are conceived as consequences of a strategic decision that, in the tactical and operational choice contexts treated here, are not considered as discretionary. Violations of the agreed work start time as a consequence of 'trip schedule delays' following departure time, mode and route choices are considered as a consequence of the travel time outcome of that choice and valued as such.

If the schedule costs are omitted from Wilson's model, a value of over 5 S$/h is found for travel time. Furthermore, Wilson's assessment disregarded interpersonal heterogeneity and thus might have underestimated the average VTTS considerably (Hensher 2001a; Van de Kaa 2006). The lognormal distribution of the VTTS for all travellers as found above from the loss-neutral assessment also resulted in an average VTTS of S$5/h. This might thus be a slightly conservative estimate rather than an overestimation. The higher VTTS values inferred from the reference-dependent, loss-aversive assessments follow straightforward from the premises of PT and EPT. The order-of-magnitude of the different VTTS values and their distributions as found from the calibrations of the EPT and UT 'models' to the actual 1975 Singapore travel choice context might thus be considered trustworthy.

7.5.5 Conclusions

The calibration of the average VTTS of different categories of car owners from their travel mode choices before 1975 was straightforward. The average VTTS of all travellers that was found from the calibration of the UT implementation was about the same as could be inferred from an earlier assessment based on the 1975 travel choice behaviour with a Random Utility Maximization model. There is thus no reason to believe that a conventional Random Utility Maximization model, if applied to the same data, would have elicited very different VTTS values. The model implementation according to the EPT paradigm contained additional parameters to account for loss aversion and the application of different choice behaviour strategies, particularly different loss aversive judgment approaches. These parameters were estimated on choice observations data outside the Singapore context and treated as constants in the calibration and prediction assessments. Just like the UT implementation, only the average VTTS and its distribution was calibrated here. The different predictions of car use that are made in the following sections according to both models can thus be used for a 'ceteris paribus' comparison of the predictive abilities of the underlying assumptions of UT and EPT.

7.6 Car drivers' responses to the introduction of the Area License Scheme

The Area License Scheme (ALS) was put into operation in June 1975. From 7:30 to 9:30 a.m., cars with less than four occupants were no longer allowed to pass a cordon around a Restricted Zone of the Central Business District unless they bought a monthly or daily license that allowed unlimited access (Watson and Holland 1978[117]). Section 7.3 considered the reference state and the feasible alternatives, with the most relevant attribute levels (Table 11 on page 200) of the pre-ALS car owners who were confronted with the imminent ALS fee if they wanted to continue their daily trips to or through the Restricted Zone during the restricted period. It also provided an overview of the observed responses (Table 10 on page 199). The present section starts with the assessment of predictions for the travel choices from a series of bioptional trade-offs of the feasible alternatives. Successively these predictions are adapted to the choice from multi-alternative choice sets. After aggregation to the population level these predictions are compared with the observed responses. The section is concluded with a short summary of findings.

[117] Unless otherwise stated, further basic information in Section 7.6 is also cited from this reference.

7.6.1 Bi-optional trade-offs of feasible alternatives

In this subsection calculations and comparisons of the responses of pre-ALS car drivers to the ALS introduction are discussed. These responses are conceived as consequences of the choice behaviour of individual car drivers. They are evaluated as bi-optional trade-offs of the feasible alternatives, for different manifestations of loss-aversive and loss-neutral appraisals. The actual calculations, evaluations and comparisons of over a dozen, for two different destinations, of solo and rideshare drivers, and three algorithms are extensively discussed in Annex F. Here, an outline of the assessment process is given, followed by an example of such a bioptional trade-off and a summary of the most important findings from Annex F.

The assessment follows the value function as developed in Section 7.4. The attribute levels adopted for the considered alternatives are derived from the extensive assessments in Annex D. Three different implementations of the value function are considered. They use the following algorithms: LA(2,2), i.e. application of a loss aversion factor 2.0 to both time and money losses; LA(2,1), application of the loss aversion factor 2.0 to time losses and loss-neutral valuation of money expenses; and LA(1,1), a loss-neutral appraisal of time and money changes. These different manifestations of loss aversion are conceived as interpersonal choice behaviour strategies that can be described by substitution of the concerned factors in the value function. The application of these fleshed-out functions to the bi-optional choice sets yields a prediction of the lowest or highest idiosyncratic VTTS for which the concerned car drivers are considered to prefer one alternative to the other. A comparison with the dispersal of idiosyncratic VTTS values across the different groups of travellers, as assessed in Section 7.5, allows a prediction of the extent to which each choice would be made. These are assessed in agreement with the EPT implementation, which is simplified to a 70-30 distribution of choice behaviour strategies over LA(2,2) and LA(2,1), and UT, which assumes that all travellers follow the LA(1,1) strategy.

After the ALS enforcement solo car drivers who commuted to the Central Business District in the restricted period could choose the 'keep-to-your-mode-and-schedule' alternative (further referred to as 'KYMS'). Compared to the reference state this alternative contained a license fee of S$3.00 and an increase of S$0.75 in parking expenses for a whole day (see Table 11, page 200, for these and successive attribute levels). The increased speeds in the Restricted Zone implied a small one-minute travel time gain compared to the pre-ALS circumstances. One of the feasible alternatives was to change to bus transit. This would cost the average solo car driver nineteen minutes additional travel time in the morning and twenty in the afternoon, plus a loss of comfort and an expense of S$0.40 for two bus tickets. They would gain back the running and parking costs for their trip. As an example of the many trade-offs described in Annex F this is evaluated as follows:

According to the value function discussed in Section 7.4 and disregarding differences in comfort, a pre-ALS solo car driver who went to work in the Restricted Zone after ALS enforcement would prefer the KYMS alternative over a change to bus riding if:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * 0 + 1\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-3 - 0.75) + 0\}[\text{S\$}] > VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-18 - 19) + 0\}[\text{min}] / 60\ [\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.4) + 2 * 0.85 + 2.5)\}[\text{S\$/h}]$$

Drivers who applied LA(2,2) would prefer the 'low travel time' KYMS alternative if their VTTS was slightly above S$8/h. Comparison with the VTTS distribution of pre-ALS solo car

drivers as found according to the corresponding LA(2,2) appraisal yields that this holds for 77% of the solo drivers who went to the Restricted Zone daily. For LA(2,1) the break-even VTTS lies well below S$6/h, and according to the corresponding pre-ALS VTTS distribution 65% of them had a higher VTTS and should thus choose for KYMS. The assumed 70-30 distributions of these choice behaviour strategies under the EPT paradigm yields the prediction that 75% of the solo car drivers would keep to their pre-ALS mode. The break-even point, according to LA (1,1), lies above S$11/h. Comparison with the corresponding VTTS distribution yields the prediction that 30% of them would be better choosing the KYMS alternative while the others should switch to bus riding. The ratio between the solo car drivers to the Restricted Zone who actually kept on driving during the restricted period and those who became conventional bus passengers was about 5:1. This ratio is higher than the 3:1 ratios that were predicted according to the reference-dependent trade-offs discussed above. The reference-independent, loss-neutral appraisals predicted a ratio of 1:2 for solo drivers. Obviously, for commutes to the Restricted Zone the reference-dependent predictions offer better approximations of the actual observed choices of solo drivers than the reference-independent ones.

Most bioptional trade-offs in Annex F are followed by a preliminary observation of the descriptive ability of the UT and EPT paradigms. The frequency of the different behavioural responses to the ALS enforcement clearly showed that by far the most travellers only adjusted their behaviour to a small extent. For example, nearly all the car drivers who joined four-person car pools had already been carrying a passenger before the ALS, and small advancements of home departure time were more popular than large advancements of home departure and work start time, even if the earlier departure time due to the small advancement was completely wasted in waiting till work started. Another interesting finding was that the strong increase in carpooling was presumably facilitated by many limited adjustments of work start times, which consisted predominantly of advancements of up to half an hour. This is what might be expected if subjective consideration sets are generated adaptively, as context-dependent changes in the actual behaviour, as assumed by EPT. If people set up more or less comprehensive sets ‘from scratch’ as reference-independent situations, without consideration of their present behaviour, as assumed by UT, one would expect a larger share of the more drastic changes in travel behaviour.

The range of idiosyncratic VTTS values for which people would actually prefer a certain alternative that are assessed in agreement with EPT are generally well in line with the observed relative frequency of behavioural responses to ALS enforcement. Many assessments in agreement with UT approach these frequencies less closely. The most conspicuous difference concerned the propensity of drivers to pay the license fee and keep to their schedule rather than to switch to transit by bus. Averaged over solo and rideshare drivers and over trips to and trough the Restricted Zone, the retraced trips in Annex C follow a 70:30 ratio where application of the EPT assumptions yields 75:25 and UT suggests 30:70. The propensity to continue using the car to get to work beyond the restricted zone instead of making a detour or switching to transit were also better explained by the EPT implementation than by UT.

7.6.2 Prediction of car drivers’ choices from multi-alternative choice sets

The bi-optional trade-offs discussed in the previous subsection offered valuable information about the predictive ability of the considered choice behaviour strategies and paradigms. In this subsection this information is aggregated and completed with adjusted predictions for the choices from more complete consideration sets, taking the constraints that limit their adoption

into account. This is done for the segments and subsegments of the travelling population that were established in Section 7.3.4. The responses to the ALS enforcement are successively predicted in agreement with the EPT and UT paradigms and compared with the estimated actual responses as listed in Table 10 (page 227).

The prediction draws on the VTTS thresholds for each alternative, above which that alternative was preferred over bus transit and below which it was preferred over KYMS, as assessed in the previous subsection. For each of the considered subsegments and according to all the considered algorithms the relevant intervals were compiled. For the alternative with the highest lower and upper interval limit, i.e. which yielded the traveller the highest value compared to the other options, the corresponding percentage of the subsegment population was calculated from the corresponding lognormal VTTS distribution. After multiplication of the percentage for each alternative with the relevant subsegment population and summation over the segments this yields a distribution of the predicted choices across the population as a whole that can be compared with the observed frequencies.

The attribute levels that were considered in the trade-offs were based on information from the household travel survey, additional measurements and statistical information, assembled in Watson and Holland and elaborated in Annex D. The most questionable level assessment concerns the travel cost attributes of rideshare drivers. In the absence of more solid information it is assumed that the passengers were compensated for 40% of the running costs, parking fares and ALS fees. These contributions are balanced with the drivers' expenses. A separate assessment was made of the willingness of passengers to pay their share of the license fee and the increase in the parking tariff. For those who were not prepared to do so the propensity of their drivers to account for this if they kept on travelling according to their previous schedule (KYMS) was assessed and this was balanced with the pros and cons of a change to bus riding. Another questionable basic assumption concerns the loss neutral assessments of work start time advancements and postponements. As these are dominant for any size, for all travellers except those with a very low VTTS, these were arbitrarily limited to at most half an hour. This was about the same level above which application of the reference-dependent choice behaviour strategies revealed that they would be rejected.

The reference state was based on information that concerned only the pre-ALS travel conditions. The distributions of individual VTTS values across the population were calibrated on pre-ALS choice behaviour (Section 7.5), for all three discerned idiosyncratic choice behaviour strategies LA(2,2), LA(2,1) and LA(1,1). In agreement with the choice behaviour consistency principle of EPT it is assumed that individuals applied the same choice behaviour strategy to select their response to ALS as they did for these earlier decisions.

In Table 14 the predictions are compared with the frequencies of the actual choices as assessed in Section 7.3. The predicted and actual frequencies are presented as percentages of the concerned pre-ALS car trips, to ease comparison with the extrapolated and retraced actual choices that differ in their absolute totals. The agreement between the percentages of the actual and predicted numbers of the four aggregated mode-destination combinations is the consequence of the study design and has no meaning for the appraisal of the predictive ability of the paradigms.In addition to the predictions found from application of the mixture of choice behaviour strategies as assumed by EPT those which followed from the LA(2,2) assessments are listed, to give an indication of the predictive ability of a simple application of PT, though applied in connection with a lognormal description of interpersonal heterogeneity in VTTS values as deduced within the framework of the more generic principles of EPT.

7.6.3 Comparison of the frequencies of retraced and predicted responses

A comparison of the predicted frequency of the responses to the introduction of the ALS with the retraced actual responses as listed in Table 14 allows qualitative observations with respect to the applicability and descriptive ability of the EPT and UT paradigms. The predictions were also compared with the 'extrapolated' response frequency that appeared less plausible (Annex C). As these comparisons yielded essentially the same inferences as those discussed below they are not reported here.

The frequencies of the responses as predicted in agreement with EPT show an overall good match with the actual frequencies. On the aggregate level they underestimate the shift to transit, to the hours before and after the restricted period, and to the detour alternative, by two to three percent. Though each of these differences is hardly significant they accumulate, together forming a serious overestimation of the number of drivers who keep on travelling by the same mode, along the same route and according to the same travel-and-work schedule. This would also result in a corresponding overestimation of inbound passenger car traffic during the restricted period. Considering a more disaggregate level, only two predicted responses differ more from the retraced choices than the 1% rounding off margin. The largest misprediction is that 8% of the population, rideshare drivers who worked within the Restricted Zone, were predicted to switch to a conventional bus service while 12% were found to have actually done so. This 4% difference yields a corresponding overestimation of the predicted choices for the KYMS alternative. The other significant difference between the predicted and found travel choices amounts to another 2% of the whole population. This concerns solo drivers who worked beyond the Restricted Zone and did not choose the detour over the ringroad, resulting in an underprediction of this response and a corresponding over-prediction of KYMS.

Predictions that assume that all travellers applied the LA(2,2) choice behaviour strategy yield similar results, though they fit less well with the actual frequencies found. On the aggregate level the underprediction of the change to transit grows to 6% compared to two according to EPT, leading to a 9% overestimation of the choices for KYMS. At the disaggregate level, the change to conventional bus services by rideshare drivers who worked within the Restricted Zone amounts to 6% compared to the retraced 12% and the 8% predicted by EPT. The 2% underestimation of the detour over the ringroad by solo car drivers is the same as that predicted by EPT.

The predictions made under the reference-independent, loss-neutral UT implementation differ more conspicuously from the retraced actual choices. For the driving population as a whole as well as for all the four main segments there is a massive underestimation of the propensity to keep on driving along the same route and according to the same daily schedule and thus to pay for it. The shift to transit and the propensity to adjust the work start time is strongly overestimated while hardly any advancement of home departure without work start time adjustment is predicted. The predictive performance of the UT paradigm might be considered as inadequate, at least if it is parameterised equally as frugally as the EPT concept.

Table 14: Car drivers' predicted and actual responses to ALS

Tactical travel choice as response to the enforcement of the ALS	Percentage [1] of the pre-ALS car drivers			
	Retraced	Predicted choices		
	Actual	EPT	LA(2,2)	UT
All drivers and destinations	**100**	**100**	**100**	**100**
Shifted to transit or Park-and-Ride	22	20	16	44
Advanced home departure time	12	10	11	21
Postponed home departure time	4	2	3	12
Detour via ring road	26	23	24	13
Kept to pre-ALS mode and schedule	37	45	46	10
Solo drivers, work within RZ	**34**	**34**	**34**	**34**
Shifted to conventional bus	4	5	4	12
Shifted to express bus	2	1	1	3
Accepted Park-and-Ride	3	3	3	2
Advanced home departure, same WST[2]	3	2	2	0
Advanced home departure and WST	2	1	1	5
Postponed home departure and WST	2	1	1	6
Kept to pre-ALS mode and schedule	19	20	21	5
Solo drivers, work beyond RZ	**30**	**31**	**31**	**31**
Shifted to conventional bus	0	1	0	8
Detour via ring road	20	18	18	10
Advanced home departure, same WST	3	3	3	1
Advanced home departure and WST	1	1	1	8
Postponed home departure and WST	1	0	0	3
Kept to pre-ALS mode and schedule	6	8	8	3
Rideshare drivers, work within RZ	**27**	**27**	**27**	**27**
Shifted to conventional bus	12	8	6	16
Shifted to express bus	2	2	1	2
Accepted Park-and-Ride	0	0	0	0
Advanced home departure, same WST	2	2	2	0
Advanced home departure and WST	1	1	1	4
Postponed home departure and WST	1	1	1	2
Kept to pre-ALS mode and schedule	10	14	14	2
Rideshare drivers, work beyond RZ	**9**	**9**	**9**	**9**
Shifted to conventional bus	0	0	0	1
Detour via ring road	6	5	5	3
Advanced home departure, same WST	1	1	1	0
Advanced home departure and WST	1	0	0	2
Postponed home departure and WST	1	0	0	1
Kept to pre-ALS mode and schedule	2	2	2	0

[1] The percentages relate to all car drivers who entered the Restricted Zone in March 1975 between 7:30 and 10:15 a.m. except those who drove a 4^+ carpool or travelled in a goods vehicle, and those who, after ALS enforcement, cancelled their trip, joined a 4^+ carpool or chose a non-motorized mode. The percentages do not necessarily add up to 100% as a consequence of rounding-off to multiples of 1%. [2] WST = work start time.

In general, the responses to the ALS introduction as predicted with the EPT model are much closer to the actual observed responses than those predicted in agreement with UT, taking into consideration that for both model implementations the same parameterization was applied and the same calibration process was followed. The predictions in agreement with EPT fit somewhat better with the actual responses than those found from the LA(2,2) choice behaviour strategy. This means that EPT offers a distinct, though moderate, improvement over the application of one set of loss aversion factors to put PT into operation.

7.6.4 Conclusions

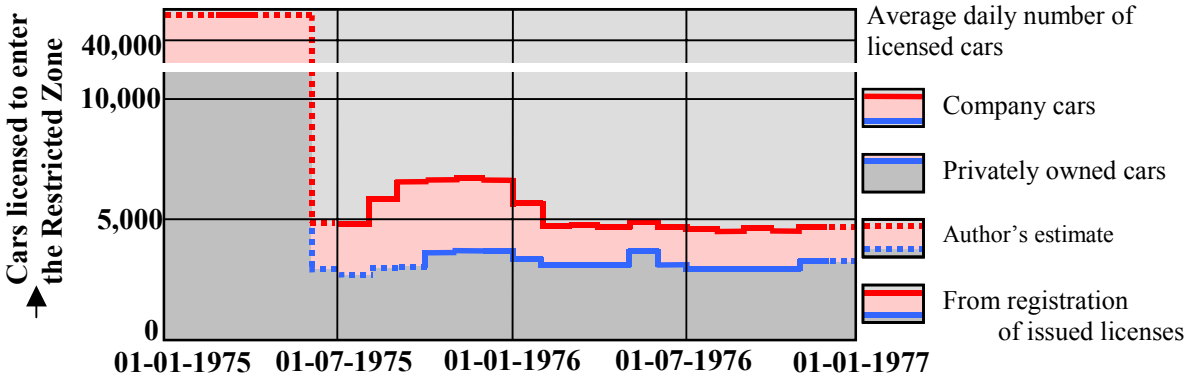
This section showed that the model implementation that adhered to the reference-dependent, loss-aversive assumptions of EPT predicted the frequencies of the many different transit, departure time and route alternatives choices much better than the alternative reference-independent, loss-neutral implementation in agreement with UT. Though a better performance of both model implementations might be expected if the parameters had been calibrated to data of individual's travel behaviour in connection with their personal context, there is no reason to expect that this would diminish the difference in predictive ability. Several improvements and refinements of the UT implementation might in the considered ALS introduction context improve its predictive quality. Unless these concern adoptions of EPT assumptions, such as reference dependency and updating, these will mostly presumably not survive when another drastic change in the travellers' context occurs. For tactical choice contexts similar to the introduction of the ALS the difference in the predictive ability of models that adhere to the EPT and UT paradigms might be attributed to a fundamental difference in the assumptions about human choice and behaviour.

7.7 Responses to the 1976 road-pricing fare increase

The 1976 adjustment of road pricing fares followed just seven months after the enforcement of the ALS regime, in a period of economic recession. The increase in license fees was drastic, from January 1976 onwards it was raised by 33% for private cars and 267% for company cars. It was accompanied by large increases in taxes related to vehicle ownership. The change in fare was announced very shortly before it was implemented. Apparently, many companies and individuals initially found no opportunity to adopt another strategy than to pay the increased license fee. The drop in the sales of licenses that occurred, as expected, in January 1976 was followed by an almost equal drop in February, after which the number stabilized at a clearly lower level than in the last months of 1976 (Figure 17). This section examines the observed responses of private and company car drivers and compares them with several predictions in agreement with EPT and UT.

7.7.1 Assessment of the actual responses to the fare increase

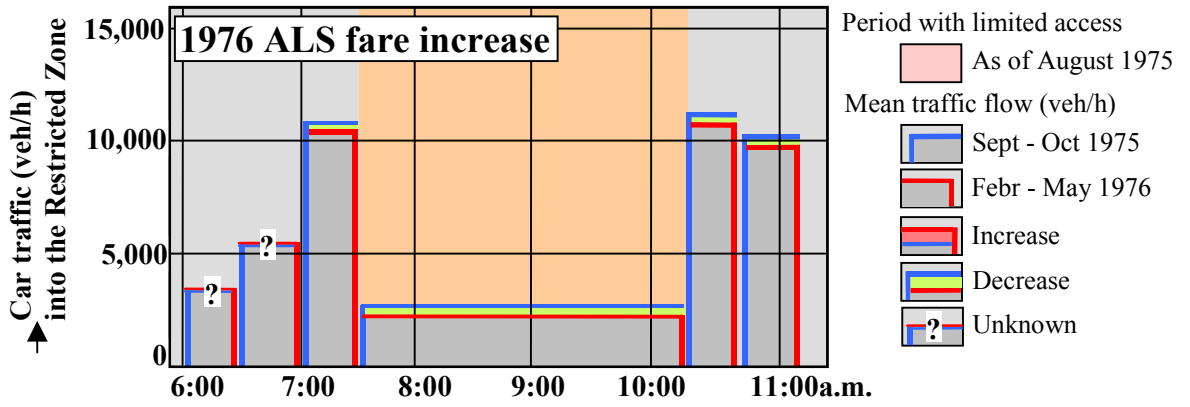
The effects of the sudden increase in ALS fees on car traffic were well documented by Watson and Holland (1978). The decrease in license sales (Figure 17) was confirmed by a similar decrease in car traffic (Figure 18). The counted number of non-carpool cars that entered the Restricted Zone in the half hour before and after the restricted period decreased by 5-7% while the decrease during the restricted period was 17%. The number of carpools that entered the Restricted Zone between 7:30 and 10:15 a.m. increased by 8%. In the adjoining half hours it decreased by more than 12 to 14%, thus at a higher rate than the non-carpool cars. This indicates a general decline of at least 5% in car traffic to which the impact of the rise in the ALS fee should be added. Between the fall of 1975 and the spring of 1976 the



Elaborated from Watson and Holland (1978, Table 3.2)

Figure 17: Impact of the 1976 ALS fare increase on the number of private cars entitled to enter the Restricted Zone

average number of privately owned cars for which a valid license was sold dropped by 15%. For company cars, exclusive taxis and light vans, this was 40% (Figure 17). Together the decrease amounted to an ample 25%, much higher than the concurrent decrease in the traffic counts. This difference might have been caused by an increasing number of travellers who managed to pass the cordon without paying the license fee or by increasing misclassifications in the traffic counts.



Elaborated from Watson and Holland (1978, Tables 4.10 and 4.12)

Figure 18: Impact of the 1976 ALS fare increase on the daily car traffic flows into the Restricted Zone

Whatever the reason, the average number of licenses that were valid on an 'average day' in the last three months of 1975 was 8% below the average number of private and company non-carpool cars that concurrently entered the Restricted Zone during the restricted period, and this discrepancy increased to 19% in the three months between February and April 1976. It 'explains' an 11% decrease in area license sales. As there is no apparent reason to believe that private persons were less motivated and less skilful in circumventing the license obligation this leaves a 29% decline for company cars and 4% for private cars that might be attributed to the combined effects of the general decline in car traffic and the license fee increase.The overall decrease in car traffic may be attributed to the steep rises in both car acquisition taxes, from 55% to 100%, and the annual road taxes (Spencer and Sien 1985). These latter taxes depended on engine size and implied an average increase of 50-75% for most private cars, taking common engine sizes into account (Watson and Holland 1978; Spencer and Sien

1985). For company cars the taxes were twice as high, though tax deductions might have mitigated the effect to some extent. The tax increases took effect on 31 December 1975, concurrent with the increase in ALS fees. Spencer and Sien (1978) found that the population of private and company passenger cars decreased by 4.7% in 1976 compared to 1975, about the same as the decrease in overall car traffic. The much higher increases in taxes and fares for company cars compared to private cars suggests that the decrease in registered company cars will have been greater than for private cars, which might have caused a greater decrease in company car traffic than in private car trips. No information is available about the share of company cars in the 1975 passenger car population but for 1976 this was 12%. The decrease in area licenses sold to company cars was 2.7 times the decrease for private cars. Taking this as an upper limit for the difference in the decline in registered cars this explains at most 8% of the decrease for company cars and about 3% for private cars.

Taking both alternative explanations for the decrease in license sales into account leaves a decrease of about 25% in the number of company cars that passed the cordon during the restricted period. The corresponding decrease for private cars was at most a few percent. One should note that the percentages relate to the fall 1975 traffic flows. Expressed in the corresponding number of cars that entered the Restricted Zone during the same hours in spring 1975 the decrease would have been about 20% for company cars and at most 1% for private cars.

7.7.2 Responses of drivers who possessed their car

The increase of the average license fee for private cars was from S$3 to S$4 per day. The increase in license fee definitely offered no reasons to consider this choice anew for individuals who, following ALS enforcement, had changed their daily trip planning to avoid paying the fee. The affected private car drivers were those who during the ALS enforcement chose the ‘keep-to-your-mode-and-schedule’ (KYMS) alternative, as they still passed the cordon between 7:30 and 10:15 a.m. To predict their response to the fare increase the same approach is followed here as in the previous section, although only the trade-off between KYMS and bus ridership will be elaborated quantitatively. Again, both reference-dependent and reference-independent appraisals will be discussed. In addition a loss aversive appraisal without reference updating will also be considered.

The sudden increase in fares enables the relevance of updating the reference state for loss aversive appraisals in agreement with EPT to be considered. For expository reasons an assessment will be described below in which the changes in attribute levels are considered relative to the pre-ALS reference. In view of the short period that had elapsed since the introduction of ALS such a choice behaviour strategy might not be implausible. However, this is not considered as a proper application of EPT and it is hypothesized beforehand that very few, if any, people would apply such a decision frame. Under the EPT-paradigm it is presumed that, after ALS enforcement, car owners almost instantaneously exhibited a shift in their reference state (e.g. Nielsen 2004; see Chapter 4 for an overview). For those who paid the fee and kept on driving during the restricted period, their December-1975 travel conditions became their updated reference state against which they evaluated the alternatives for payment of the fare increase. Of course, the reference-independent appraisals according to the UT paradigm should not be considered to be subject to changes in the choice context. As the comparative assessments in the previous section were made for attribute levels relative to those in the pre-ALS implementation context, the same definitions of attribute levels could be followed here.

The attribute levels of the reference-independent and the reference-dependent strategy without reference updating are almost the same as those considered in the previous section. They only differ with respect to the level of the license fee. For KYMS travellers now have to pay S$4 for the license and still have a S$0.75 additional parking fee, and would improve their travel time by on average one minute. Pre-ALS solo car drivers working within the Restricted Zone need eighteen minutes additional travel time in the morning and nineteen in the afternoon, plus the expense of two S$0.40 tickets if they want to switch to bus riding. They would gain the running and parking costs for their car trip. For the reference-independent evaluationan 'average' solo driver would prefer the KYMS-alternative to bus riding if:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * 0 + 1\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-4 - 0.75) + 0\}[\text{S\$}] > VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-18 - 19) + 0\}[\text{min}] / 60\ [\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.4) + 2 * 0.85 + 2.5)\}[\text{S\$/h}]$$

For drivers who applied LA(2,2) this would become true for VTTS > S$10/h, 20% above the threshold found for the initial enforcement of ALS. The same relative increase was found for rideshare drivers. For the LA(2,1) and LA(1,1) strategies the relative increases are only 15%. Comparison with the relevant VTTS distribution yields the share of drivers who would opt for bus riding over KYMS, increasing from about 25% to about 35% according to EPT, if it was applied without reference updating, and from 70 to 75% following UT, which principally assumes reference independency. Assessments for destinations beyond the Restricted Zone showed similar increases in thresholds, resulting in 8% additional shifts from driving to bus riding according to EPT and 9% following UT. Of course, similar increases could be found for the express bus, carpool, detour, departure time and work start time adjustment alternatives. According to these appraisals, during the restricted period the inbound traffic of private cars should thus decrease by at least another 5% of the original pre-ALS flow. The reference-independent simulations thus predict that the rise in license fee would cause a further decrease from the level of pre-ALS private car traffic, by 8% if loss aversion is assumed and 7% if not.

When the reference state is updated for the situation in December 1975 most attribute levels differ from those considered in the previous section. A shift to bus transit would still imply a loss of two times S$0.40 for the bus tickets and a loss of nineteen minutes travel time in the evening but the travel time loss in the morning increases to the same nineteen minutes. To the gains of S$1.70 running costs should be added a S$3.25 instead of S$2.50 parking fee decrease and the S$3.00 license fee. The KYMS alternative only differs from the updated reference state by a S$1.00 increase in the license fee. The 'average' driver should now prefer bus transit over KYMS if:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * 0 + 0\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-1) + 0\}[\text{S\$}] > VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-19 - 19) + 0\}[\text{min}] / 60\ [\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.4) + 2 * 0.85 + 3.25 + 3)\}[\text{S\$/h}]$$

From this it follows that according to LA(2,2) only pre-ALS car drivers with an idiosyncratic VTTS below S$7/h would switch to bus transit, compared to S$10/h for the corresponding appraisal without a reference shift and S$8/h as assessed in the previous section for the response to ALS enforcement. As all drivers with such a low VTTS would already have made this change after the June 1975 ALS implementation, LA(2,2) with the updated reference state predicts that the rise in ALS fee incites no further modal shift of commuters who drove a private car to bus riding. For LA(2,1) there is also a decrease in the VTTS threshold compared

to the reference-independent appraisal above, but this is marginal. This is the consequence of the fact that the large shift of money expenses from the loss to the gain domain does not affect the valuation while on balance the sign of only one-minute travel changes. Combination of the LA(2,2) and LA(2,1) appraisals with an updated reference state under the EPT model predicts an increase of 2% in the ALS-induced preference for bus riding over KYMS after the increase in the license fee, compared to the about 25% predicted for the fall of 1975. Of course, LA(1,1) yields the same thresholds as the reference-independent appraisal above and thus the predicted additional shift away from driving according to the UT model is 7% higher than the 65% predicted for the S$3 fare.

7.7.3 Responses of drivers who used a company car

For company cars the ALS fee increased from S$3 to S$8. This implies that much higher VTTS thresholds will be assessed for individuals who have a company car at their disposal but have to pay for the license fee out of their own pockets. According to the reference-independent UT model a shift to bus transit might now be preferred by the average solo driver with an idiosyncratic VTTS of up to S$19/h compared to S$11/h after the initial ALS introduction. Without updating the reference state the LA(2,2) and LA(2,1) algorithms yields thresholds of S$16/h and S$10/h, about twice those found for the S$3 fare. When the reference shift is modelled, as should be done in a proper application of EPT, these values decrease to S$13/h and S$9/h. For rideshares and destinations beyond the Restricted Zone similar relative increases in VTTS thresholds were found. After deducing and combining the predictions for all pre-ALS drivers and destinations the reference-independent appraisal in agreement with UT predicts 90% shifts to transit compared to the 70% predicted for the initial introduction of ALS. The reference-independent assessments incorporating loss aversion yield 60% choices for bus over KYMS compared to 25% as a consequence of ALS introduction. According to EPT's reference-dependent appraisal, with reference updating, 50% of the pre-ALS travellers should switch to bus ridership. Again, similar changes in thresholds and percentages would be found when other alternatives for continued use of company cars during the restricted period are considered.

One might consider that people who feel responsible for the company that owns their car might make similar assessments of the costs and benefits of the different alternatives for car driving during the restricted period. However, for them as well as for firms who considered whether or not to pay the license fee for their employees when the ALS was introduced, a late-1975 re-appraisal in view of the large increase in the fee would yield a lower propensity to keep on paying, whatever the paradigm was according to which the assessment was made. As no further information is available about the arrangements between the employees who used company cars and their employers, the extent to which the 1976 increase in fees for company cars induced a reduction in the inbound traffic of company cars into the Restricted Zone during the restricted period remains unsettled. However, according to every considered arrangement and choice behaviour paradigm a drastic decrease is predicted.

7.7.4 Discussion

The reference-independent appraisals in agreement with UT predicted an additional shift of 7% of the pre-ALS private car drivers to non-driving modes and of 25% of the company cars. If the same reference state is presumed as before ALS enforcement, loss aversive assessments yield an additional decrease of 8% and 35%, respectively. When the reference state is updated for fall 1975, in agreement with the EPT paradigm the predicted decreases are 2% and 25%. The actual percentages found were about 1% and 20%. A comparison shows the importance

of a proper assessment of the reference state in travel behaviour predictions: without proper reference updating the loss-aversive assessments may perform even worse than loss-neutral ones, while after a proper adjustment of the reference state the loss-aversive prediction according to EPT predicts the actual responses much better than UT for the drivers of private cars and equally well for the company car drivers[118].

7.8 Long-term responses to road pricing (1976-2005)

In the previous sections the VTTS values as estimated for the pre-ALS circumstances of car drivers were treated as part of their reference state, both for the choice between alternatives for payment of the initial ALS fee and for payment of the 1976 fare increase. This was assumed justified as the time lapse between introduction and fare increase of the ALS was small and the travellers' income and discretionary time spent did not change radically in the intervening months. However, in the longer term income and prices in Singapore changed to such an extent that the VTTS would quite definitely have deviated from the nominal values as settled in Section 7.4. This section explores the long-term predictive ability of the EPT and UT paradigms by considering the travel mode choice of car owners who worked in the Restricted Zone or started to do so between 1976 and 2005. Compared to the previous sections a less detailed and in some respects more qualitative approach will be followed. After a description of this approach in the following subsection the actual developments in travel behaviour will be considered from the perspective of UT and EPT, successively. The section is finalized by an overview of the most important conclusions.

7.8.1 Adopted approach for the evaluation of different prediction principles

The model adopted for the predictions in this section was developed in Section 7.4. The most important consideration is how to deal with long-term changes in VTTS (see Subsection 7.4.7). It was established there that under the UT paradigm the travellers' VTTS values are commonly supposed to co-develop with the nominal wage rate or to lag behind that development. Following the hedonic valuation principles of the EPT paradigm it was hypothesized that the VTTS for most individuals might follow the development of the nominal household income or consumer price index. In this section development of the VTTS proportionate to the nominal wage rate, nominal household income and consumer price index is considered[119] for model implementations in agreement with UT and EPT. Comparison of the six predicted developments in car use with the actual development allows separate inferences about the descriptive ability of the considered VTTS indexation assumptions and choice behaviour paradigms.

As all price and income indices are based on nominal monetary values it seems most appropriate to avoid other designations for the value of currencies. That is why in this section

[118] It might be more appropriate to relate the predicted additional decreases to the predicted preference for KYMS after ALS introduction and compare it with the actual decrease between Fall 1975 and Spring 1976. For private car drivers this would imply a decline of 20% as predicted by UT, 10% following a loss-aversive valuation without reference updating, 3% according to EPT and 2% observed. For company cars the percentages would be: UT 67%, loss aversive without reference adjustment 45%, EPT 34% and actual 25%.

[119] For these developments the national averages of wages, household incomes and consumer prices were used. In the considered period the average number of workers per household and the average working week remained approximately the same. For a more refined indexation of the developments for different population segments a proper assessment of the monthly household income effect on VTTS requires that the average number of commutes and working days per household remains about constant for each considered segment.

all monetary values are expressed in nominal Singapore dollars (S$). The real monetary value of any amount of dollars mentioned in this section thus depends on the year to which it applies.

The recovered long-term information about the socio-economic circumstances and travel conditions of Singapore's commuters stems from a more heterogeneous origin and is at a higher aggregation level than the data that were analysed in the previous sections. In Annex G the developments in car ownership and in the actual travel choices of car owners are estimated, starting from the situation that emerged after the 1976 ALS fare increase. The annex also gives an overview of the development over time of consumer prices, travel time and spending of money of commuters, and their wages and household income. This section builds on the results of these assessments.

The recovered information on the development over time of the relevant time and money attributes for the different travel mode and schedule alternatives is less refined than for the 1975 conditions. The assessment of the monetary attribute values is described in Annex G.3 and summarized there in Table G.2 (page 389). The often small differences in travel time between solo and rideshare drivers that were considered in the previous sections are fully disregarded hereafter. More importantly, the about 15% higher 'equivalent' travel times of car users compared to transit riders, caused by the different 'average' accessibility characteristics of both population segments, had to be abandoned due to lack of data. For the daily commutes to and from the Restricted Zone these simplifications enabled the adoption of the same 41 minutes average transit times and 28 minutes average car trip time for the whole 1976-2005 period (see Annex G). These simplifications have the advantage of easing the required calculations but obviously require a re-calibration of the VTTS distributions as assessed in Section 7.4.

Only the VTTS distributions for 'all car owners' according to the UT and EPT model implementations, as depicted in Figure 16 (page 231) for EPT, were re-calibrated. The same approach was followed as for the pre-ALS calibration. Again, the procedure was applied separately for the UT and EPT models. It was applied to 33,000 car-owning travellers as estimated in Annex G, i.e. the almost 20,000 drivers who were affected by the ALS enforcement, an additional 7,000 pre-ALS car drivers who entered the Restricted Zone before 7:30 a.m. and kept on doing so and about 7,000 car owners who commuted by public bus. First, the trade-offs between the different alternative travel choices to cope with the ALS introduction (Annex F) and the corresponding numbers of car owners that choose that option were considered, yielding upper and lower VTTS thresholds. As the carpool 4^+ option was a dominant alternative, travellers who choose this alternative were considered to have exhibited the same distribution of thresholds as pre-ALS car drivers. The pre-ALS VTTS thresholds for switching to car driving or refraining from it and keeping to the bus were added as far as they increased the constraints. For EPT the thresholds were derived from those assessed according to the appraisals with a loss aversion factor of 2.0 for time as well as money and the corresponding ones for a loss aversion factor of 2.0 for time and 1.0 for money, using the 70:30 weight factors (see Section 7.4). Estimating lognormal distributions for all car owners that satisfied the constraints concluded the process. The following step was a re-calculation of all the relevant thresholds using the re-assessed, simplified attribute values of Annex G, followed again by an estimation of the appropriate parameters of lognormal distributions for all car owners. Finally, the assessment was repeated for a population to which 8,500 non-car owners were added to the 33,000 car owners, to ascertain that over the years the same socio-economic composition of the considered 'car owning population' was considered. Using the

income distributions of car-owning and non-car-owning households as a base and taking the highest 25% income segment of the non-car owners into account as 'future car owners' their VTTS was estimated at 75% of that of the car owners who commuted by bus before the 1975 ALS introduction.

The shape parameter $\sigma = 0.9$ as found for the pre-ALS distributions also appeared appropriate for all newly re-calibrated lognormal distribution functions that considered all these different groups of travellers. The medians for the re-calibrations that were based on the outcomes of the trade-offs in the previous sections and Annex F were higher than those based on the pre-ALS trade-offs only. One explanation is the addition of the 7,000 car drivers who commuted before and after the restricted period, the majority of whom were solo drivers with an above-average VTTS. This might explain the 15% higher VTTS values according to EPT. However, according to the UT-confirmative assessment the VTTS increase was 40%. This is according to expectations, in view of the underestimation of the propensity to pay the license fee and the overestimation of the shift back to transit after ALS enforcement (see Section 7.6). Of course, when this higher VTTS distribution was adopted in the previous sections the UT model would have had overestimated the frequency of car use, once acquired, for the daily commute in the pre-ALS period (Section 7.5). The calibration to account for the simplified travel time differences between car driving and transit, as adopted in this section, yielded virtually the same VTTS values as for the more detailed travel times considered in the previous sections. Finally, the addition of a large group of low income 'future car owners' led to a 20% decrease in VTTS values.

In the end, the median VTTS value as found for all 1976 car owners who worked in the Restricted Zone, including the 8,500 potential future owners, was S$6.5/h according to the UT model and S$8.5/h according to EPT. The first value is 10% above the corresponding pre-ALS median VTTS as found for the more constraint 'genuine car-owning population' that was considered in the previous sections while the latter value was 10% higher. As mentioned above these lognormal distributions had a shape parameter of about 0.9.

Based on the appraisals in Section 7.5 the shape parameters for different more homogeneous subgroups can be assumed to be about 0.75. The VTTS distributions for several specific segments of the population of car owners who commuted to the Restricted Zone were estimated from the covering distributions by considering the relevant VTTS thresholds. These are listed in Table 15.

In Annex G the cost attribute levels for different travel options (Table G.2 on page 389) and the price and income indices (Table G.3 on page 391) were inferred for the years from 1976 to 2005 in which important changes in the road-pricing regime occurred. Substitution of the relevant cost and time attributes in the value functions (Section 7.4) enables the VTTS threshold levels for the choice to drive to work during the restricted hours or the choice of another alternative to be established in the concerned years. Comparison with the indexed corresponding median VTTS values makes it possible to predict the number of car owners who might actually drive in that year. Inferences of the predictive ability of the different indexation approaches and paradigms can successively be made by comparing the predicted car trips and the actual numbers listed in Table G1 (page 385). The next subsection describes this inference process for the UT model. Subsection 7.8.3 does the same for the EPT model. Some conclusions are formulated in the final subsection.

Table 15: Estimated 1976 VTTS of different groups of car owners

Commuters who worked in 1976 in the Restricted Zone	Shape parameter	Median of lognormal distribution of VTTS (S$/h)	
		UT	EPT
All potential car owners	0.9	6.5	8.5
Actual car owners	0.9	8	11
Solo drivers during RP	0.75	18	24
Solo drivers, advanced home departure	0.75	11	14
Rideshare drivers during RP	0.75	12	16
Rideshare drivers, advanced home dep.	0.75	7	9
Carpool drivers	0.75	9	12
Car(pool) passengers	0.75	6	7
Car owning transit passengers	0.75	5	6
Non-car owning transit passengers	0.75	3	4

7.8.2 Evaluation of the predictive ability of UT for long-term responses

This section adheres to the UT paradigm. It considers the long-term developments in the trade-offs of alternatives from the perspective of the 'average' car owner of several groups that in 1976 had chosen for different travel options to cope with the ALS enforcement and the early 1976 fare increase. After discussing the predicted changes in travel behaviour within these groups the subsection ends with a discussion about the predicted and actual numbers of car drivers who entered the Restricted Zone during the restricted hours.

The modal shift from transit passenger to solo car driver

Following the model developed in Section 7.4 and realizing that under the UT paradigm all loss aversion factors are equal to unity, a transit passenger would become a solo car driver if:

$$VTTS_{\text{transitpass.}}[\text{S\$/h}] * 2\ [\text{trips/round trip}] * (t_{\text{transitpass.}} - t_{\text{solocardr.}})[\text{min}] / 60[\text{min/h}] + (c_{\text{transitpass.}} - c_{\text{solocardr.}})[\text{S\$}] > 0$$

Substitution of 41 minutes as the one-way transit travel time and 28 minutes for car driving, S$0.80 for 1976 transit ticket costs and S$9.10 for the corresponding costs of a car round trip (see Table G.2 on page 389) yields a threshold value of S$19/h. Calibrated in agreement with the UT paradigm the median VTTS value for transit passengers who owned a car in 1976 was S$5/h (Table 15 above). For the relevant years between 1976 and 2005 the threshold values for the change to solo car driving were inferred by substituting the relevant travel costs listed in Table G.2 while the corresponding median VTTS values of the concerned travellers followed from application of the indices in Table G.3 (page 391). The results of this process are listed in Table 16.

A conspicuous finding is that the growth rate of the median VTTS was higher than that of the VTTS threshold, whatever index was applied. This implies that over the years an increasing share of the 7,000 transit passengers who owned a car before 1975 and had continued to commute by bus, would shift to solo car driving during the restricted period, if they could not arrange for a more attractive alternative like driving a 4^+ carpool. By 2005 the cumulative

shift appeared to be about 400 trips when the median VTTS of bus riding car owners was scaled according to the consumer price index. Scaling in agreement with the household income index resulted in 4,500 transit passengers who changed to solo driving and the hourly wage rate in 4,900. The income-related indices thus predict that a large majority of all transit passengers who in 1976 owned a car would in 2005 use it for the daily commute. The contribution of the 1989 reduction of the ALS fare to the final shift was a sudden 300 to 800 jump in solo car driving while the 1980 ALS fee increase predicted that 100 to 150 fresh solo drivers would switch back to transit. The predicted responses to the replacement of the ALS by electronic road pricing also indicate that about 150 to 300 'new' solo drivers who entered in the most expensive hour would shift back to transit.

Table 16: VTTS values of transit passengers found according to UT

Year [1]	**VTTS threshold** [2] (nom.S$/h)	**Median VTTS of car owning transit users** (nominal S$/h)		
		CPI [3]	Income [4]	Wage [5]
1976	19	5	5	5
1980, before change in ALS fare	21	6	8	8
1980, after change in ALS fare	23	6	8	8
1989, before ALS adjustments	24	8	16	16
1989, after ALS adjustments	19	8	16	16
1994, before ALS extension	21	9	23	26
1994, after ALS extension	21	9	23	26
1998, before ERP introduction	22	9	28	35
1998, after ERP introduction	27	9	28	35
2005	28	10	35	40

[1] For an explanation of the changes in road pricing see Table G.1. [2] VTTS threshold for the change from transit passengership to solo car driving, for commuters to the Restricted Zone who owned a car in 1976. [3] Indexed for the development in the Consumer Price Index (CPI) since 1976. [4] Indexed for the development in the household income since 1976. [5] Indexed for the development in the average wage rate since 1976.

Similar calculations were made for the 4,500 former car drivers who chose to commute by bus after the ALS introduction and/or the 1976 fare increase. Of course, the propensity to switch from transit to solo driving appeared higher amongst them than amongst the pre-ALS transit passengers, as their VTTS was higher. Another group for which calculations were made was the increasing number of transit passengers who between 1990 and 2005 were predicted to become car owners (see Annex G.2). Only some of these transit passengers revealed the inclination to drive solo once they acquired a car, as their average VTSS was assumed to be lower than for the 1996 car owners.

Taken together the appraisals showed a shift from transit to solo car driving over the years. If the VTTS followed the consumer price index this would accumulate to 1,600 additional solo car trips in 2005 compared to 1976. If it followed the household income or wage rate it would amount to about 15,000 and 18,000 trips, respectively.

Transit passengers who become rideshare or 4^+ carpool drivers

The predicted numbers of transit passengers that changed to solo driving can be considered as minima for the total shift to car driving, as the associated increase in travel expenses is much higher than for a change to driving a rideshare or 4^+ carpool. The propensity to drive a rideshare where the passengers would contribute 40% of the running expenses appeared two to three times higher than for solo driving, and before 1979 the same held for driving a 4^+ carpool without the financial contribution of any passengers. If the three passengers together contributed 50% of the running expenses, the shift from transit to 4^+ carpool would in the longer term become profitable for a large majority of all car-owning transit passengers.

In 1976, 4^+ carpools made up about 45% of all car trips to work in the Restricted Zone and another 25% consisted of rideshares. By then almost all the carpools that were feasible would have been arranged but in the following years the number of jobs in the Restricted Zone increased greatly and many new households were formed by youngsters who came of age. This might have provided ample opportunities for the formation of new rideshare agreements and 4^+ carpools. It is assumed here that about 25% of those car drivers could have arranged to drive either a rideshare or a 4^+ carpool. Compared to the 70% of the drivers who succeeded to organize such an arrangement in 1975 and 1976 this is considered as a conservative estimate. The predicted number of shifts to 4^+ carpools peaked before 1989 at 6,000 to 8,000 trips and dropped immediately by 600 to 2400 when they were brought under the license obligation. Other, less drastic decreases were predicted as a consequence of the ALS fee increases in 1980 and 1998. The cumulative growth from 1976 onwards until 2005 in commuter traffic to the Restricted Zone with 4^+ carpool and rideshare cars trips was almost negligible, assuming that the VTTS co-developed with the consumer price index. If it followed the car owners' incomes or wages it would amount to 10,000.

Responses of 4^+ carpool and other car passengers

In 1976 about 4,000 4^+ carpool and rideshare passengers who commuted to the Restricted Zone owned a car. This group increased continuously to about 35,000 in 2005 (Annex G.2). In view of the 1976 distribution of car trips over 25% rideshares and 45% 4^+ carpools, and taking into account the different average occupancy rates of the vehicles that carried them, a rough 1:3 distribution of the car owning passengers is assumed. One-third of the 4^+ carpool passengers were considered as a separate group to accommodate the about 6,000 carpooling commuters who in the 1980s went back home by transit in the afternoon. It was considered that they might not have contributed to the running costs until this 'free ridership' ended in 1989. The other 4^+ carpool passengers were considered to pay on average 25% of the running expenses of the cars, and rideshare passengers 40%.

The model calculations predicted that, except for the 'free riders', few car passengers who became car owners would change to transit if they had the opportunity to continue the rideshare, as according to most feasible arrangements this latter alternative dominates bus transit. They might, however, have chosen to use their car as a solo driver or in a rideshare agreement. If their VTTS co-developed with their income, 16,000 to 18,000 were predicted to have done so in 2005, mostly to become rideshare drivers. If the VTTS was considered to follow the consumer price index the prediction amounted to almost 3,500. Until 1989, when 4^+ carpools were brought under the ALS regime, few car owners changed from riding along to driving their own car. Since then, most carpool passengers will have been confronted with a share of the road pricing fee while offers for 'free ridership' to complete the carpool will have

vanished. This and the ALS fee decrease apparently boosted the propensity of passengers to start driving their own car.

Secondary modal shifts

The assumption that over the years 25% of the car-owning passengers who wanted to were able to organize a rideshare or 4^+ carpool is rather arbitrary. When the VTTS follows the household incomes or wages it predicts a particularly large number of carpool drivers. This shows an increase of 4^+ carpool drivers from 4,000 in 1976 via 6,000 in 1980 and 8,500 before the 1989 ALS regime adjustment to almost 10,000 in 2005. The actually observed number peaked at almost 7,000 in the early 1980s and dropped to about 5,000 just before the 1989 regime change (Annex G). This suggests that in the 1980s it became increasingly difficult to organize and maintain 4^+ carpool arrangements. The main reason may be that about 1,500 carpool passengers were predicted to change to rideshare or solo driving. If the drivers of those carpools were not able to recruit another passenger they might continue as a rideshare driver or switch to transit. In the 1980s about half of them were predicted to choose the driving option, and in the 1990s about 80%. As a lower limit estimate of the shift from passenger to driver one might disregard from 1980 onwards the shift to carpool driving completely. In 2005 this assumption yields about 2,500 passenger-carrying car-driving trips by former passengers when the consumer price index is applied and about 11,000 to 12,000 when the income or wage increases are followed. The predicted number of rideshare trips is then 20% (consumer price index) or 30% (income and wage index) of the solo car trips. The latter percentage also follows from the estimated 1.3 to 1.4 car occupancy rate in 2005 (Annex G) if on average 1.5 passengers per rideshare are assumed. This approach is adopted further on in this section to arrive at a realistic estimate of the total car traffic.

Responses of the 1976 car drivers

Since 1976 the consumer price index and, to a much larger extent, the income indices increased faster than the running costs for car driving. This implies that there was no reason for the 4,500 solo and rideshare car drivers and the 4,000 carpool drivers who in 1976 entered the Restricted Zone during the morning restricted hours to stop doing so. The only exception is a sizeable number of 500 carpool drivers who in 1989, when they were brought under the license obligation, were predicted to switch back to transit if their VTTS increased with the consumer price index. Scaling the median VTTS proportional to the income and wage indices predicts that all carpool drivers would prefer to keep on driving as a rideshare than change to transit.

Before the ALS was introduced about 7,000 car drivers were already used to commuting to the Restricted Zone before 7:30 in the morning. There was no reason for them to change their behaviour as a consequence of the changing travel conditions or increasing income. The about 1,000 car drivers who advanced their home departure in 1975 without adjusting their work start time would gain some discretionary time if they returned to their pre-ALS schedule. If they adjusted their VTTS proportional to the consumer price index about 30% of them would have done so in 2005. The income and wage indices predict a corresponding 90%. By far most of these schedule readjustments were already attained in 1989, after the reduction of the ALS fare. About the same percentages of the about 1,500 car drivers who had adjusted their work start time and home departure time to avoid the ALS fee might from 1989 onwards have returned to their pre-ALS schedule.

Comparison of actual car traffic with predictions under the UT paradigm

Whatever index is applied to estimate the VTTS development, the UT model predictions of commuters' car trips during the restricted hours show a decrease of about 5% after the 1980 and 1998 fare increases. Likewise, the 1989 ALS fare reduction for non-carpool cars combined with the taxing of carpools predicted an ample 20% increase. As elicited in Annex G the ongoing increase in car traffic did not stagnate in 1980 and 1998 while in 1989 a sudden 20% increase occurred. The inability of the UT model to cope with the differences in the responses of car owners to positive and negative changes in their travel conditions, as extensively discussed in the previous section, is thus confirmed, unless its assumption of a context-independent preference order is allowed to be violated.

The predictions in which the consumer price index was applied yielded for 2005 15,000 trips to the Restricted Zone between 7:30 and 10:15 a.m. Application of the household income index resulted in about 47,000 trips and the wage index in 52,000. The assumption that the VTTS follows the wage rate yielded a larger overestimation of the actual 35,000 car trips than the application of the income growth index. This assumption should thus be rejected. Application of the household income index to the VTTS resulted in a 35% overestimation while the consumer price index predicted only 40% of the actual car trips. The hypothesis that the consumer price index would be followed more closely than the household income should thus also be rejected, at least when the UT paradigm is followed. By and large these findings support the suggestion by Gunn (2001) and Mackie et al. (2001b) that when the UT paradigm is followed the VTTS of travellers should be considered to lag significantly behind the real income growth.

7.8.3 Evaluation of the predictive ability of EPT for long-term responses

This section adheres to the EPT paradigm. It considers the long-term developments in the trade-offs of alternatives from the perspective of the 'average' car owner of several groups that in 1976 had chosen for different travel options to cope with the ALS enforcement and the early 1976 fare increase. After illustrating the differences in the trade-offs of travel alternatives with those above according to UT the predicted changes in travel behaviour are briefly mentioned. The subsection ends with a discussion about the predicted and actual numbers of car drivers who entered the Restricted Zone during the restricted hours.

The modal shift from transit passenger to solo car driver

Following the model developed in Section 7.4, realizing that travel time by transit is larger than by car while for money expenses the reverse holds and applying loss aversion to both time and money losses relative to the reference state, a transit passenger would become a solo car driver if:

$$VTTS_{\text{transitpass.}}[\text{S\$/h}] * 2[\text{trips/round trip}] * (t_{\text{transitpass.}} - t_{\text{solocardr.}})[\text{min}] / 60[\text{min/h}] + \lambda_{\text{money}} * (c_{\text{transitpass.}} - c_{\text{solocardr.}})[\text{S\$}] > 0$$

while for the reverse modal change holds:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * 2[\text{trips/round trip}] * \lambda_{\text{time}} * (t_{\text{solocardr.}} - t_{\text{transitpass.}})[\text{min}] / 60[\text{min/h}] + (c_{\text{solo cardr.}} - c_{\text{transitpass.}})[\text{S\$}] > 0$$

Substitution of 41 minutes for one-way transit travel time and 28 minutes for car driving, S$0.80 for 1976 transit ticket costs, S$9.10 for the corresponding costs of a car round trip (see

Table G.2 on page 389) and $\lambda_{time} = \lambda_{money} = 2.0$ for the loss aversion factors yields a lower VTTS threshold of S$40/h for a transit passenger to become solo car driver and an upper limit of S$9/h for a change from driving solo to transit ridership. For travellers who exhibit no loss aversion for daily monetary expenses the corresponding thresholds are S$19/h and S$10/h. Assuming the 70-30 distribution of travellers over both loss aversion strategies yields S$34/h and S$9/h according to the current implementation of EPT. Following the same approach as for the UT model the threshold values for later years were found by substituting the relevant travel costs listed in Table G.2. The median VTTS value for transit passengers who owned a car in 1976 was calibrated at S$6/h with the EPT model (Table 15 on page 246). The corresponding median VTTS values of the concerned travellers follow again from application of the indices in Table G.3 on page 391. The results are listed in Table 17.

Table 17: VTTS values of transit passengers found according to EPT

Year [1]	VTTS threshold (nominal S$/h)		Median VTTS of car owning transit users (nominal S$/h)		
	Transit to solo car [2]	Solo car to transit [2]	CPI [3]	Income [4]	Wage [5]
1980, before change in ALS fare	> 37	< 9	7	10	10
1980, after change in ALS fare	> 41	< 11	7	10	10
1989, before ALS adjustments	> 43	< 15	9	19	19
1989, after ALS adjustments	> 35	< 8	9	19	19
1994, before ALS extension	> 40	< 9	10	27	31
1994, after ALS extension	> 40	< 9	10	27	31
1998, before ERP introduction	> 41	< 9	11	33	41
1998, after ERP introduction	> 49	< 13	11	33	41
2005	> 52	< 12	11	41	47

[1] For an explanation of the changes in road pricing see Table G.1. [2] VTTS thresholds for the change from transit passengership to solo car driving or vice versa, for commuters to the Restricted Zone who owned a car in 1976. [3] Indexed for the development in the Consumer Price Index (CPI) since 1976. [4] Indexed for the development in the household income since 1976. [5] Indexed for the development in the average wage rate since 1976.

In comparison with the 'break even' VTTS values according to UT (Table 16 on page 247) those according to EPT show the much stronger resistance of travellers to a change in established behaviour as a consequence of reference-dependent framing and loss aversion. But according to EPT the growth rate of the median VTTS was also higher than that of the VTTS thresholds, for all the indices applied. This implies that over the years an increasing share of the 7,000 transit passengers, who owned a car before 1975 and had kept on commuting by bus would shift to solo car driving during the restricted period if they could not arrange for a more attractive alternative like driving a 4^+ carpool. As the upper threshold for a switch back to transit is far below the lowest threshold that applied to new solo drivers this behaviour will not be predicted by EPT under the prevailing circumstances.

By 2005 the cumulative shift appeared to be about 200 trips when the median VTTS of bus riding car owners was scaled according to the consumer price index. Scaling in agreement with the household income and hourly wage increases resulted in 3,300 and 3,800 transit passengers who changed to solo driving. The income-related indices thus predict that about

half of all transit passengers, who in 1976 owned a car, would in 2005 use it for the daily commute. Due to the much lower thresholds for a solo car-to-transit shift the predictions in agreement with EPT indicated that after the 1980 and 1998 fare increases the former transit passengers would not make this choice. The contribution of the 1989 reduction of the ALS fare to the final shift was a sudden 100 (consumer price index) or 500 (income indices) jump in solo car drivers.

Similar calculations were made for the 4,500 former car drivers who chose to commute by bus after the ALS introduction and/or the 1976 fare increase. Of course, the propensity to switch from transit to solo driving appeared higher among them than among the pre-ALS transit passengers, as their VTTS was higher. Calculations were also made for the increasing number of transit passengers who between 1990 and 2005 became car owners (see Annex G.2). Only a small part of these transit passengers revealed the inclination to drive solo once they acquired a car, as their average VTSS was assumed to be lower than for the 1996 car owners.

All together the appraisals showed a shift from transit to solo car driving over the years. If the VTTS followed the consumer price index this would accumulate to 500 additional solo car trips in 2005 compared to 1976. If it followed the household income or wage rate it would amount to about 10,000 and 12,000 trips respectively. Compared to the assessments in agreement with UT these numbers are clearly lower. It reflects the higher resistance to change from transit and car passengership to car driving, as a consequence of loss-aversive valuation. This effect obviously outnumbers the effect of the virtual irreversibility of the predicted transit-to-car shifts.

Other modal shifts over the years

Except for the application of loss aversion, which causes differences in VTTS thresholds depending on the direction of changes in travel behaviour, similar calculations as for the UT model were made for the shifts of transit passengers to rideshare or carpool driving, of 1976 car drivers to transit and of car passengers to car driving. All results differ from the corresponding UT assessments in the same way as found for the transit-to-solo driving shift above: less shifts from transit and car passenger to solo, rideshare or carpool driver, and virtually no changes back from driver to passenger.

Comparison of actual car traffic with predictions under the EPT paradigm

Whether the consumer price, income or wage indices are applied, the different predictions of car-owning commuters' car trips during the restricted hours that followed the EPT paradigm directly before and after the 1980 and 1998 fare increases were the same. However, the same model predicts the sudden increase of about 20% following the 1989 ALS regime change, i.e. the fare reduction for non-carpool cars combined and the taxing of carpools. The ability of the EPT paradigm to cope with the differences in the responses of car owners to positive and negative changes in their travel conditions is thus confirmed.

The predictions in which the consumer price index was applied yielded 13,000 car trips between 7:30 and 10:15 to the Restricted Zone for 2005. Application of the household income and wage rate growth resulted in about 36,000 and 41,000 trips. The actual number was assessed at 35,000 (Table G.1, page 385). The hypothesis that VTTS follows the wage rate (Section 7.4) yielded a 15% overestimation. Application of the monthly household income index resulted in a very small overestimation while the consumer price index predicted only 35% of the actual car trips. Apparently the VTTS of most travellers kept pace with their

household income. The hypotheses in Section 7.4 that the wage rate increase or the consumer price index might be followed more closely than the household income should thus be rejected under the EPT paradigm.

7.8.4 Discussion

The predicted long-term development of the use of cars for the daily commute to Singapore's Restricted Zone and the actual development are depicted in Figure 19. It clearly shows the deviation of the actual development from the predictions based on the assumption that VTTS co-develops with the consumer price index. This supports the rejection of the hypothesis that the VTTS might follow the consumer price index as established in the previous subsections.

In the previous subsections it was also found that, when the VTTS was scaled with the wage rate development, the predictions according to UT as well as EPT overestimated the 2005 car traffic considerably. Figure 19 confirms the conclusion that this practice, which is commonly adopted in travel behaviour research, would be better being discontinued, whether the UT or EPT paradigm is followed. At the same time the predictions that assumed that the VTTS followed income development reveal a similar overall trend to that actually found. This holds particularly for the predictions according to the EPT paradigm but also, though to a lesser extent, for those that agree with UT.

These latter conclusions are supported by a closer inspection of the divergence of the predicted and actual traffic in the preceding periods. Between 1989 and 1998, when wages increased faster than household income, the predicted growth rate was higher than the actual growth when VTTS was scaled with the wage rate while for the 1998-2005 period, when household income increased faster than individual wages, the predictions lagged behind the actual developments. In both periods the predictions based on UT as well as EPT that assumed co-development of VTTS and household income yielded a growth in car traffic that was closer to the actual developments. As discussed in Section 7.4 this would be the more appropriate indicator of money in a VTTS concept that considers hedonic adaptation to discretionary time and money budgets, as not the official hourly wages but the monthly salary drawings are what most individuals really experience in everyday life. The comparison of the predicted development of traffic over the years as found according to the UT as well as the EPT paradigm endorses that it is better to disregard the wage rate as an indicator for the development of a traveller's VTTS. When the development of the VTTS of groups of travellers is considered, according to the reasoning in Section 7.4 indexation with the monthly household income might hold, provided that the average number of commutes and working days over the considered households remains constant. For the predictions in this section, national averages of wages and household incomes were used. In the considered period the average number of workers per household and the average working week remained approximately the same. If, for example, the national average of the number of workers per household decreased significantly, for example due to a significant increase in households of employed singles, indexation with the national average monthly household income might become less appropriate. Another caveat might be that if the current trend towards individualization continues the monthly individual income might become a better index than the household income.

The long-term predictions in agreement with UT in which the VTTS was adjusted proportionally to the development of the household income are significantly higher than the actual number of car trips and the predictions according to EPT. In 2005 the difference between the predicted and the actual number of car drivers amounted to 35%. Figure 19 above

shows that this difference started to build up from 1976 onwards. Only from 1998 onwards did the annual growth drop to the same level as the predictions in agreement with EPT and lag slightly behind the actual development. The difference suggests that when the UT paradigm is followed it might be better to consider the actual VTTS growth to be less than proportionate to the average real household income growth, as suggested by Gunn (2001), based on an analysis of the Dutch 1989 and 1997 VTTS surveys with Logit models that agreed with the UT paradigm. Another explanation might be that the 1976 VTTS distributions, which were found from the re-tuning of the UT model to the observed responses to the 1975 ALS introduction, were too high. Actually, the re-calibration of the VTTS distributions to the 1975 ALS responses resulted in idiosyncratic VTTS values that were about 30% higher. Predictions in which the VTTS levels as calibrated to the pre-ALS conditions (Section 7.5) were employed were still above the actual car traffic and also above the predictions in which the EPT model was applied. One should consider that the UT model that used these VTTS values underestimated the propensity to keep on car driving after the 1975 ALS enforcement severely (Section 7.6). The predictions in agreement with EPT used consistently the same idiosyncratic pre-ALS VTTS values for the same population segments, obviously after accounting for the household income development. The difference in the UT predictions and the observed long-term development of car use might thus be the consequence of the non-existence of a restraint for modal shifts comparable to the reference-dependent upper and lower VTTS thresholds that follow from the loss-aversive behaviour assumed in the EPT paradigm. When long-term travel predictions are made in agreement with the UT paradigm

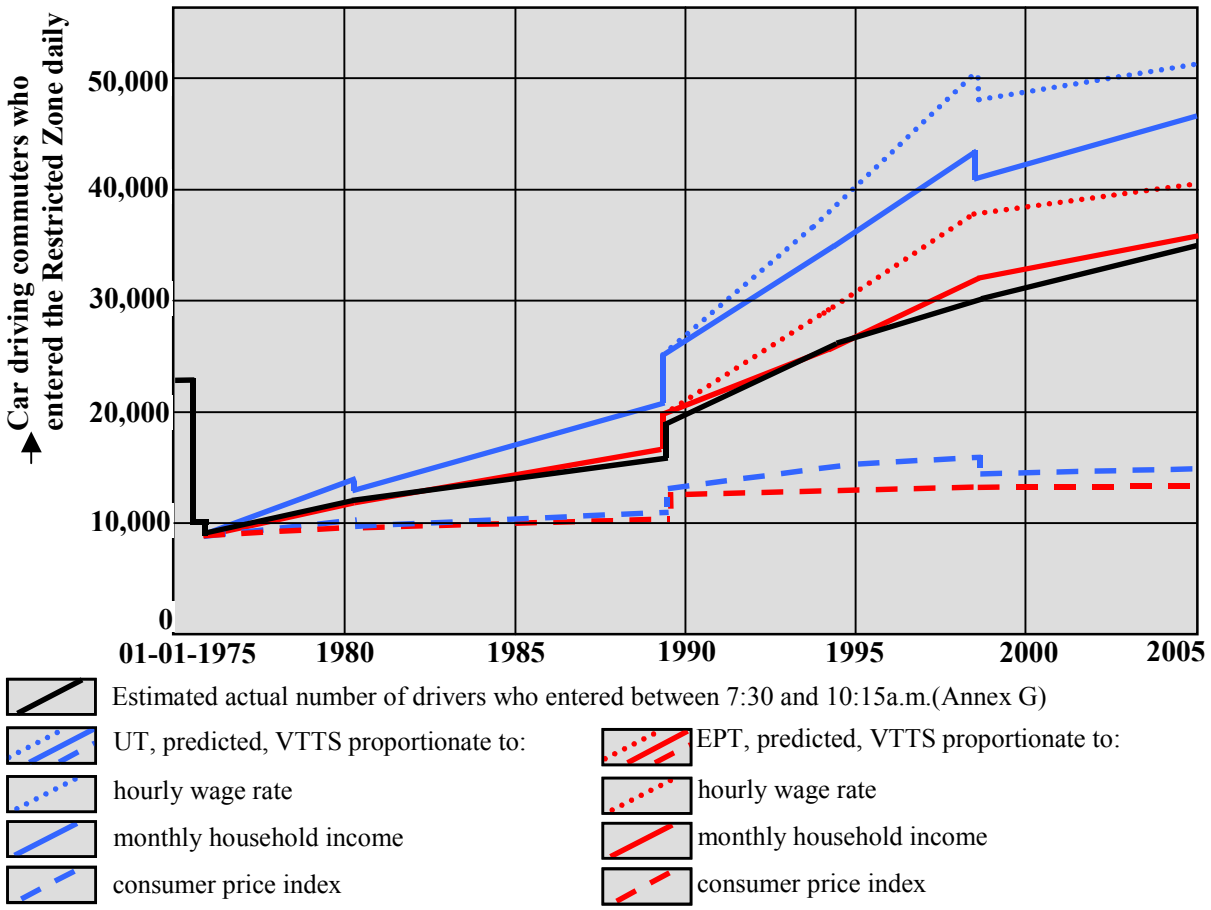


Figure 19: Predicted and actual development of car traffic to Singapore's Restricted Zone

the application of a reduction factor to the household income development with which the VTTS development is scaled might quite definitely improve the quality of the predictions.

With respect to the considered short-term responses, the reference-independent appraisals in agreement with UT predicted a decrease in the number of car trips during the morning commute to the Restricted Zone after the 1980 and 1998 road-pricing fare increases. The corresponding development in actual car trips (Section G) showed that this number did not change significantly. In agreement with the UT paradigm the 'non-response' of car drivers to the 1980 fare increase might, just as the response to the 1996 fare increase, be explained by one of the different theories that attributes a negative utility to 'transition costs' for the change from one behaviour to the other, like for information acquisition (Search Theory, Stigler 1961), transaction costs (Coase 1937) or mental inertia (e.g. Mackie *et al*. 2001a), or simply assign a positive alternative-specific constant or status quo parameter (Samuelson and Zeckhauser 1988) to the incumbent alternative. Whatever the reasoning on which such an effect is founded, it should add a value of at least S$1 in 1980 currency to the car driver's utility to annihilate the impact of the concurrent ALS fee rise. In 1989 the nominal hourly wages and household incomes in Singapore were at twice the 1980 level. By then, the size of the 'status quo' effect would thus have been at least a nominal S$2 value, equal to the reduction in ALS fee for car drivers and S$1 less than the S$3 increase in costs for a 4+ carpool. If the transition costs caused the non-response of commuters to the 1980 ALS fee increase these should thus also explain a constant or decreasing number of car trips after the 1989 ALS regime change. The different transition cost theories that go under the UT paradigm are thus able to explain the refusal to accept higher 'travel time losses' to avoid limited cost increases, but at the expense of disregarding the 'gain-taking' responses to cost decreases.

The different concepts that try to accommodate aspects of reference-dependent preferences under the UT paradigm are thus not able to predict the responses to road-pricing fare increases and decreases in a consistent way. As is easily seen in Figure 19 models that adhere to the principally reference-dependent EPT paradigm are well suited to predicting the responses to both sudden road price increases and decreases and to long-term changes in the travellers' welfare position and travel conditions.

7.8.5 Overview of findings about the long-term development in the travel choice behaviour of Singapore's car owners

The long-term responses of Singapore's car owners to changes in their travel circumstances in connection with changes in their idiosyncratic VTTS values can be predicted well with a proper implementation of the simple model developed in Section 7.4. To disentangle the effect of the difference in premises between the UT and EPT paradigm from the effect of different VTTS indexation principles, three long-term developments in car use were predicted for each paradigm, in which the VTTS was considered to be proportionate to the nominal wage rate, nominal household income and consumer price index, successively. Comparison of the six predicted developments with the actual development allows separate inferences about the descriptive ability of the VTTS indexation assumptions and choice behaviour paradigms considered.

In travel behaviour literature the wage rate development is commonly considered to be the best measure for the development of VTTS over time. This assumption appears to be inappropriate. In the considered Singapore context it results in an overestimation of the shift

to car use if it develops faster than the household income and an underestimation if it develops less fast. This holds for calculations with the UT as well as the EPT model implementation. Alternative hypotheses, deduced from a hedonic adaptation assumption that could go under the EPT paradigm, is that either the monthly household income or the inflation might be the best measure for the assessment of the long-term VTTS development. Following the consumer price index results in a massive underestimation of car use, both with the UT and EPT model and should thus also be rejected. This leaves the monthly household income development as the best available indicator of the three considered ones. From a hedonic appraisal and adaptation perspective this makes sense, as it directly influences the changes in the travellers' available budget, which is what they actually experience over time.

The development of car use by Singapore's commuters predicted using the model implementation of EPT and an idiosyncratic VTTS indexed with the household income followed the actual development very closely. The same indexation applied in a model implementation of UT, calibrated in the same way to the same base-year, resulted in an overestimation of shifts to costly, time-saving car-driving modes. This may be addressed by applying a reduction factor to the actual income development and/or by adding some kind of inertia parameter to the utility specifications, as suggested in Search Theory, for example. Such empirical extensions of the model can also remove the predicted shifts back to cheaper modes after sudden travel cost increases, like after the road-pricing fare rise in 1980, that did not actually happen. The consequence is that strong shifts to car driving, as actually occurred after the 1989 fare decrease, would also disappear in the predictions.

In general it did not appear possible to find combinations of 'status quo' parameters, base year VTTS estimates and/or indexing principles that fitted the UT paradigm and predicted both the responses to long term developments in welfare and travel conditions and to discrete travel cost increases and decreases. The same model but with implementation of the EPT premises was able to predict these different responses adequately without adjustments to the VTTS values calibrated on the pre-ALS conditions, except for their indexation with the monthly household development. At least for these long-term predictions of tactical travel choice behaviour the EPT paradigm thus outperformed its UT counterpart.

7.9 Summary, discussion and conclusions

7.9.1 Summary

This chapter aimed to provide a comparison of the predictive abilities in a real-life travel choice context, for implementations of the UT and EPT paradigms in which their relevant assumptions are considered in connection. To that aim it investigated the tactical travel choice behaviour of Singapore's car owners, i.e. persons who took care of a car that was at the daily disposal of their household, by driving it to some activity location or by leaving it at home. More particularly it considered the travel mode, time schedule and route choices for their daily commutes to the Central Business District. In agreement with the EPT paradigm the relevant choice processes at a higher level of the strategic-operational hierarchy were not analysed.

The daily commute by Singapore's car owners offered a useful travel choice context. An extensive search and analysis of the transport literature revealed sufficient information about the tactical travel behaviour responses to both abrupt and gradual changes in the travel

circumstances (Annexes C … G). It appeared feasible to develop a discrete choice model that allowed the implementations of both UT and EPT that contained their most distinguishing assumptions to be accommodated (Section 7.4). As such the following were considered: UT's context independency versus EPT's context dependency, the latter including the updating of the car owners' reference state and their VTTS by adhering to hedonic appraisal and adaptation principles; and UT's sole, loss neutral choice behaviour strategy versus EPT's mixture of different loss-aversive choice behaviour strategies. The modelling of EPT's diminishing sensitivity, non-linear probability weighting and mixed affective-utilitarian valuation was considered but appeared unnecessary in the tactical travel choice contexts discussed in this chapter. Both the EPT and UT implementations conceived a lognormal distribution of the VTTS over the discerned population segments, as a consequence of the observed skewness of the income and discretionary time available distributions. This allowed personalized, 'deterministic' interpersonal differences to be taken into account in the attribute valuation. Implementations of both paradigms yielded plausible predictions of the frequency of different responses to changes in the individual's welfare and travel circumstances (Section 7.6 … 7.8).

The treatment of VTTS as a constituent element of the reference state introduced the socio-economic characteristics of the traveller into the choice process. From its definition one might infer that the VTTS co-develops with the psychological value attached to travel expenses or income (Section 7.4). In the travel behaviour literature it is most often considered to be a stable percentage of the hourly wages. When one considers the travel expenses instead one might assume that VTTS co-develops with the experienced travel expenses that, as a first approximation, might follow the development of the consumer price index. The long-term comparison of predicted and observed travel choices shows that the adjustment of the VTTS to both wage rate development and inflation yield a larger misprediction than when VTTS is indexed with the monthly household income (Section 7.8). Hedonic adaptation to a changing household income might thus be the driving force behind the travellers' VTTS annex reference-updating process.

The UT model strongly overestimated the sudden shift to transit, for example, after the 1975 ALS introduction while it underestimated the number of car owners who paid the bill to keep on driving during the tolled period (Section 7.6). The same was predicted for the 1976 and 1980 fare increases and the 1998 transition to Electronic Road Pricing (Sections 7.7 and 7.8). At the same time it predicted the sudden increase in car driving after the 1989 fare reduction correctly. The introduction of transition cost parameters in agreement with Search Theory, Transaction Cost theories, Status Quo or Inertia concepts might cancel out the actually not occurring decrease in private car driving in 1976 and 1980 but, if applied consistently, they would also make the 1989 increase vanish. After re-calibration to the observed 1975 responses to road pricing and using household income as a scale parameter for the development of VTTS over the years the UT model systematically overestimated the actual gradual growth in car driving between 1975 and 2005 (Section 7.8). A better approximation would have been found if the VTTS development had been assumed to lag behind the household income growth, as suggested by Gunn (2001). Another possibility would have been to lower the re-calibrated VTTS to the level found from the pre-ALS conditions (Section 7.5). This would, of course, have continued the large misprediction of the consequences of the 1975 ALS enforcement. It appeared not possible to conceive a consistent combination of base-year VTTS values and scaling principles for the UT model implementation that could predict the character of the responses, to abrupt positive and negative travel cost changes as well as to gradual changes in travel costs and income, in a qualitative plausible way.

7.9.2 Discussion of the predictive ability of the models

The discrete choice model that was developed in Section 7.4 allows calibrations and predictions to be performed that adhere to the UT or to the EPT paradigm, depending on the assumed choice behaviour strategies and loss aversion factors that are substituted. The loss aversion factors and the distribution of choice behaviour strategies across the population, as applied in the EPT implementation, were estimated from information about choice behaviour in contexts other than Singapore's morning commute. This meant that in the UT and the EPT implementation the VTTS was the only parameter that had to be calibrated to the Singapore travel context. The calibration processes followed in the previous sections to assess the average VTTS for both implementations were straightforward and applied to the same pre-ALS and 1976 conditions in a similar way. The predictions according to both models can thus be used for a 'ceteris paribus' comparison of their predictive abilities.

With respect to the 1975 ALS introduction EPT's reference-dependent, loss-aversive appraisals of the bi-optional trade-offs between the many different specific transit, departure time and route alternatives on the one hand and KYMS or conventional buses on the other appeared to approach the actual choice frequencies better than or as well as the loss-neutral algorithm. The comparison of the choice frequencies predicted from the multi-alternative consideration choice sets confirms that the tactical travel choice behaviour of Singapore's car drivers was predominantly reference-dependent. The very limited response of car owners to the 1976 fare increase was predicted well by the calculations according to the EPT paradigm while those that followed UT mispredicted a considerable additional modal shift to transit, amongst others. The same difference in predictive ability was found for the 1980 and 1998 fare increases. The 'gain taking' response to the 1989 fare reduction was also correctly predicted by the EPT model, in this case just as the calculations according to the UT paradigm did. Finally, the UT calculations, with a VTTS re-calibrated for the 1975 responses to the ALS and indexed with the household income development, over-predicted the long-term shift to car driving as a consequence of increasing welfare by 35%. The corresponding VTTS assessments and predictions according to EPT approached the actual development closely, yielding a cumulative difference of less than 5% in 2005[120].

In view of the aggregated nature of the available information about the travellers' accessibility contexts and working hour arrangements the predictive performance of the EPT model might be considered impressive. Compared to a regular implementation of PT it appeared to merit considering different idiosyncratic choice behaviour strategies consistently applied by the same individuals or population segments during successive choices in similar contexts and domains.

Following the UT paradigm it was not possible to calibrate a set of VTTS distributions in connection with a long-term income or cost related VTTS indexation that allowed for a proper prediction of both the positive and negative changes in travel costs. This also held if some kind of loss-neutral transition cost parameter was added to the utility specification, whether this was in terms of search or transaction costs, or the status quo of inertia parameters. As the

[120] Note that in addition to the common socio-economic parameters the actual development of car ownership and travel costs over the years were used as exogenous variables. Also, the post-1990 data about the actual number of cars used for commutes with a destination in Singapore's Restricted Zone were estimated rather than counted (Annex G). The almost exactly correct prediction with the EPT model of the car use in 2005, with 1976 as base year, may thus be a coincidence, though the order of magnitude of prediction and observation were definitely much closer than found with the UT model.

EPT model implementation only differed from the UT implementation in the systematic updating of the reference state and the corresponding attribute levels and in the application of a mixture of loss-aversive choice behaviour strategies, the difference in predictive ability can be attributed to these fundamental differences in the constituent assumptions of both paradigms. Putting it differently, the collective of Singapore's car-owning commuters did not follow the 'price elasticity of demand' concept of economics, which agrees with UT's context independent idiosyncratic preference order in connection with a linear indifference curve. Following a similar analogy from Physics, several actual observed responses to price changes might be better called 'price plasticity[121] of demand', with hedonic adaptation as the driving force that causes the hysteresis of the behavioural response that the human choice behaviour process shares with most complex systems.

Several adjustments might be considered to improve the predictive performance of the UT-based prediction process in this chapter. One is to assume higher idiosyncratic VTTS values for the prediction of the responses to the 1975 introduction of ALS than were calibrated in Section 7.5 for the pre-ALS circumstances. The median VTTS of car drivers might, for example, be doubled. This would boost the share of drivers who preferred KYMS to transit but leave the dominance of work start time advancements and postponements for KYMS unaltered. On balance, the propensity to choose KYMS would still be underestimated and the shift to bus transit overestimated. If the same VTTS was applied to the pre-ALS situation virtually no car owner would travel by bus, which is clearly contradictory to the observed behaviour. Actually, the higher VTTS values found according to a re-calibration of the observed 1975 behaviour yielded an over-prediction of the car owners' propensity to use the car for their daily commute, as established in Section 7.8.

Another approach to improve the UT model might have been to add several parameters to the value function as deduced in Section 7.4, as is the time-honoured practice in travel behaviour research. Obviously, these additional parameters have to take the reference-dependency into account to improve UT's predictive quality, for example by introducing non-linear VTTS terms, schedule-delay parameters, status quo terms or alternative-specific constants. As all these parameters have to be calibrated on observed behaviour the reference dependency is introduced by induction, which makes the models susceptible for overfitting to the elicitation context. As discussed above such adjustments may work if only positive or negative changes in the travel attributes are considered. For successive positive and negative changes in, for example, road-pricing fares these additions will only be useful if they are 'sign-dependent'. One would, of course, thus introduce reference dependency and loss aversion deliberately in discrete choice models. When doing so one arrives at a model that fits within the EPT paradigm. In the author's opinion one is better starting such a modelling effort with a

[121] In Physics, '*elasticity*' is the property of a material that deforms under stress caused by an external force but regains its original shape when the stress disappears. '*Plasticity*' is the property of a material that deforms when subjected to a strain but remains deformed when the stress disappears. A stress-strain relationship exhibits '*hysteresis*' when the deformation depends on the size of the stress change as well as on its development over time that resulted in the actual strain. For the analogy with travel behaviour as a consequence of travel costs one might imagine, for example, that the demand for car driving by car owners would diminish by 50% if the running costs doubled suddenly, as was more or less the case after the 1975 ALS introduction. Price elasticity of demand would imply that a further say 10% increase in running costs would cause another 5% decrease in car driving while a 20% reduction in costs would cause a 10% increase in demand. The corresponding shift of car drivers to transit and loss-aversive valuation of all running costs for car driving, however, means that a large reduction in those costs is required before the first transit user switches back to driving. The modal shift thus causes hysteresis of the price-demand relationship.

deduction from first principles, as was actually done in Section 7.4, to dispose of superfluous inductive parameters.

It is telling that the applied model in agreement with EPT was able to predict the modal choices well while they did not consider mode-specific attributes with an alleged high affective valence like convenience, comfort, status or luxury. Even the suggested reference-mode specific stochastic parameter that was proposed in Section 7.4 to catch the interpersonal taste heterogeneity that is not proportionate to the total travel time and costs was disregarded in the actual predictions. The limited success of the Blue Arrow and Air Conditioned Coach express bus services, particularly among car owners who were used to commuting with conventional buses (Annex F), illustrates that affectively salient attributes have little effect on modal shifts. Nevertheless, from many studies it was found that travellers are willing to pay for extra comfort. In fact, the existence of 'classes' in trains and planes, with higher levels of comfort for those who can and want to afford it, leave no doubt about this phenomenon. These similarly contradictory observations might be reconciled if many travellers disregard differences in comfort in the tactical trade-offs of alternative schedule-mode-route combinations for their daily commute but consider them, at a lower level of the strategic-operational choice hierarchy, once they have made their tactical choice. This might easily explain why several trials to incite modal shifts by improving the affective quality *per se* of public transport failed in many countries. It would be interesting to study whether the inclination to stick to transit in cases where its travel time improvements lag behind those of other modes would be higher for individuals who estimate transit's experienced comfort higher.

Though the agreement between the prediction according to EPT and the actual choice frequencies is quite satisfactory, it is easy to conceive improvements that might yield an even closer match. A first observation is that the largest misprediction might have been caused by the least substantiated assumption, i.e. the 40-60% split of all operational costs of rideshares over passengers and drivers. Alternative assumptions may result in a larger shift to bus riding after the ALS enforcement and thus to a better model fit. If, for example, all passengers paid only half of the running and parking costs and rejected sharing the ALS fee, the predicted shift of Restricted Zone-bound rideshare drivers to transit would already surpass the retraced number. Another adjustment might be to consider another choice frame for the 40% contribution. In the present treatment this is framed as a deductible that reduces the driver's expenses and thus her losses. If the driver valued it separately as a gain the whole increase in parking expenses and ALS fee would be subject to loss aversion. This, too, would increase the predicted shift of Restricted Zone-bound rideshare drivers to bus transit such that it might cancel out the misprediction. Also the predicted popularity of the detour over the ring road would increase to the observed extent if a larger share of the commuters than supposed experienced the relatively smaller travel time increases that were considered. And if the calibrations and predictions assumed that car drivers valued their running costs loss neutrally but their toll fares loss aversively, as was actually suggested by several studies (e.g. Hensher 2001b; Nielsen 2004), this would have a similar effect on the agreement between the predicted and observed choices for the detour as well as the transit alternatives. As reliable information about actual rideshare arrangements, idiosyncratic framing and travel time distributions is lacking such alternative choice frames and adjusted attribute levels are not considered here.

The EPT paradigm assumes that all alternatives in the subjective consideration set are framed as changes relative to a reference state that, in turn, is the consequence of the implementation

of previous choices at the same or higher levels of the choice hierarchy. This implies that the outcome of the choice process depends on the composition of that consideration set. When, for example, all schedule adjustments are disregarded by the car drivers, the number of carpools would have been much lower and almost one in two pre-ALS car drivers who kept on commuting to the Restricted Zone might in that case have switched to bus transport. Consequently, when an analyst disregards these alternatives the switch to bus transport is overestimated. The reference-dependent, loss-aversive valuation of separate attributes makes the chosen alternative 'dependent on all relevant alternatives'. Obviously, EPT-based models for parameter estimation and prediction should also obey the generic 'Independence from Irrelevant Attributes' principle. The dependence of an individual's choices on all attributes that are relevant for her in the personalized context calls for very careful consideration of the application of nested model structures. In this sense EPT differs fundamentally from the choice concept of the UT-paradigm. Under UT's assumption of the reference-independent, loss-neutral valuation of attributes, all alternatives in the subjective consideration set – and, for that matter, the universal choice set as well – are positioned in a stable preference order. This enables the consideration set to be split up into homogeneous subsets (like all alternative routes, all possible home departure times, …) that may be treated in any sequence in a nested model structure.

Obviously, the parameter estimation of both EPT-based and UT-based models might be better based on data of individual' s travel behaviour in connection with their personal context rather than on the highly aggregated data used in this chapter. This would enable a better assessment of the VTTS distributions, maybe even resulting in a stochastic function that offers a better description of the interpersonal variation in VTTS than the lognormal distribution that was found here. It might also underpin several more choice behaviour strategies as combinations of framing and loss aversive judgment in addition to the two that were here applied to put the EPT paradigm into operation. Even if the personalized contextual information remained covered, aggregated information about the dispersal of attribute levels in addition to the recovered averages would enable a much more appropriate assessment of parameters, VTTS distributions and predictions. From a theoretical mathematical perspective the choice behaviour of the collective of individuals might also be modelled more appropriately by approaching both their lognormal VTTS distribution and their distribution of accessibility attributes, the distributions of which might or might not be correlated. An agent-based micro-simulation model might do this job by drawing a set of attribute levels and an idiosyncratic VTTS value from the relevant distributions and substituting them in the value functions. The development of such a model was clearly 'a bridge too far' within the context of the actual research. But nevertheless the global re-analysis of the aggregated average travel circumstances yielded convincing evidence for the better descriptive potential of the EPT model compared to the one that followed the actually prevailing UT paradigm.

7.9.3 The effect of policy measures on the car owners' tactical choice behaviour

The frequencies of the behavioural responses to the ALS enforcement as found in this chapter make it clear that by far the most travellers adjusted their behaviour to only a small extent. For example, by far the most car drivers who joined four-persons car pools carried a passenger before while very few solo drivers did so, and small advancements of home departure time were more popular than large advancements of home departure and work start time, even if the earlier departure time due to the small advancement was conceived as completely wasted. EPT took the adaptive character of human choice behaviour as one of its

constituent principles. From the comparison of predicted and observed choices in Table 14 (page 237) it is obvious that this offers a better explanation and prediction of the behavioural responses of Singapore's car drivers to the ALS implementation than the principally constituent, context-independent UT paradigm.

Nevertheless the ALS introduction in connection with the rise in parking fares had a profound effect on the car owners' modal choices for their daily commutes. While in early 1975 about 80% of them went by car this was well below 60% after the introduction of ALS and fell to below 55% after the increase in the ALS fare in 1976. The latter decline was almost exclusively caused by a shift from license-obliged commutes with company cars to carpooling and transit. One should consider that the cost increases that mattered were considerable: for all cars the ALS introduction implied a 90% increase in the perceived pre-ALS running costs for a round trip with entrance of the Restricted Zone between 7:30 and 10:15 a.m., and the extra expenses of about S$80 per month amounted to 5% of the average monthly household income of Singapore's car owners which was far below the contemporary welfare level. The 1976 fare increase added another 120% to the pre-ALS running costs of company cars which made the same round trip. Between then and 2005 between 45% and 55% of car owners used it for their daily commute. The reference shift caused by the original introduction of ALS in combination with the loss-aversive valuation of the running costs, including road pricing, for car use in the case of a shift back in later years to car driving during the tolled period were apparently responsible for the continued effect of the initial introduction of road pricing. Successive fare increases with about 10% of the contemporary running costs did not affect the travel mode choice to an even remotely similar extent.

7.9.4 Conclusions

In a qualitative as well as quantitative sense the EPT model implementation approached the actual frequency of the responses to both abrupt and gradual changes in the car owners' choice context much more closely than its UT counterpart. The eagerness to 'cash' travel time gains as shown by non-driving car owners following the 1989 fare reduction and the unwillingness to accept time losses inherent to a modal or schedule shift by the car drivers following the 1976 and 1980 fare increases cannot be explained by a loss-neutral kind of inertia. The extensive evaluation of the responses to the 1976 fare increase show that loss aversion alone is not enough to explain the behaviour, but that reference updating to account for hedonic adaptation appeared at least as important. This much better predictive quality of the EPT-based model implementations compared to their UT counterparts should be attributed to the differences between their basic assumptions.

Chapter 8
Conclusions and Recommendations

Although I am fully convinced of the truth of the views given in this volume ... I by no means expect to convince experienced naturalists whose minds are stocked with a multitude of facts all viewed, during a long course of years, from a point of view directly opposite to mine. A few naturalists, endowed with much flexibility of mind ... may be influenced by this volume; but I look with confidence to the future, to young and rising naturalists, who will be able to view both sides of the question with impartiality

Charles Darwin (1859)

Context: In the concluding section of '*The Origin of Species*' Darwin expresses his doubts about scientists' propensity to adopt his new paradigm or to stick to the incumbent. Apparently he intuited that most scientists would frame this choice as changes in their personal interests. Following EPT, adopting the new paradigm would then imply a loss in the scientist's intellectual endowment, in terms of expertise and knowledge that was valid under the previous paradigm, combined with a gain of fresh insights and the potential expansion of knowledge under the new paradigm. Scientists who surrender to this judgment bias should, of course, be blamed for the confusion of their professional and private interests but would definitely exhibit themselves as human beings.

Implementations of Utility Theory are commonly considered as the most useful concept for the description, modelling and prediction of human choice behaviour. The purpose of the current research was to examine whether the assumptions of Prospect Theory, superadded with insights from other social sciences, might be synthesized into a theory that offers a better explanation of observed human choices. If such a better explanatory theory could be found, a further ambition was to investigate whether, after parameter estimation, it could be put into operation to predict travellers' choices. As demonstrated in the previous sections, both questions can be answered positively. The present research that led to this conclusion consisted of four phases:

1. A re-examination of the basic principles of human choice behaviour (Chapter 2 and Annex A);
2. An evaluation of the assumptions of choice behaviour from microeconomics and the behavioural sciences in concrete contexts (Chapter 3 to 5);

3. A re-examination of the assumptions of Extended Prospect Theory and Utility Theory against actual travel choice behaviour (Chapter 6); and
4. The development of a prediction model and its application to the car use by commuters in Singapore (Chapter 7).

The research brought about several methodological challenges which are addressed in the introductory sections of Chapter 3, 4, 6 and 7. This Chapter lists the conclusions that were found in the four phases of the study and summarizes recommendations for researchers and transport policy makers.

8.1 Conclusions

Subsection 8.1.1 presents the main conclusions. The main findings that support them are listed in subsections 8.1.2 … 8.1.5, in the sequence of the four phases of the present research. The main contributions of this research to science are listed as the conclusion to this section.

8.1.1 Covering conclusions

1. Human choice behaviour can be described as a mental process of four functions in order to arrive at a choice: framing, judgment, evaluation-and-choice and choice behaviour strategy. Human reasoning, which takes place predominantly unconsciously, might complete them in any sequence.
2. The concrete assumptions about choice behaviour, as accepted in the different forms of Utility Theory and Prospect Theory, can be assembled in two different sets that each offer a complete and non-redundant implementation of the four functions of choice behaviour.
3. Most of Prospect Theory's assumptions describe various elements of choice behaviour better than the corresponding assumptions of Utility Theory, in both experimental and real-life settings as reported from the behavioural sciences.
4. Some alternative assumptions proposed in the behavioural sciences offer a better match for the observed choices in the context to which they apply than the corresponding premises of both Utility and Prospect Theory. Together with those of Prospect Theory that show a good descriptive performance these are assembled into Extended Prospect Theory.
5. Tested against observations from 85 studies retrieved from the transport literature, which cover the whole range of travel behaviour research, the five assumptions of Extended Prospect Theory in Table 18 (page 269), which distinguish it most from the corresponding assumptions of Utility Theory, show a better descriptive ability. Virtually no studies were found that provided evidence to the contrary.
6. Prospect Theory offers no clear directions about how to deal with the context dependency of choice behaviour when one considers using it for policy impact analyses and prognoses. Adopting three additional assumptions from different social sciences Extended Prospect Theory can be expanded from a descriptive model to one that is also useful for predictions.
7. Starting from the assumptions of Extended Prospect Theory, discrete choice models can be developed that can also accommodate implementations of Utility Theory, by imposing restrictions on parameters in the value function.

8. Such a model was developed for the Singapore commuting context. It contains a crucial value-of-travel-time-savings parameter that was calibrated using the travel choices of Singapore's car owners as observed before the introduction of road pricing, both for implementations of Extended Prospect Theory and Utility Theory. The first implementation predicted the observed responses of car owners to both short term and long term changes in their travel conditions better than the second.

8.1.2 First principles of choice and behaviour

The purpose of choice behaviour can be defined as providing sustainable guidance for the subject's actions in her environment, adapted to her needs and in the interest of her fitness to survive and happiness. No information was found from any society that demonstrated large-scale deviations from this somewhat self-interested purpose.

The duration, the complexity and the impact of the individual choice processes might be considered as moderately correlated elements of a continuum that constitute a weak hierarchy. Depending on their character these processes might be classified as strategic decision making, operational or tactical choice behaviour.

Until the 20th Century most scientists adhered to the Rationalist's paradigm of human choice and behaviour. It may be characterized by considering the human body as a 'machine' that is controlled by an autonomous, conscious, literally 'reasonable' mind that does so to attain happiness.

The Behaviorist's paradigm of the first half of the 20th Century depicts a reactive behaviour with an output in terms of material assets. The context-independent preference order of microeconomics can be considered as one of its relics.

The most persuasive new insights in human choice and behaviour might well be assembled in a Cognitivist's paradigm, as depicted in Figure 1 (page 13). Its long-term purpose is improving the subject's well-being, which presupposes fitness to survive. Concrete choices are motivated by more myopic objectives, notably expectations of hedonic experiences. Choice behaviour can be described as a stimulus-organism-response feedback system that accounts for both gratification of the organism's needs and coping with the environmental stimuli. This paradigm underlines the context dependency of human behaviour.

The mental processes that account for choice behaviour can be discerned in two modes or 'systems'. System 1 runs unconsciously, parallel and automatically. System 2 is conscious, serial, rule-based and severely hampered by man's limited working memory. System 1 dominates everyday human choice behaviour.

As unconscious thought is by definition covert and not controlled by consciousness, human choice behaviour appears to be a predominantly covert process. As the actual changes in the content of the information brought about by the choice behaviour process are not physically measurable, no theory exists or can be developed that rightfully claims to provide the 'right' descriptive human choice process theory.

The overall function of choice behaviour can be defined as choosing, in each choice situation, one possible course of action (including doing nothing) from a set of alternatives that, in that particular context, meets certain of the subject's concurrent needs. This definition is not

contradictory to the dominant scientific paradigm of human behaviour but emphasizes the opportunistic, context dependent character of it.

This overall function can be decomposed into framing, judgment, evaluation-and-choice and choice behaviour strategy. In interplay they transform mental perceptions originating from the senses and from memory into the choice decisions that guide the subject's behaviour.

There are no hard facts that support or exclude any particular sequence in which the functions are completed. Due to the many possible interactions, iterations and/or sequences of its four functions and their sub-functions, choice behaviour should be considered as a complex system (Figure 2 on page 21).

This functional perspective of choice behaviour is called the Meta Theory of Choice Behaviour as it covers any set of assumptions about what choice behaviour does to arrive at a concrete choice decision. It does not claim to offer a true-to-life description of the mental processes that perform these functions. It can therefore be used to test the completeness and internal consistency of operational choice theories but not their descriptive-behavioural plausibility.

8.1.3 Assumptions with respect to observed choice behaviour

In microeconomic literature there are two different, internally consistent, non-redundant sets of assumptions about concrete operations that are able to perform the overall choice behaviour function. Each is thus apt as a concrete functional-descriptive model that complies with the Meta Theory.

Framing arranges the perceived choice context in a reference state, several alternatives with their perceived outcomes, a preference order related to the subject's concurrent needs and an aspiration level for their gratification.

The elements of framing appear to be strongly interrelated and dependent on the choice context (domain and actual state of the environment, choice task complexity, current needs, moods and aspirations of the subject).

UT's premises that each individual considers a complete range of alternatives in terms of expected states of assets and that each has a context-independent, temporally stable and complete preference order against which she can evaluate them has to be rejected in a generic functional-descriptive theory of human choice behaviour. Preference orders should be considered as dependent on the context and the way in which alternatives are presented and perceived.

The reference state can be conceived as the expected 'no change' state of assets, and the attributes of alternatives as expected gains and losses with respect to it. Previous choices on the same or higher levels of the strategic-operational choice hierarchy will act as constituent elements of the actual reference state. In different domains and choice contexts the same subject may adopt different reference states.

Judgment accounts for assessment of the sizes or levels of the expected outcomes of alternatives and their valuation on some affective, utilitarian or importance scale.

Heuristic judgment plays a crucial role in an individual's assessment of the probabilities, contingencies and outcomes of alternatives. For a functional-descriptive model of choice behaviour the UT assumption of exclusively rational and/or belief-based assessment of attribute levels has to be rejected.

Subjects might frame alternatives as a mixture of cognitive and affective attributes that are valued on non-commensurable dimensions. These may either be intuitively integrated into some qualitative affect scale or be evaluated with a non-compensatory decision rule.

A functional-descriptive theory of choice behaviour should include loss aversion, diminishing sensitivity and weighted probabilities. However, in many studies a minority of the subjects either framed attribute levels in the gain domain or valued them loss neutral. This possibility should be included in a functional-descriptive model.

Evaluation-and-choice attaches an overall value to the alternatives, compares these with each other and selects an alternative that meets the aspirational level.

In many choice contexts most subjects may compound the characteristics of alternatives in a compensatory way in one overall value and successively select the alternative with the highest value. Other individuals might evaluate the alternatives attribute-wise and/or select any alternative that meets a satisficing aspiration level. The assumptions of UT and PT concerning evaluation-and-choice should thus be relaxed in a functional-descriptive model of choice behaviour.

Evaluation and comparison of multi-attribute alternatives might be either alternative-wise or else attribute-wise, based on a sequential evaluation of attributes against an attribute maximizing or elimination (threshold) criterion.

The choice criterion might be either maximizing, by the selection of an alternative with the highest overall value or the highest value on the most important attributes, or satisficing, by selecting the first alternative that meets an acceptable overall value and/or successively rejecting alternatives that do not meet threshold values on separate attributes.

Choice behaviour strategy is a coordinating function required because of the decomposition of the overall function.

A person's idiosyncratic choice behaviour strategy is neither stable nor context-independent and the order and sequence of function completion is not necessarily sequential.

UT's context independency implies that each individual follows the same choice behaviour strategy in any context and allows predictions by transferring preference orders elicited in one context to any other. The context dependency of PT implies that intrapersonal and interpersonal differences in preference orders as well as choice behaviour strategies may occur in different contexts which, in the absence of assumptions about the transfer of choice findings from one context to another, constrains it to an explanatory-descriptive choice theory.

Extended Prospect Theory (EPT) is established on the many assumptions of PT that appeared to provide a better descriptive performance than their UT counterparts. These

assumptions were accomplished with other assumptions that appeared to hold according to different studies in behavioural sciences.

EPT's assumptions differ with respect to the range of choice contexts in which they matter. While the context-dependent, change-oriented framing of attributes relative to a reference state is a universal principle, the assignment of non-linear weights to probabilities, for example, only applies to choice under risk or uncertainty.

Three additional assumptions were adopted to extend EPT from an explanatory theory to one that can be used for predictions as well:

- Most individuals use consistently the same choice behaviour strategy in recurrent choice processes, at least if these deal with the same or similar contexts;
- Individuals adjust their reference state almost immediately when changes in their circumstances are experienced; and
- In a particular context previous choices on the same or a higher level of the strategic-operational choice hierarchy act as constituent elements of the actual reference state.

Successive choices of an individual are thus considered as an ongoing process, with reference updating after each concrete choice. Together these additional assumptions offer a substitute for UT's context-independent preference order.

EPT can be used to model most other theories of choice behaviour by 'narrowing' assumptions. Expected Utility Theory, for example, can be accommodated by setting all feasible loss aversion factors and probability weights at unity, disregarding all satisficing and non-compensatory aspiration levels and evaluation-and-choice rules and enforcing the same idiosyncratic preference order on any context.

8.1.4 The descriptive ability of EPT for travel choice behaviour

Rearrangement leaves five EPT assumptions that most distinguish its descriptive ability from UT and PT. These assumptions are compared in Table 18 (next page).

An extensive literature search yielded empirical observations about travel choices from 85 different studies that enabled comparison of their descriptive ability. Together the range of real-life as well as research contexts of the studies covered the diversity and extent of travel behaviour research approaches.

Reference-dependent framing and loss aversion might be expected in any travel-related choice process. It was demonstrated or appeared plausible in 70 studies. The remaining fifteen studies offered no clues to accepting or rejecting this assumption.

The loss aversion factors for the most common travel time and cost attributes appeared in the 1.4 to 2.8 range, which yields the 'average' value of 2.0 as found from observations in behavioural sciences as a useful first estimate for applications in travel behaviour, if more specific information is lacking.

Diminishing sensitivity could only be considered by re-examining thirteen studies. Apparently a kinked-linear approximation of the value function may commonly suffice, just as a linear utility function may do to model UT's diminishing marginal utility.

Most re-examined research designs did not consider probabilistic outcomes and thus they did not allow validation of the EPT assumption that an individual attaches subjective non-linear probability weight factors to them. Evidence of application of this assumption is remarkably absent in studies dealing with strategic decision making related to accessibility and travel.

Demonstrations of the affective valuation of some attributes in addition to the utilitarian valuation of others were almost completely confined to strategic decision making and stated preference surveys with explicitly submitted ethically salient attributes, in terms of a number of casualties.

Table 18: Discriminating assumptions of EPT, UT and PT

Extended Prospect Theory	Utility Theory	Prospect Theory
Reference-dependent framing and loss aversion		
Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to an updated reference state, and most individuals value losses higher than gains of equivalent size	Alternatives and attributes are framed context-independent, as post-decisional states, independent of the sign of the change	Alternatives and attributes are framed as context-dependent changes (gains and losses) relative to a reference state, and each individual values losses higher than gains of equivalent size
Size-dependent valuation of attributes		
Diminishing sensitivity: the value function is concave for gains and convex for losses	Diminishing marginal utility: the utility function is concave	Diminishing sensitivity: the value function is concave for gains and convex for losses
Valuation of probabilities		
Most individuals weigh expected probabilities of uncertain outcomes with a subjective non-linear probability weight	Individuals do not weight expected probabilities	Each individual weights expected probabilities of uncertain outcomes with a subjective non-linear probability weight
Compounding of attributes		
Affectively salient attributes may be valued in a qualitative affect dimension, other attributes on a monetary or medium scale	All attributes are valued in a commensurable medium	All attributes are valued in a commensurable medium
Heterogeneity in choice behaviour strategies		
Within-context interpersonal differences in choice behaviour strategies occur (framing of attributes, satisficing and maximizing, compensatory and non-compensatory rules, etc.)	Each individual chooses the alternative with the highest (compensatory compounded) overall ordinal utility	Within-context interpersonal differences in framing occur, but each individual chooses the alternative with the highest (compensatory compounded) overall value

Most studies revealed interpersonal heterogeneity in the application of choice behaviour strategies. This covers framing of objectively the same context differently, loss-aversive or loss-neutral valuation of the same attributes, and the co-occurrence of compensatory and non-compensatory decision rules. Differences in the reference-dependent framing of different attributes and in the corresponding loss-aversive valuation might be the major source of interpersonal choice heterogeneity.

8.1.5 The predictive ability of EPT for tactical travel behaviour

The travel mode, departure time and route planning of the daily trip of car owners to their work in Singapore's Central Business District offers an interesting opportunity to compare the predictive ability of the EPT paradigm compared to UT. Sufficient information could be retrieved to evaluate the sudden as well as long-term responses of the car owners to changes in their travel circumstances.

Starting from the first principles of EPT it appeared possible to deduce a discrete choice model that, after appropriate calibration to a particular elicitation context, could be used to predict travel choices by the same traveller in other contexts. The model was also suited to simulate the corresponding UT premises.

The simplified value function that was finally applied only considered travel time and running cost attributes. It appeared justified to disregard the diminishing sensitivity, non-linear probability weighing and mixed affective-utilitarian valuation assumptions in the context to which this model was applied in this research.

All interpersonal differences in the valuation of the considered attributes as well as in the idiosyncratic attribute decision weights can be assimilated into just one stochastic value of travel time savings (VTTS) parameter of the time attributes. This VTTS is conceived as the ratio between the marginal psychological value of the discretionary available time and that of the money for discretionary spending. It is considered an important element of the subject's reference state that should be updated regularly, at least in assessments that adhere to the EPT paradigm.

On the aggregate level of a population of travellers the discretionary available time and money distributions will hardly change over short periods of, say, a year or two. For predictions of responses to 'sudden' changes in the travellers' circumstances the VTTS can thus be treated as an idiosyncratic constant.

The calibration process that was followed to assess the average VTTS for the reference states was the same for the implementations of the EPT and UT paradigms. There is no reason to believe that a conventional Random Utility Maximization model would have elicited mean VTTS values of another order-of-magnitude. The predictions according to the EPT and UT model implementations can be used for a *ceteris paribus* comparison of their predictive abilities.

The UT model implementation strongly overestimated a sudden shift, amongst others, to public transport after the introduction of road pricing in 1975, while it underestimated the number of car owners who paid the bill to keep on driving during the tolled period. The same situation occurred in 1976 and 1980 with fare increases and in 1998 with the transition to Electronic Road Pricing. At the same time it predicted the sudden increase in car driving after the 1989 fare reduction accurately.

The introduction of parameters in the UT model, to simulate Search or Transaction Cost theories, Status Quo or Inertia concepts, can annihilate the incorrectly predicted decrease in private car driving in 1976 and 1980. If applied consistently they would also make the correctly predicted 1989 increase vanish. Thus, the eagerness to 'cash' travel time gains after the 1989 fare reduction and the unwillingness to accept time losses after the 1976 and 1980

fare increases cannot be explained simultaneously by accounting for a loss-neutral kind of transition cost.

The predictions of the EPT model approached the actual responses of the car owners to all the sudden changes considered in the road-pricing regimes closely. Though this could not have been attained without accounting for loss aversion, the extensive evaluation of the responses to the 1976 fare increase showed that this was not enough to explain the observed behaviour. Reference updating to account for hedonic adaptation appeared at least as important.

Over a longer period the changes in discretionary time available to Singapore's commuters hardly changed in the 1975-2005 period. The corresponding long-term development of their VTTS can thus be considered as a linear function of their discretionary available money for spending. Meanwhile prices doubled and real income quadrupled. By considering several budgeting strategies it was hypothesized that individuals might adjust their VTTS proportionately to the Consumer Price Index, the monthly nominal household income development or the nominal wage rate increase.

The predictions with the EPT and UT model implementations showed that indexing of the VTTS with the monthly household income development offered by far the best matches between predictions[122] and actual long-term changes in travel behaviour. Indexing with the Consumer Price Index yielded the largest mismatch. Indexing with the hourly wage rate development, as is commonly assumed in travel behaviour research, also appeared unsuitable.

The UT model implementation, in which the VTTS was indexed with the monthly household income, overestimated the long-term development in car use for the daily commute to Singapore's Central Business District while the EPT implementation predicted it closely (see Figure 19 on page 254).

It appeared thus impossible to find a consistent combination of VTTS values and scaling principles that, with one UT model implementation, could predict the responses to abrupt positive and negative travel cost changes at the same time as the gradual changes in travel circumstances and income in a qualitative plausible way. In a qualitative as well as a quantitative sense the EPT model implementation approached the actual frequency of the responses to both abrupt and gradual changes in the car owners' choice context much closer.

8.1.6 Contributions to science

Several research approaches and theoretical concepts in this book are new contributions to science, as, to the author's best knowledge, they are published here for the first time. Some more prominent ones are:

- The systems-theoretical interpretation of the development of the philosophical and psychological paradigms of human choice and behaviour from the Renaissance era up until today;

[122] For these predictions national averages of wages and household incomes were used. In the considered period the average number of workers per household and the average working week in Singapore remained approximately the same. Indexation with the average monthly household income of (sub)populations might hold elsewhere insofar as the average number of commutes and working days over the considered households remains constant.

- The functional decomposition of choice behaviour into a complete, non-redundant set of functions and sub-functions[123] that are able to fulfil its overall purpose;
- The Meta-Theory of choice behaviour, meant as a tool to assess the comprehensiveness of the descriptive ability of any theory of human choice behaviour and as a framework for the comparison of the theoretical assumptions of functions of human choice behaviour and actual observations;
- The listing of a comprehensive set of assumptions of PT, analogous to a similar listing of UT, both considered as functional-descriptive paradigms of human choice behaviour;
- The foundation of EPT as a synthesis of assumptions that, compared to other assumptions from economics and the behavioural sciences, offered a better description of the observations of human choice and behaviour from a range of behavioural sciences;
- The assessment of the descriptive ability of five sets of discriminating assumptions of UT and EPT in a meta-analysis of the travel behaviour literature;
- The definition of the Value-of-Travel-Time-Savings (VTTS) parameter based on hedonic valuation principles;
- The estimation of the distribution of the VTTS over a population of travellers by a lognormal distribution with a shape parameter equal to the root-mean-square of the shape parameters of the distributions of the income and the inverse of the discretionary time of the travellers;
- A discrete choice model for the prediction of tactical travel choices that can accommodate similar implementations of UT and EPT; and
- The systematic comparison of both short-term and long-term responses to road pricing and changes in socio-economic circumstances by Singapore's commuters with predictions in agreement with the UT and EPT paradigms, which demonstrated a better descriptive ability of the latter.

8.2 Recommendations

8.2.1 Prospects for future research and development

This subsection lists some recommendations for research aiming to improve the understanding of human choice behaviour.

Spinoza's '*Ethica*' merits a more profound re-examination from a systems-theoretical perspective than was feasible within the current research.
Considering that the lens sharpener Spinoza might have conceived the laws of physics, amongst others, as constituent elements of his generic 'mind' concept suggests that one should start from the original Latin texts, with interpretations of the relevant concepts that are as generic and de-personalized as possible. The functional view(s) on choice behaviour that would follow from such a re-examination could then be compared with the findings from present-day neuroscientific research to adjust the functional picture if and where required into a comparatively ageless choice behaviour concept.

Comparative studies of subjects' post-decisional affective appraisal of losses and gains of equivalent sizes are needed to fill a conspicuous hole in the understanding of human choice behaviour.

[123] Most of the functions and subfunctions are not new, but their arrangement in relation to each other such that they can fulfil the purpose of human choice behaviour is.

There are some weak indications that hedonic adaptation to improvements occurs faster than to deteriorations (e.g. Frederick and Loewenstein 1999). If this is true losses incurred as the consequence of a choice would have a larger impact on the subjects' well-being than gains. Reference-dependent framing in connection with loss aversion would then be more purposeful, or 'ecologically rational', than loss-neutral valuation. The findings of such studies would boost the understanding of choice behaviour and clarify the implications of the 'greatest happiness' principles of government policy.

A related research effort might examine whether a subject updates her reference state faster following an improvement in circumstances than after deterioration.
In travel behaviour research, for example, the tendency to 'return to the peak hour' after a future improvement in traffic circulation might be caused by limited hedonic adaptation to the individual's current activity schedule if this is experienced as an unfavourable change from an earlier schedule. Customized stated choice surveys, combined with assessment of the subjective well-being and contextually relevant circumstances of the participants, as well as open interviews about the development of their preferences and behaviour in similar contexts over time, might be appropriate to grasp an idea about the occurrence and relevance of such differences in reference updating. Obviously, the researchers should anchor the reference state firmly, preferably in a real-life experience of the subjects, to get useful choice statements.

Another promising research area is reference updating during recurrent choices under uncertainty.
EPT assumes that individuals apply, after each experienced choice outcome, idiosyncratic reference state updating 'rules' in connection with re-framing the alternatives relative to that updated reference. It might be worthwhile examining the '*peak-end heuristic*' (Kahneman 1999) as one element of the 'learning routines' for recurrent choices. Replication of the simple route choice experiments of Avineri and Prashker (2005; 2006), for example, and identification of consistent choice sequences that follow from application of such routines will identify several idiosyncratic choice behaviour strategies. It might also reveal to which extent different individuals apply myopic or wide frames in connection with non-linear probability weighting.

Some in-depth studies of subjective consideration choice set formation are wanted, as this is a crucial element in the choice framing function.
Very few studies were found that investigated this process at the level of the individual either in depth or even superficially. Researchers should follow an open interview approach to elicit *what* alternatives and attributes the subject considered in a particular context, while discouraging causal explanations for their preferences. Hoogendoorn-Lanser (2005), for example, followed such an approach for multi-modal route choice and if the data are still available for the individual level re-analysing them from this perspective may be worthwhile.

Elicitation of interpersonal differences in choice behaviour strategies that subjects apply in different domains and contexts would boost the understanding of heterogeneity in human choice behaviour.
Such research might start with the analysis of recurrent choices by the same individual in the same context, without affectively salient feedback to prevent reference updating. From a functional perspective the structural approach of Behavioural Decision Theory appears the best-suited tool for the elicitation of domain-specific choice behaviour strategies. From many stated choice surveys and experiments the observed 'intrapersonal choice sequences' may still be available. Using this as the basic entity for an analysis that follows the deterministic

interpretation of the structural approach would allow the elicitation of idiosyncratic choice behaviour strategies and their interpersonal heterogeneity, as was practised by Van de Kaa (2006).

One more welcome survey might assess whether or not interpersonal differences in choice behaviour strategies are related to relatively stable personality characteristics.
In the present book some indications were discussed for this, while interpersonal differences in tastes and the valuation of alternatives depend on the subjects' socio-economic circumstances. From a behavioural perspective one should not exclude the possibility that these differences persist over a large range of domains and contexts. Therefore it seems more appropriate to investigate the correlation of idiosyncratic choice behaviour strategies and scores on the Big Five personality trait scale (e.g. Norman 1963; Levin *et al*. 2002) than domain-specific population segments like those proposed by Need (2003), for example. One might use an experimental stated choice setting and analysis, as proposed in the previous recommendation, in which stated choice games concerning different domains and levels of choice behaviour are combined with assessments of the personality trait scores.

As a next step in the introduction of EPT in travel behaviour research the development of an agent-based micro-simulation model is wanted that allows the simulation of the choice context of individuals.
Such a model might draw the individuals' VTTS from an appropriate lognormal distribution and the relevant alternatives and attribute levels from accessibility characteristics distributions. Its core might be the generic value function as proposed in Section 7.4. This appeared useful for the prediction of the responses of 'representative average car owners' but a micro-simulation model would allow a more refined 'personalized' prediction. Replication of the predictions of the tactical travel choices of car owners as discussed in this book, assuming a 'reasonable' shape and dispersion of the accessibility characteristics frequency distribution, might be used as a first stage in the validation of the model. Such a micro-simulation model might also be useful for the inference of choice behaviour from aggregated choice data that are available from other contexts. The model might be developed in such a way that simplifying and/or fixing parameters might implement both the UT and EPT paradigms. This enables them to be used for comparison of both paradigms in other contexts.

8.2.2 Recommendations for policy making

Accepting that government policies depend on the support of the public, Extended Prospect Theory offers several notions for a better understanding of the public's responses to policy measures. Roughly speaking people may react to policy measure in three different ways, dependent on how they are affected by them:

i. People's eagerness to 'cash' gains means that policies that 'go with the flow' by increasing their expected improvements as a consequence of the desired change in behaviour will be very successful and will assure the support of those concerned.
ii. Moderate opposition will be met when measures aim to prevent a person's desired change of behaviour by decreasing the expected benefits from it or by even turning those into disadvantages.
iii. People's resistance to accept losses will mobilize tough opposition to measures that are expected to deteriorate their circumstances compared to the current situation.

The following generic policy recommendations are meant to anticipate these three foreseeable patterns of reaction. They will be illustrated with examples from policy measures that might influence people's travel behaviour.

The development of a transport policy should start with a search for measures that contribute to the intended outcome and motivates citizens to change their behaviour in ways that they experience as improvements in their travel context.
It is not hard to find examples of policies that are embraced by the travelling public. The creation of the expressways that circumvented Singapore's Central Business District effectively removed the through traffic from the city streets and many bypasses around population and business centres all over the world have stimulated a similar instantaneous shift of non-local traffic. The increased patronage of public transport services once the frequency is increased is another well-documented example of this gain-taking reaction in which individuals are apparently not inhibited by inertia or transition costs. Evidently, the creation of additional tolled infrastructure that is financed with private money also belongs to this policy category.

If the intended outcomes of a transport policy cannot be attained without harming citizens' interests, the policy makers should search for measures that dissuade individuals to change their behaviour if that change would undermine the desired policy outcomes.
Singapore's successful car ownership determent policy, that started in the early 1970s and has continued to date, is a good example of such a policy. It did *not* primarily impose a loss on existing car owners, by taxing them to the extent that they had to abandon their car, but rather incited individuals who did not yet own one to give up the prospective gain of getting one.

Only if the previous measures are insufficient to attain the desired outcomes should policy makers consider measures that enforce citizens to incur deteriorations in their actual travel circumstances.
The introduction of road pricing in 1975 in Singapore was a clear example of this type of measure. It implied a sudden shift in the reference state of the concerned car owners. In combination with the loss-aversive valuation of the increase in running costs in the case of a shift back, this reference shift was apparently responsible for its continued effect. Successive instantaneous fare increases of about 10% of the contemporary running costs did not affect the travel mode choice significantly. Road-pricing policy measures that aim to persuade individuals to change their travel behaviour in such a way that they incur longer door-to-door travel times should thus impose fares such that the experienced monetary loss is valued higher than the time loss caused by the change. Obviously, rewards for individuals to incite them to accept time losses will be valued in the gain domain[124] and thus have to be about twice as high as the road-pricing fares to have the same effect.

The EPT paradigm should be developed further for use in policy impact assessment studies, as it appears to be able to predict the responses of individual citizens as well as their distribution over different socio-economic segments of the population and thus

[124] However, one might arrange such financial incentives as advance payments for an agreed travel behaviour where the receiver has to pay back for any violation of it by falling back to the original behaviour. The endowment effect will then place the travel time reductions incurred by the violation in the gain domain and the backpayments in the loss domain, which makes sticking to the alternative behaviour even more profitable than changing to it in order to prevent an imminent money loss. For a real-life demoinstration of this effect, see the discussion of Nielsen (2004) in Subsection 6.3.5.

enables an estimation of both the overall public support and the outcomes of the policy more closely than the actual implementations of the UT paradigm.

The responses to different types of transport policy measures were explained above as the outcome of the choice behaviour of individual citizens. If the objective of a policy is to incite citizens to change their behaviour it appears possible to estimate the success beforehand by considering the balance of the positive and negative changes that it imposes on different individuals. As a consequence, under many circumstances models in agreement with EPT may predict people's responses to policy interventions systematically differently from models that adhere to the UT paradigm. Compared to models that follow the UT paradigm similar ones that adhere to EPT will predict, for example, a larger response to measures that "seduce" people to change their behaviour by offering them an 'instantaneous' direct profit. The reverse will hold for the predicted responses to measures that aim to dissuade behaviour by imposing a disadvantage on those who refuse to change it. Also, the EPT paradigm explicitly considers a non-random interpersonal dispersal in choice behaviour strategies and in values or preferences.

Chapter 9
Epilogue

We believe that economists should proceed as they typically do. Economists are forced to intuit, to the best of their abilities, which considerations are likely to be important in a particular domain and which are likely to be largely irrelevant.

Shane Frederick *et al.* (2002: 394)

Context: Address of Frederick and colleagues from other social sciences to economists in the concluding section of an article about time discounting. The considerations apply to the interests of the concerned individual choice subjects. The address seems equally appropriate for transport researchers and scientists from other social sciences when considering employing the EPT paradigm.

Finally my quest for a better descriptive theory is approaching its end. It has led me down many different fields and has provided lots of answers. However, I realise that among the readers it might have raised even more questions than I have tried to answer. I will here consider a few questions that have greatly puzzled me. These deal with unconscious versus conscious choice behaviour, the critical observations of the different theoretical assumptions and theories of choice behaviour as encountered in the literature of several fields, and the potential applicability of Extended Prospect Theory (EPT) for research and transport policy impact analyses in a national and regional context.

9.1 What does conscious reasoning attribute to choice behaviour?

It was one of those bleak days last November when I wheeled a barrow load of leaf litter to the temporary municipal depot a hundred yards away from my home. All of a sudden I noticed a faint tickling sensation in the front muscle of my right upper leg, almost immediately followed by, successively, a fast approaching loud barking sound, a high fence overgrown with ivy on the right hand side of the footpath, the awareness that I kept on wheeling seemingly regardless, and the observation that the still loud barking sound came to a standstill. I concluded that I did not have to change my behaviour. While returning back home

along the same route, after unloading the barrow, my mind was occupied with anything but the barking incident until exactly the same sequence of impressions came over me, except that the tickling feeling, the barking sound and the ivy clad fence were all on the left hand side now. Back home I laid these observations down in writing, as they seemed illustrative of unconscious operational choice behaviour. When I did so I was sure about the sequences of events.

The unconscious choice process that resulted in my decision to continue what I was doing and not to care about the barking sound apparently contained all the functions of the Meta Theory of Choice Behaviour as developed in this book. Yet the first conscious awareness of my behavioural response was an *ex-post* observation of it. The reference-dependent framing of the choice context was almost certainly recognition primed. I did not, for example, bother to take a second look at the bark-emitting device by climbing on the fence and did not even take the effort to turn my head to see whether there was an opening in it – or, more properly, if I turned I did not notice and/or remember it. My subjective consideration choice set might have contained alternatives like kicking the dog or running away from her if she had attacked me, walking to the fence to tease her or just ignoring her as irrelevant. Had I grown up in a society where boys became dog hunters I might have considered grabbing my bow and arrows, rushing to the fence and shooting her. Had my tribe worshipped dogs I might have considered falling on my knees and praying.

Though these latter and other alternatives of a complete choice set might have passed through my mind unconsciously this seems highly unlikely to me. But whether or not this was the case, my mind might have been able to judge the probability of the states of the world in which each considered alternative action would be appropriate, to attach a value to the expected outcomes and to select the alternative that maximized my utility and/or optimised my interests in the given context. In retrospect, continuing to push the barrow seems the most rational choice that I might have made after an extensive conscious assessment and trade-off of all feasible probabilities and consequences and a value or utility maximizing choice. However, just the rational conscious calculation of the time it would take for the bark or dog to reach a possible hole in the fence would have lasted until long after the moment that the barking object might have jumped upon me. Luckily my unconscious mind made a choice long before it informed my consciousness about what it had done.

This leaves the awareness of the tickling feeling in my right and left upper leg. I have to accept that I will never know if this was caused by actual muscular activity and/or local working of the sympathetic or somatic nervous system. Remembering that long ago my schoolmates told me that I blushed even before I was aware that I felt embarrassed, this interpretation does not seem too far-fetched to me. But the feeling might just as well have been a mental illusion that evolved and remained an action of the central nervous system only. It might also have been a coincidence, although as it happened twice, at the same moment in a similar sequence but in different legs, this seems very unlikely. Anyhow, to me it seems some sign of a preparation for action, for a kick and/or run alternative, that was not followed through by conscious thought.

Once I became consciously aware that I had chosen to continue wheeling in connection with the few other notions of the choice situation I had a picture of my behaviour and concluded not to retrace my steps. This conscious ‘second thought’ allowed me to revise my unconscious choice and to take action to repair or confine the damage that might have been caused. I would therefore conceive conscious thought in operational choice contexts as post-

decisional, as meant by Svenson (1992), rather than on-line monitoring and controlling, as suggested by Kahneman (2002).

Though, like in the barking dog context, consciousness might in most choice contexts accept the unconscious conclusions without much deliberation, one should not underestimate the importance of the second-thought conscious consideration. Dijksterhuis (2007), for example, who doubted the advantages of conscious attention and thinking in the development of important decisions, himself made the apt remark that an unconscious choice to acquire a residence because one likes it might be turned around by the simple conclusion of conscious deliberation that one cannot afford its price. Nevertheless Dijksterhuis and colleagues have a point in contexts where conscious thinking is restrained to the 'operational' processing of information into choices, without, for example, paper and pencil at hand to overcome the limitations of working memory. My own experience with several strategic decision-making processes concerning the acquisition of houses, amongst others, was that the conscious rating of the different attributes of the alternatives was most helpful. In doing so I essentially followed Franklin's famous 1772 letter about how to make a sound rational choice among affectively salient alternatives. Though in all choices affective motives dominated I remember at least two much desired houses that my wife and I had to reluctantly reject after a 'rational' comparison of pros and cons.

9.2 What are the critics of Utility and Prospect Theory?

The publications from the different disciplines that I have reviewed in this book contained many more or less extensively substantiated criticisms of the constituent assumptions of the Utility Theory (UT) and Extended Prospect Theory (EPT) paradigms as considered here. It is not feasible to address them all. I will mention here those that I found most pertinent and add my observations to them.

Critics of the application of UT often follow Simon (1955) who rejected it as a descriptive model of actual human choice behaviour because it supposed 'unbounded rationality', i.e. that people dispose of omniscience and the unbounded computational power required to consider all alternatives in all contexts (e.g. Gigerenzer and Todd 1999). The UT paradigm was indeed developed from a normative-rational view of decision making: each individual would follow this concept in any context to arrive at decisions that make sense, and the necessary comparative assessments should be made in a deliberate-conscious way. The poor processing capacity of the conscious mind supports this criticism. However, for a long time UT has been predominantly used as an approximate descriptive-behavioural model and most contemporary scientists are well aware of that. As Chater *et al.* (2003: 67) posed it '*Rational description is the view that behaviour can be approximately described as conforming to the results that would be obtained by some rational calculation. This view does not assume (though it does not rule out) that the thought process underlying behaviour involves any rational calculation*'. When the formidable processing power of the unconscious human thought processes (e.g. Dijksterhuis 2004) is considered I see little reason to doubt the feasibility of this interpretation of UT. This does not mean that I consider its descriptive ability above suspicion.

The cognitive limitations of, or hypotheses about, the sophistication of cognitive processes are often advanced to reject descriptive concepts for complex judgment processes, like the expected utility assessments of probabilistic prospects according to Expected Utility Theory and their weighted counterparts of Prospect Theory (e.g. Avineri and Prashker 2006; Fujii and

Kitamura 2004). The required calculations might be unfeasible for the conscious mind but they would by no means be more complex than, for example, everyday size assessments if these were performed by mathematical calculations according to geometric principles. Accepting that it is not known *how* the unconscious mind processes information but that it has a huge ability to do so I have no doubt that it can accomplish similar judgments as assumed by Expected Utility Theory and Prospect Theory. For the moment it seems that the cumulative functional form of PT (Tversky and Kahneman 1992) offers the best functional description of travel choice under uncertainty in a wide variety of contexts, although when an algorithm is found with an overall better descriptive performance there would be no objections to adopting it.

Maybe the most common objective to alternative theories uttered by scientists who follow the UT paradigm is that UT might not be perfect but 'it works'. Most of the almost one hundred studies that I re-examined in Chapter 6 showed that the travel choices in the considered context could be described quite well with discrete choice models that followed the UT assumptions. However, to arrive at a satisfying model fit the utility specifications often included alternative specific constants that may be hard to interpret from a descriptive-behavioural perspective. This might be illustrated by the different elicited marginal values of travel time savings on the same long-distance rail corridor in the United Kingdom. Bates *et al*. (2001) estimated a linear utility specification of early and late schedule delay, fare, mean delay, headway and a hierarchical parameter and found £1.266 per minute mean delay while Michea and Polak (2006), who used the same model but without the headway and hierarchical parameters, elicited £0.55 per minute for it. These and the discrete choice models encountered in most other studies were almost exclusively used to estimate parameters that allowed the 'best achievable' fit with the choices as observed in the considered context. Without disputing the descriptive performance of these models in the considered contexts one should realize that the differences undermine the predictive credibility of UT, i.e. the applicability of the context-independent preference order principle that discerns it from the EPT paradigm. In my opinion one should conclude that 'UT does not work' if one needs alternative-specific constants to attain an acceptable goodness-of-fit in the considered contexts, unless they are based on observed behaviour and have values that are validated for the range of contexts for which the UT model is considered to work.

Plott and Zeiler (2005), amongst others, disputed that loss aversion in agreement with PT explains the gap between the willingness to pay and the willingness to accept compensation for a good, depending on its endowment status. Partly based on their own experiments and on a review of other experiments, they stated that when the gap was observed this was a consequence of the design of choice experiments in psychological laboratory settings, suggesting that loss aversion might disappear in real-life economic exchanges. A re-examination of their experiments yielded the reverse conclusion if their interpretation of endowment as ownership in the strictly juridical sense is replaced by the common behavioural interpretation of 'getting the good at one's disposition'. The road pricing study reported by Nielsen (2004), as re-examined in this book, offers a nice real-life example of the instant shift from the gain to the loss domain following the real-life endowment of money for toll expenses. In sum, therefore, I consider the existence of a strong endowment effect that, immediately after transfer of ownership, affects the framing of alternatives and the successive judgment and choices by most individuals, to be beyond reasonable doubt.

Some authors consider that both UT and PT are not designed to describe repeated choice tasks because they are not apt to account for feedback-based learning (e.g. Barron and Erev 2003;

Avineri and Prashker 2005). This is definitely true for UT if one does not relax the context-independency of preference orders. It also holds for the way in which these authors applied PT, i.e. by adopting an 'average' travel time as reference state for all their choice subjects and by assuming that these made a one-shot decision at the start of the choice sequence, without updating the reference state and the expected attributes of the alternatives. However, many individuals may keep on updating their reference state following the experience of an outcome of a previous choice, though others might choose the most rewarding probabilistic alternative systematically after a learning period in which they assess the frequency distributions of outcomes (Schul and Mayo 2003). PT neither rules out nor prescribes its application for one-shot decision making as well as for repeated choices under uncertainty. EPT explicitly assumes that almost all travellers will update their reference state and choice frame after a significant change in traffic circumstances whilst many of them may keep on updating it day after day. Actually Barron and Erev (2003) demonstrated the descriptive ability of a simple learning model that accounted for loss-aversive valuation of the feedback in a choice experiment after which Avineri and Prashker's route choice experiments were modelled. I therefore consider that PT and EPT are very apt for the description of recurrent choices.

9.3 Why is EPT considered as an elaboration of PT instead of UT?

As UT and PT share several basic principles of human choice behaviour, like its self-interested purpose and the decreasing sensitivity for increases in the subject's endowment status, I could have started from UT as the most ancient one. This would, however, have meant that I had to reject the individual's context-independent preference order or ordinal utility principle. This is, in my opinion, the backbone of all current applications of UT as it allows the transfer of individual choice behaviour as elicited from one context to another under the UT paradigm. It implies that, for example, someone who would prefer to keep her current roadway rather than paying €1 for a newly opened express lane that would save five minutes of her travel time would make the same choice tomorrow, all other things being equal. As I see it the use of UT as a paradigm for policy impact analysis and prediction relies on this principle, including the use of Stated Preference surveys for the understanding of travel behaviour in real-life contexts, for example. As this principle is rejected in EPT I considered it highly inappropriate to found this as an extension of the UT paradigm.

EPT assumes that the preference order of an individual changes when her circumstances change, not only in the long term but also instantaneously, from one day to the other for example. The subject who would not pay the 'loss' of €1 to use the express lane today to 'gain' five minutes might do so in a week's time, provided that her reference has changed in the meantime. Suppose, for example, that the express lane authority gave her a free ticket for a week and that she happily cashes in on the five-minute travel time gain. At the end of the week her reference will have changed and she then has to trade a five-minute time loss for a €1 loss. According to UT's 'loss-neutral' evaluation this would yield the same choice as one week earlier. Also according to PT, with loss aversion but without reference updating, the trade-off remains the same as the week before: €1 loss plus 5 minutes gain, compared to the reference before the express lane was opened. In other words: the subject's preference order remains the same. EPT assumes that the subject's preference order changes due to reference

updating. The trade-off shifts, from €1 loss plus five minutes gain versus the old reference to €1 loss versus 5 minutes loss.

In view of the prominence of loss aversion it is tempting to add it to models adhering to the UT paradigm. Several researchers have actually done so. The previous simple example and the more extensive elaborations in Chapter 7 show that this does not necessarily offer an improvement of the paradigm. As the context dependency of human choice behaviour and the framing of attributes relative to a reference state are constituent premises of PT I chose to take this as a starting point for the foundation of Extended Prospect Theory, in which I also adopted assumptions from other behavioural sciences as a substitute for UT's ordinal utility principle. I would underline, however, that I am by no means suggesting that the current generation of discrete choice models that were originally founded on the Random Utility Maximization principle cannot be adapted to accommodate implementations of the EPT paradigm.

9.4 How can EPT be applied for the prediction of travel behaviour?

In this book I started from generic principles of choice behaviour and confronted these with observations to arrive at EPT's set of assumptions. These appeared useful for the description of choices as observed over the full width of travel behaviour research. Considering these principles together a parsimonious model was developed. The backbone of it was a generic value function tailored to the travellers' interests in the context of the Singapore commute. This implementation was able to offer fair calibrations and predictions of the tactical travel choices in the considered context. It depicts, however, only one level of the strategic-operational hierarchy of choice processes that together generate traffic flows. Within this level it considers only a part of the relevant choice processes at that level.

Although the considered tactical trip planning processes might have a decisive influence on the traffic flows, the hysteresis of the process and the dependency of the outcomes on the individuals' travel characteristics and socio-economic circumstances requires a major effort in data collection. Even the establishment of the aggregated trip attribute levels and price and income developments that were used as exogenous parameters in the Singapore study largely exceeded the effort needed for the actual assessments of the choice predictions. One should consider, however, that attributes like door-to-door travel time and costs of the daily commute are similarly important for choices on other levels of the strategic-operational hierarchy, whether it is considering moving house, the acquisition of an annual season ticket or the possibility of leaving the car at home today and taking the bike in view of the pleasant weather. A shift to Extended Prospect Theory as the backbone for transport policy impact assessment and prediction modelling in a country or region might be accompanied by a reconsideration of the transport data management.

Such a reconsideration might start with the development of parsimonious descriptive models in agreement with EPT for the travel-related choice processes on the different levels of the strategic-operational hierarchy as discussed in Chapter 6. This might be done in the vein of the tactical model development in Section 7.4. A rough-and-ready approach would yield an overview of the required attribute levels and the character of their interpersonal distribution. Such an exercise should not start with a blind slate but might consider, for example, the

existing UT models for residence location and vehicle ownership with the corresponding data sources, which might reveal a few gaps in the basic information building rather than an empty building lot. Like in the case of the Singapore commute it might, however, ask for extensive additional analyses to refashion the databases to allow simulation of, for example, change-oriented framing. Encouraged by the predictive ability of the very simple EPT model used to evaluate the Singapore case I feel quite convinced that the fast-and-frugal transport model that would originate by combining the models that apply to the different levels of the strategic-operational hierarchy might already improve the impact estimation of transport policy measures.

A more refined approach might start with an evaluation of the descriptive and predictive abilities of the current models developed for the different strategic-operational choice levels. Even if a thematic approach with sufficient resources available was followed this might require a few years before the whole choice hierarchy would be covered. This would allow a better assessment of the character and extent of the required data. Taking the Dutch situation as an example, one should consider that many recurrent surveys and corresponding useful databases might fit well into such a picture. Some of the more obvious ones in the strategic-operational choice hierarchy order include: VROM's Netherlands Housing Research WoOn, SCP's Trends in Time and RWS's Mobility survey Netherlands and ongoing traffic intensity registrations. The large representative samples of the population that are surveyed should allow the assessment of at least the character of the frequency distributions of choice attribute levels. The excellent Dutch traffic simulation models might be used to complement idiosyncratic accessibility data. Taken together, this may just leave the need for some moderate adjustments and the filling of a few gaps to arrive at a data management infrastructure that allows a fully-fledged implementation that exploits the advantages of EPT for a better description, understanding and prediction of travel behaviour and traffic.

9.5 Is EPT useful in domains other than travel behaviour?

The findings about choice behaviour that I have considered in this book to evaluate the descriptive and predictive ability of Extended Prospect Theory have only concerned situations in which individuals and/or households made choices that affected their day to day travel behaviour. This might raise the question to what extent its observed abilities might hold in other domains and fields of choice behaviour. In doing so, one might observe that the assumptions of EPT were derived from fields other than transport research. There is therefore no reason to expect that they should be less appropriate for the description and prediction of, for instance, people's choices to trade-in a life insurance policy or to make a tour around the world. One should bear in mind, however, that '*Economists are forced to intuit, to the best of their abilities, which considerations are likely to be important in a particular domain and which are likely to be largely irrelevant.*' (Frederick *et al*. 2002: 394). This is what I did in the discussion of the 'fast-moving barking object' context above and what guided me in Section 7.4 when I developed the value function for the Singapore travel context. In my opinion this 'putting myself in the choice subject's shoes' attitude is a prerequisite for researchers in other fields if they want to develop successful implementations of the generic principles of Extended Prospect Theory that are tailored to the domains and contexts of their expertise.

9.6 Is EPT useful for the description of choice behaviour of organizations?

Another question might be how far Extended Prospect Theory is useful in choice contexts in which social interactions play a prominent role. This question is discussed briefly here.

I have no doubt that with respect to households the answer is affirmative. Many travel-related choices as discussed in this book might be the result of processes at the household level rather than of the individual members. The functional-descriptive character of EPT and the basic principle that choice behaviour serves the interests of the subject makes it possible to describe and predict the behaviour of household members with it, including actions that bind the whole family. This holds as long as potential conflicts of interests are resolved and all members to whom it concerns follow the final choice. It does not matter whether such a final choice is achieved by reaching consensus or by the enforcement of the will of a dominant member on everyone. This process independency is an incidental advantage of Extended Prospect Theory. It extends its applicability to the choice behaviour of other organizations, once more as far as internal conflicts of interests are settled.

Though not developed for that purpose, Extended Prospect Theory might also be a useful tool for the behaviour of firms and non-profit organisations. Understanding it starts with an assessment of the interests of the different individuals and groups and their roles that make up the organisation. If collective and individual interests are shared by all actors the organization as a whole can be considered as a 'person' that follows EPT. More often, there are conflicts of interests in a particular context. Some examples are: a strategic decision at the concern level that is not implemented in the operational work processes of some departments or even not communicated and 'translated' to the shop floor at all; an turnover-based reward system for department chiefs who are allowed to sign small contracts while they are not paid for more profitable large contracts that may be signed by the director. The choice behaviour of such organizations may appear Janus-faced from the outside, often with marked differences between strategic decisions and intentions carried out by the top management and concrete operations that completely disregard these. In such circumstances one might use the principles of EPT to develop appropriate value functions and choice models for the individual actors and roles and accommodate these as agents in a micro-simulation model. Calibration of the strength and content of the most relevant interactions might then offer a fair description of the behaviour of the considered organisation, which might allow the prediction of its future behaviour in similar contexts.

The application of EPT in multi-agent micro-simulation models might also be a useful way to describe and predict human choices in other social interaction contexts, like keeping up with the latest fashion, herding or group-thinking. Again, the starting point for such an approach might be to intuit the interests of the individuals in the considered context and take this into account when modelling the individual agents. As such multi-actor choice processes might be conceived as extremely complex adaptive systems one should consider the common phenomena of such systems, like emergent properties, bifurcations and hysteresis at the group level, in the modelling exercise.

9.7 What are the challenges for policy makers posed by the insights into human choice behaviour as offered by EPT?

As I see it there are many similarities between the choice behaviour of individual citizens and the policy-making of governments and organizations. A conspicuous one is the context dependency. Both individuals and governments commonly choose for context dependent means, like paying for travel time savings and imposing road pricing, instead of ends such as increasing one's discretionary time or improving the town's air quality, let alone that they would systematically strive for outcomes like one's subjective well-being or the greatest happiness for all citizens.

Accepting that context-dependent choice behaviour is a fact of life for both governments and citizens and realizing that government policies depend on the support of the public, reveals a major dilemma for administrators and politicians in a democratic society. This dilemma is how to deal with policies that are deemed to be in the long-term interest of the society, like the reduction of greenhouse gases, but require citizens to change their behaviour in a way that they perceive as contrary to their individual interests. I will illustrate this by a comparison of actual and potential road pricing policies in Singapore and the Netherlands, respectively.

Though to date many car users in Singapore might consider road pricing as just a trick of the government to get money[125] off them the original introduction of road pricing in Singapore was accompanied by little overt public opposition. Policy makers elsewhere should consider that the introduction occurred in a rather autocratic society. It was at short notice – about a year – and the increase in travel costs for those to whom it concerned was drastic. It almost doubled the running costs for a round trip by car to the city. About 30% of the concerned commuters were persuaded to incur the time loss caused by a change to another mode, schedule or route. This implied a sudden shift in their reference state. In combination with the loss aversive valuation of the increase in running costs in the case of a shift back, this reference shift was responsible for the continued effect of the ALS. Successive fare increases of about 10% of the 'new' running costs did not affect the travel mode choice significantly.

'Translated' to the actual conditions in the Netherlands in 2005, a similar measure would imply a *sudden increase* in running costs of well over 0.1 €/km, accumulating to about 100 €/month for the 'average' commuter, without any reduction in car ownership taxes. Such a drastic increase would inevitably mobilize the opposition of the affected individuals. The natural reaction of policy makers might be to mitigate the opposition by imposing less drastic taxes or by spreading the cost increase over a number of years. However, the extent of the desired changes in travel behaviour might then dwindle at a faster pace than the opposition of the public. In the end, individuals might continue their usual travel behaviour while paying for road pricing. They would not contribute to the intended outcomes of the road pricing policy but it might endorse their view that the government and policy makers consider car owners as milch cows and transport policy as a money pump. This in turn might endanger the career prospects of the concerned individual politicians and officials and the prospects of their parties for the next elections.

[125] Personal communications by several Dutch colleagues of Rijkswaterstaat and consulting firms who visited Singapore over the years, about their talks with cab drivers and colleagues.

In general terms the dilemma concerns administrators in a profoundly democratic society who consider policy measures that aim to change citizens' behaviour in a way that seems to conflict with their current interests. To attain the desired outcome of the policy the imposed fares or other measures must be such that they really matter, i.e. imply an abrupt loss if the current behaviour is continued. The more drastic the measure is, the larger the number of citizens who will change their behaviour and thus switch to another reference state, but the stronger their opposition to the introduction will be. Any attempt either to gain public support for the measure or ease the opposition by reducing fares or spreading tax increases over time will enlarge the chance that it will be put into operation, but the more effective the mitigation is in terms of increasing public support the less effective the policy will be in terms of the intended behaviour change and the more it will boost the government revenues and feed the distrust of the public. From this perspective alternative government policies like, in the transport policy case, offering room for privately financed additional toll roads or improving the accessibility of concentrations of work and other activity centres from attractive residential quarters in the neighbourhood while leaving the quality of long-distance travel with any mode as it is, might offer a better outlook in terms of both public support and a more sustainable transport system.

9.8 Winding up

Though my supradisciplinary research of human choice behaviour and its description in this book were a major undertaking, I am well aware that I only examined and processed a small part of the vast body of available knowledge. By focussing most of my research and development on the generic level it appeared nevertheless possible to develop a generic theory of human choice behaviour. This Extended Prospect Theory owes about half of its basic assumptions to Kahneman and Tversky, whose work I gratefully acknowledged in the name of the theory. Many other elements were borrowed from a diversity of scientists and disciplines that are referred to elsewhere in the text. This allowed me to extend it into an operational model that enables the description as well as the prediction of choice behaviour. The degree to which this appeared feasible in the Singapore commute context came to me as a pleasant surprise. In my opinion the paradigmatic character of Extended Prospect Theory opens an array of avenues for challenging research and promising applications, in transportation as well as most social sciences. In conclusion I wish that the colleagues who endeavour to tread one of these avenues will find the same amount of pleasure that I have encountered during my renewed acquaintance with scientific research.

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Annex A
Historical development of the choice-and-behaviour paradigms

This book reviews concepts and findings about choice and behaviour from many different disciplines. A risk that might be encountered when studying the literature of an unfamiliar field is that a particular view may seem to reflect the prevailing opinions in the discipline at hand but on closer inspection might rely on insights that were once dominant but are now out of date. One way to reduce this risk of misapprehension is to examine the development over time of the scientific paradigm in the disciplines of interest. This also enables a proper assessment of the current generic, 'supra-disciplinary' paradigm of human choice and behaviour.

This annex explores the development of the scientific views on human choice and behaviour from the Renaissance era up until today. The interrelationships of human choice and behaviour are amongst the most crucial topics of research in many social and behavioural sciences. Before economics and psychology became separate disciplines (in the 18th and 19th century, respectively) these phenomena were studied as a part of philosophy. Many notions on choice and behaviour can be retrieved from the Greek philosophers. However, in the Middle Ages these concepts were either rejected or adapted to fit in with the Christian religious doctrine. The relevant literature is examined from a systems-theoretical perspective, an interdisciplinary field that offers a methodology to accentuate the understanding of all kinds of processes (e.g. Weinberg 1975).

The current Western scientific views on human choice and behaviour are the result of an ongoing tradition, from the end of the Middle Ages onwards, in which little by little science and faith were disentangled. It appears that three periods can be discerned: pre-20th century, early 20th century up to the 1960s, and late 20th-early 21st century. In each of these periods the scientific insights appeared to develop into what in broad outlines may be considered as dominant supra-disciplinary paradigms, the Rationalist's, Behaviorist's and Cognitivist's paradigms of choice and behaviour. The findings are aggregated into descriptions of the supra-disciplinary paradigms that prevail at the end of each period.

A.1 The Rationalist's paradigm (1500 – 1900)

A.1.1 Renaissance

The disentanglement of religious belief and science started during the Renaissance[126], and gradually led to a tradition in which knowledge was based solely on reason and empiricism (e.g. Störig 1982). A first surge of new concepts in philosophy came from humanism, which combined an ethical view on the dignity and potential of people in their environment with the doctrine that the truth should be searched by reason and analysis of observations. The range of opinions among humanists about how ethics should influence behaviour was huge. Where Erasmus (1469-1536) advocated that people should behave according to religious-ethical convictions like charity, Machiavelli (1469-1527) developed a rigorous rational way of thinking about how rulers should behave to stay in power, apparently following the principle that '*the end justifies the means*' (e.g. Bor 2003).

A.1.2 Continental Rationalism

The Frenchman Descartes (1596-1650) started the continental rationalism tradition in which human reason is the source of all knowledge. In the same work in which he introduced the Cartesian coordinates he posited '*I think, therefore I exist*'[127] and successively deduced a distinction between the human soul or mind (more or less identical to consciousness) on the one hand and the human body on the other. In his main work, Descartes (1642), as discussed in e.g. Burnham and Fieser (2006), posited that all objects in the visible world, including the human body and animals, are determined by the rules of physics and can be studied as machines. On earth only humans have been endowed with a soul (or mind) of a different substance. This mind is sustainable in itself and is characterized by *ratio* or reasoning. It conceives 'innate' ideas when stimulated by the senses, activates these when appropriate and processes these by active, conscious thought, leading to particular judgments, conclusions and decisions, and a conscious will that controls the body that it animates. From a systems-theoretical perspective this view of the mind-body interaction can be conceived as a non-adaptive open-loop controller in which the conscious mind monitors the body and controls its behaviour, while feedback loops are missing. Descartes' dualist body-mind distinction and the conviction that human behaviour should be guided by conscious reasoning remained the mainstream approach to all social sciences for centuries.

In his '*Pensées*' (French for 'Thoughts')[128] Blaise Pascal (1623-1662) adhered to the soul-body distinction, the concept of mind = thought = reason as a unique capacity that distinguishes humans and animals, and the notion that the material world is made by extension and motion. He extended Descartes' solely conscious-rational definition of mind by assuming that people may have an '*intuitive mind*' (characterized by feeling, judgment '*which has no rules*', and mental perception) in addition to a '*mathematical mind*' (reasoning, intellect including science)[129]. However, he demonstrates over and over that reasoning may result in contradictory conclusions depending on the principles employed. Other interesting

[126] This transition started in the 14th century in Italy and reached England in the late 16th century.

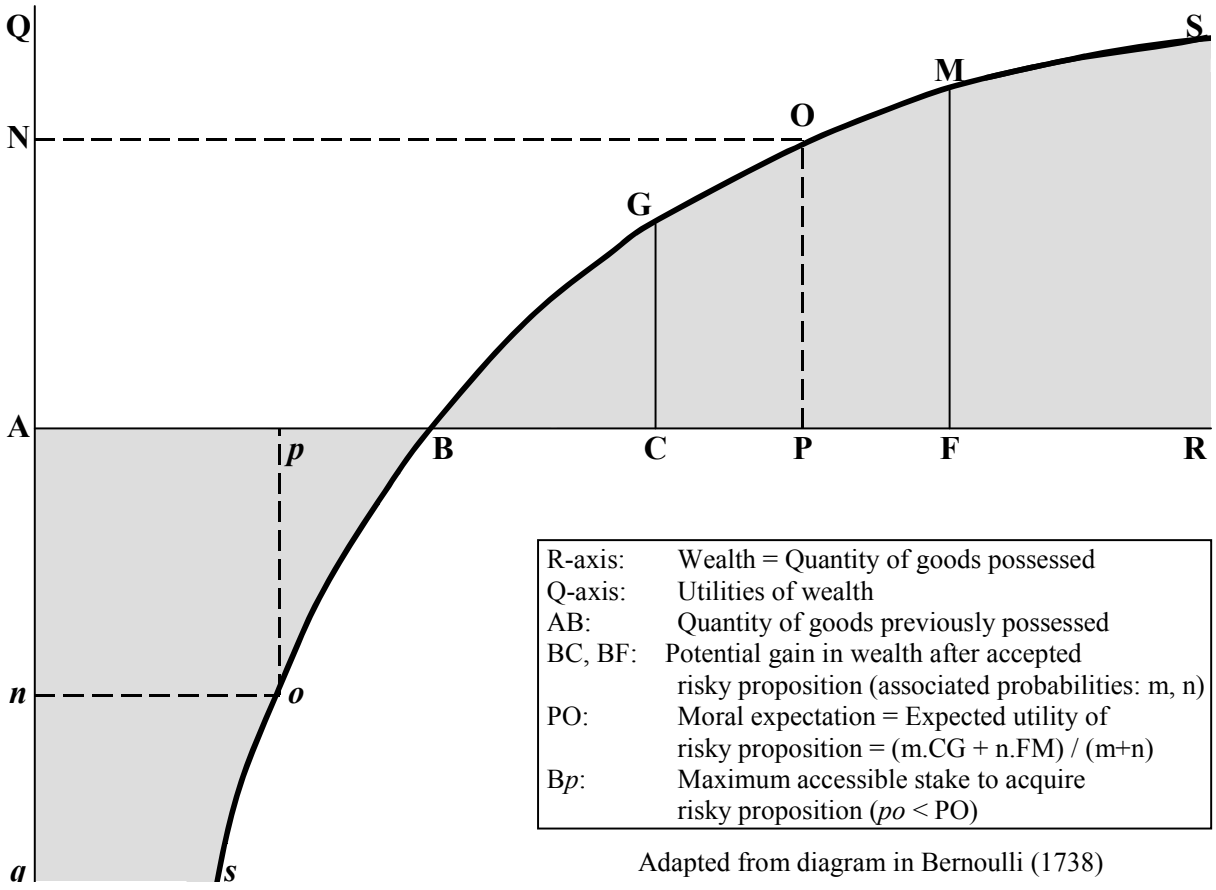
[127] Mostly cited as '*cogito, ergo sum*' which occurs in a later writing, but it first appeared in '*Discours de la Méthode*' (1644) which was in French: originally he stated '*je pense, donc je suisse*'.

[128] A collection of partly unfinished notes, published posthumously in Pascal (1670).

[129] In Pensée 1 (emphasis added) he stated: '*It is rare that mathematicians are intuitive and that men of intuition are mathematicians, because mathematicians wish to treat matters of intuition mathematically and make themselves ridiculous, wishing to begin with definitions and then with axioms, which is not the way to proceed in this kind of reasoning. Not that the mind does not do so, but it does it tacitly, naturally, and without technical rules*'.

lines of thought are: '*Nature gives us passions and desires suitable to our present state; As nature makes us always unhappy in every state, our desires picture to us a happy state; because they add to the state in which we are the pleasures of the state in which we are not. And if we attained to these pleasures, we should not be happy after all; because we should have other desires natural to this new state*' (Pascal 1670: Pensée 109); '*Memory is necessary for all the operations of reason*' (Pensée 369); '*All men seek happiness*' (Pensée 425).

In a correspondence with Fermat about the monetary value of gambles Pascal had earlier (1654) laid the foundations of probability theory. His application of this '*Expected Value Theory*' in the Pensées, to prove that it is rational to believe in God, is a demonstration of a logically sound choice process that was based on an improper framing of the alternatives. Almost a century later, Bernoulli (1738: 24-25, his emphasis) followed Pascal's probability concept but introduced the utility concept as a substitute for the monetary value: '*The determination of the **value** of an item must not be based on its price, but rather on the **utility** it yields … **Any increase in wealth ... will always result in an increase in utility which is inversely proportional to the quantity of goods already possessed.** By this expression (i.e. quantity of goods) I mean…anything that can contribute to the adequate satisfaction of any sort of want.*' He thus arrived at utility as a logarithmic function of wealth, as depicted and explained in his article (reproduced in Figure A.1). Bernoulli essentially reframed the alternatives into combinations of chances and *ex post* states of wealth. The concavity of the utility function implied risk aversion in probabilistic choices. His state-dependent utility maximization concept fits well with an open-loop control system.



Adapted from diagram in Bernoulli (1738)

Figure A.1: Bernoulli's Expected Utility concept

The Dutch philosopher Spinoza (1632-1677) rejected the existence of different substances in his posthumously published *Ethica* (Spinoza 1677[130]). He posited the identity of one Substance = God = Nature, that has no beginning or end. All material and immaterial objects and concepts are modes, i.e. transitory manifestations of this eternal substance, determined by causal relationships with other modes. Humans and other modes can be characterized by two features or attributes, extension or body and thought or mind, that are not separate entities but two sides of the same reality. All modes strive for self-preservation. Focussing on human choice and behaviour, Spinoza conceives man's driving force as '*reason ... demands that every man should desire everything which really brings man to greater perfection, and should, each for himself, endeavour as far as he can to preserve his own being*' (Spinoza 1997: Ethics IV Prop. 18, Scholium). In a particular context '*we endeavour to bring about whatsoever we conceive to conduce to pleasure; but we endeavour to remove or destroy whatsoever we conceive to be truly repugnant thereto, or to conduce to pain*' (Ethics III Prop. 28[131]). Spinoza considers the feelings[132] of '*pleasure*' and '*pain*' as primary affects of the mind that accompany changes (increases or decreases) in the body's '*power to act*'. Many different context-dependent feelings can be discerned that belong to this aggregate. Perception of everything internal or external to the body that affects it, did so in the past or might do so in the future, arouses desires and other feelings in the mind that might incite different courses of actions. He considers choice (here conceived under '*volitio*') as a mental '*idea*' (concept, element of thought) that immediately precedes and accompanies the actions of the body that aim to satisfy these desires. When a man in such a situation has chosen to follow her desires without further mental consideration this will most often not promote her well-being as these feelings are confused, often incomplete and mutually conflicting. Such a choice is an '*inadequate idea*', i.e. it is an '*opinion*' or '*imagination*', based on sensory perceptions from random experience and/or on association with incomplete ideas from memory (Ethics II Prop. 40). '*Adequate ideas*' based either on '*reason*', i.e. an analysis of the essential characteristics of 'things' perceived followed by logical deduction, or on '*intuition* [133].'

From a systems-theoretical perspective one might describe Spinoza's monist view on choice and behaviour as an implicit descriptive model of a purposeful, functional, context-dependent adaptive system, with the subject's urge for fitness to survive as the driving force, her actual feelings as input for actual, at least partly unconscious choice processes, and with her will to

[130] In this book, Elwes' 1883 English translation is referred to as (Spinoza 1997).

[131] Spinoza (1677) used '*laetitia*', which Elwes translated as '*pleasure*' (Spinoza 1997). '*Happiness*' seems a better translation these days. Likewise, '*Unhappiness*' or '*Sadness*' might be a better match for Spinoza's '*tristitia*' than Elwes' '*pain*'.

[132] Spinoza (1677) uses the same term, '*affectus*', for dispositions of the conscious mind as well as the body. Elwes (Spinoza 1997) translates those of the mind as '*emotions*', those of the body as '*modifications*'. Following Zajonc (1980) and neuroscientist Damasio (2001), '*feelings*' are considered here to relate to the conscious mind, '*emotions*' to the body. One should be aware, however, that many scientists do not make this distinction. Frijda (1999: 190), for example, defines '*emotions*' as '*responses (...) belonging to the domains of subjective experience, behavior, and physiological reaction*' and avoids '*feelings*' but discerns their conscious experience in '*affect*' for the '*hedonic experience of pleasure and pain*', '*appraisal of an object or events*', '*action readiness*' etc. Many psychologists use emotions, feelings and affects indiscriminately to indicate what are termed feelings in this book.

[133] Dutton (2006) considers it difficult to understand what Spinoza means by his '*scientia intuitiva*'. Spinoza explains this as follows under Ethics II-Prop. 40, the only place where the term is used: '*Three numbers are given for finding a fourth, which shall be to the third as the second is to the first. Tradesmen without hesitation multiply the second by the third, and divide the product by the first ... by virtue of the proof of the nineteenth proposition of the seventh book of Euclid. But with very simple numbers ... one, two, three, being given, everyone can see that the fourth proportional is six; and this is much clearer, because we infer the fourth number from an intuitive grasping of the ratio, which the first bears to the second.*' He thus apparently describes the '*intuitive knowledge*' of a heuristic, brought to consciousness in a '*flash of inspiration*'.

perform an actual behaviour that contributes to her ongoing pursuit of happiness as output. However, this radical view of human behaviour did not take root. For a long time Spinoza was despised as an atheist for his monist (essentially pantheist) view on the substance-God-Nature identity and its mind-body attributes. Though he definitely influenced several philosophers (e.g. Hume 1740), his mind-body identity and his explanation for the origin and relevance of conscious feelings, their influence on conscious reasoning and intuition and their impact on human choice and behaviour were rejected by mainstream science. This lasted till the end of the 19th century when the psychologists Wundt, James and Lange 'discovered' anew that conscious feelings correspond to and are preceded by changes in the body, an insight that towards the end of the 20th century found its way into mainstream psychology (e.g. Zajonc 1980) and was in the last decade firmly established in neuroscience (Bechara *et al.* 1997; Damasio 2001; 2003).

A.1.3 British Empiricism

Building on a British empirical tradition in philosophy, Francis Bacon (1561-1630) criticised the deductive reasoning approach of his days that followed untested principles based on intuition: *'Man ... can do and understand so much and so much only as he has observed in fact or in thought of the course of nature. ... There are and can be only two ways of searching into and discovering truth. The one flies from the senses and particulars to the most general axioms, and from these principles, the truth of which it takes for settled and immovable, proceeds to judgment and to the discovery of middle axioms. And this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untried*' (Bacon 1620: Aphorism I, XIX). Elsewhere he rigorously rejected chance and the existence of a human 'will' detached from reason as an explanation for human behaviour and prescribes a strict rational analysis of cause and effect instead (e.g. Durant 1962).

His fellow-Englishman Thomas Hobbes (1588-1679) saw humans as selfish individuals that are prepared to fight for their fitness to survive and their happiness, the latter by the acquisition of as many goods as possible: '*Continual success in obtaining those things which a man from time to time desireth ... is that men call felicity*' (Hobbes 1660: Chapter VI). This would result in a '*war of all against all*' that can only be avoided because of people's '*fear of death; desire of such things as are necessary to commodious living; and a hope by their industry to obtain them*' (Chapter XIII).

Both Bacon and Hobbes are considered early exponents of British empiricism, culminating in David Hume's (1711-1776) radical rejection of any '*substance*' of the soul. Distributed over his '*Treatise of Human Nature*' (Hume 1740) one finds another coherent concept of human choice and behaviour. He considered behaviour (actions, motion of the body) as motivated, purposeful, context-dependent and guided by conscious reasoning: '*We are conscious, that we ourselves, in **adapting means to ends**, are guided by **reason** and design, and that it is not ignorantly nor casually we perform those **actions**, which tend to **self-preservation**, to **obtaining pleasure**, and **avoiding pain***' (Hume 1740: Book I Part III Sect. XVI, emphasis added). Affective feelings are the motives that determine the context-dependent choice between alternative behaviour or actions: '*It is obvious, that when we have the **prospect of pain or pleasure** from any object, we feel a consequent **emotion of aversion or propensity***' (II.III.III); '*inferences concerning **human actions** ... are founded on the experienced union of **like actions** with **like motives** and **circumstances***' (II.III.I). Hume discerned '*intuition*' and '*mathematics*' as elements of conscious reasoning. This reasoning is just a way to '*calculate*' the actions that are expected to be most appropriate in view of the prevailing mixture of motives ('*passions*' like '*ambition, vanity, desire, aversion,*

grief, joy, hope, fear' (II.III.I): '*Reason is, and ought only to be the slave of the passions, and can never pretend to any other office than to serve and obey them*' (II.III.III)[134]. He rejected '*the fundamental principle of the atheism of Spinoza (which) is the doctrine of the simplicity of the universe*' (I.IV.V) but it is easy to see that his view on choice and behaviour is very close to Spinoza's. From Hume onwards up until the 20th century mainstream philosophy adhered to the view that conscious reasoning should order human motives and govern successive human actions.

A.1.4 Utilitarianism

Joseph Priestley (1733-1804) is well known for his book '*Treatise on Government*' (Priestley 1768). In this book he stated that '*The good and happiness of the members, that is the majority of the members of the state, is the great standard by which every thing relating to that state must finally be determined.*' Later on he asked Benjamin Franklin (1706-1790) to advise him on how one might arrive at a sound, rational choice in complex matters. In his famous 'Moral Algebra' letter Franklin (1772) replied: '*my way is to divide half a sheet of paper by a line into two columns, writing over the one Pro, and over the other Con. Then during three or four Days Consideration I put down under the different heads short hints of the different motives that at different Times occur to me for or against the measure. When I have thus got them all together in one view, I endeavor to estimate their respective weights; and where I find two, one on each side, that seem equal, I strike them both out … and thus proceeding I find at length where the balance lies; and … I come to a determination accordingly*'. This is equal to the compensatory Weighted-additive rule, which is the most commonly assumed decision rule to date.

Bentham (1748-1832) called Priestley's proposition initially the '***principle of utility***' (Bentham 1789: Ch. I, his emphasis), though he later added a note that it could be better replaced or supplemented by '*the greatest **happiness** or **felicity** principle*' as '*the word **utility** does not so clearly point to the ideas of **pleasure** and pain*'. He listed the following denominations of pleasures: '***good** (which is properly the cause or instrument of pleasure) or **profit** (which is distant pleasure, or the cause or instrument of it) or **convenience**, or **advantage**, **benefit**, **emolument**, **happiness**, and so forth*' and of pains: '*whether it be called **evil** (which corresponds to **good**), or **mischief**, or **inconvenience**, or **disadvantage**, or **loss**, or **unhappiness**, and so forth.*' The absence of the possession of goods in its materialistic meaning is meaningful, as this distinguishes his concept from Bernoulli's utility concept.

Successively Bentham (Ch. IV, his emphasis) proposed a method to quantify the effects of government policy in terms of an objectively measurable happiness: '*Pleasures then, and the avoidance of pains, are the **ends** that the legislator has in view; it behoves him therefore to understand their **value***'. He considered that the value of a particular pain or pleasure as experienced by an individual depends on its expected intensity, duration, chance (certainty or degree of uncertainty) and nearness or remoteness. When the expected effects of an act on the happiness of a population are assessed, the value for the chance that the initial experienced pleasure is followed by more pleasure or pain, and vice versa, should be added to the value of that initial

[134] He considered that reasoning can only lead to certainty in relationships in terms of '*resemblance, contrariety and **degrees in quality**'*, which '*are discoverable at first sight, and fall more properly under the province of **intuition** than demonstration*', and of relationships in terms of '*proportions in quantity and number*' that are based on intuition or mathematical deduction and calculation. Reasoning can only lead to probabilities of '*identity, relations of time, and causation*' (Hume 1740: I.III.I, emphasis added). From Hume's successive explanation it follows that he considered the individual's judgment of attributes of objects like heat or taste as intuitive knowledge mapped on a qualitative, ordinal hedonic scale that cannot be mapped on a quantitative, ratio scale. Recently this limitation of human choice behaviour was discussed extensively by Kahneman and Frederick (2002).

experience, after which the individual overall values should be multiplied by the number of people that are equally affected by the act. Summarizing, to assess the overall effect of an act on the interests of a community a compensatory, linear-additive composition of the individual experienced values should be followed.

A.1.5 The Nature versus Nurture debate in the 18th and 19th Century

It is often posited that, according to Continental rationalism, human reason could be the source of all knowledge whilst at the same time, following British empiricism, all knowledge should be based on experience. The German philosopher Immanuel Kant (1724-1804) proposed a compromise between both traditions and also suggested that people should apply some general applicable, ethical 'laws' both in judgment and choice (e.g. Störig 1982). Later philosophers, however, kept on discussing and developing theories about the origin of knowledge and the character of the mind, particularly whether or not the conscious mind has innate knowledge (the 'Nature' view) or should be considered as a 'clean slate' at birth (the 'Nurture' position). The proposed theories often reflect the religious beliefs of their inventors and the degree to which they want to stay at peace with religious and civil authorities. Notwithstanding these differences, almost all these philosophers conceived the soul or mind as identical to consciousness. Focussing on their views of everyday human choice and behaviour it is hard to see major differences, particularly in the sequence Hobbes – Spinoza – Hume – Bentham.

A.1.6 Early Economics

Bentham's approach to calculating a 'cardinal happiness' of populations was not followed in economics, in which Adam Smith (1723-1798) had just defined the '*real value*' of commodities and labour: '*labour, like commodities, may be said to have a real and a nominal price. Its real price may be said to consist in the quantity of the necessaries and conveniences of life which are given for it; its nominal price, in the quantity of money*' (Smith 1776: I.V). Smith and later economists of the 'classical' school considered that this real value was determined by the production costs of the commodity. However, in the course of the 19th century scientists from several countries considered that the real value of a good depends on the one hand on the subjective scarcity of it as perceived by the consumers and on the other on their desire to acquire it (say the utility). Within this supply-and-demand approach to consumer behaviour, Bernoulli's (1738) 'diminishing marginal utility' concept was extended with the notion that the demand of consumers follows the principle that '*The magnitude of each single pleasure at the moment when its enjoyment is broken off shall be the same for all pleasures*' (Gossen 1854: Second Law). Later several scientists arrived at almost the same view that was codified in the first textbook of neo-classical economics in which Marshall (1890: III.III.1, his emphasis) defined the neo-classical utility notion as: '***diminishing utility****: The* ***total utility*** *of a thing to anyone (that is, the total pleasure or other benefit it yields him) increases with every increase in his stock of it, but not as fast as his stock increases*'). Thus Bernoulli's idea that happiness increases with any increase in wealth or material goods was taken for granted, without empirical support. This utility concept does not require the direct assessment of a cardinal happiness measure and thus differs clearly from Bentham's '*greatest happiness*' principle, though it is often referred to as such.

A.1.7 Early Psychology

In the course of the 19th Century psychology developed into a separate scientific discipline. An early empirical-quantitative finding was the just noticeable difference principle found by Weber (1834): the threshold for the mental perception of a small difference in a stimulus

increases proportional to the increase in its physical intensity. Later on, Fechner (1860) generalized this to his law that perception is directly proportional to the logarithm of stimulus intensity. Though Weber's and Fechner's laws describe only empirical findings they have proved to be quite useful to date in practical applications, like noise hindrance measurement and control. One might note that earlier Bernoulli (1738) intuitively proposed the same relationship between utility and wealth.
With respect to judgment and choice the early psychologists '*defined psychology as "the study of mind and consciousness" and used the introspective method to study consciousness (until) the early 1900s*' (Atkinson *et al.* 1983: 166). This holds for the Voluntarism approach of the German Wundt (1874), the 'father' of psychology as a science, as well as for the Functionalism school of James (1890).

Wundt (1896: 262) who, like Fechner, referred to Spinoza's view of mind and body as different features of the same reality, observed that feelings ('*Gefühlselemente*') appear in consciousness following physical bodily changes caused by external or internal phenomena, before the perception of their characteristics ('*ehe noch von den Vorstellingselementen irgend etwas wahrgenommen wird*'). He conceived reasoning as a creative mental process that relates these feelings and successive perceptions to existing '*ideas*' in memory, resulting in a choice ('*volition*') which gives rise to '*volitional acts*' or motivated behaviour. This might be impulsive or could become automatic over time, but might also comprise complex decisions and acts that require great mental effort.

In his description of the function of the mind, James (1890: 13, 20, 78, his emphasis) suggested that '*the criterion of mind's existence (is) the choice of the proper means for the attainment of a supposed end*'; '***the hemispheres act from perceptions and considerations***. *But what are perceptions but sensations grouped together? and what are considerations but expectations, in the fancy, of sensations which will be felt one way or another according as action takes this course or that?*'; '*The consciousness must everywhere* ***prefer*** *some of the sensations which it gets to others; and if it can remember these in their absence, however dimly, they must be its ends of desire. If, moreover, it can identify in memory any motor discharges which may have led to such* ***ends****, and associate the latter with them, then these motor discharges themselves may in turn become desired as* ***means****. This is the development of* ***will****; and its realization must of course be proportional to the possible complication of the consciousness*'. The latter quotation like many other passages in his book underlines the importance that James attached to the purposefulness of behaviour as a means to an end.

A.1.8 Synthesis: The Rationalist's paradigm at the dawn of the 20th century

Refraining from metaphysics and different opinions on *how* the mind works there appears to be a common view on what the mind does with respect to human choice and behaviour. When we sketch this Rationalist's paradigm that reigned at the threshold of the 20th century in systems-theoretical terms we see a free, autonomous, conscious, literally 'reasonable' mind that acts as the 'controller' that guides the 'machine' or 'plant' of the human body to attain happiness (Figure A.2). The inputs to the mind consist of facts and feelings, i.e. mental representations of measurable characteristics and affects, passions and desires. One category of these consists of the experienced characteristics of objects (creatures or material goods) and experienced changes in the person's 'own' body as observed concurrently by the body's senses, and another category concerned with experiences retrieved from memory. Choice behaviour is the conscious reasoning that transforms the feelings associated with the expected results of different behaviours (courses of action by the body) into the choice (volition, will)

of an alternative behaviour that offers the highest expected cardinal utility as a consequence of the expected state of wealth. The realized change in wealth as expressed in terms of cardinal utility is considered to be proportional to the change in the subject's happiness. Most prominent in Figure A.2 is the absence of feedback loops, thus in control theoretical terms this paradigm is an open-loop controller.

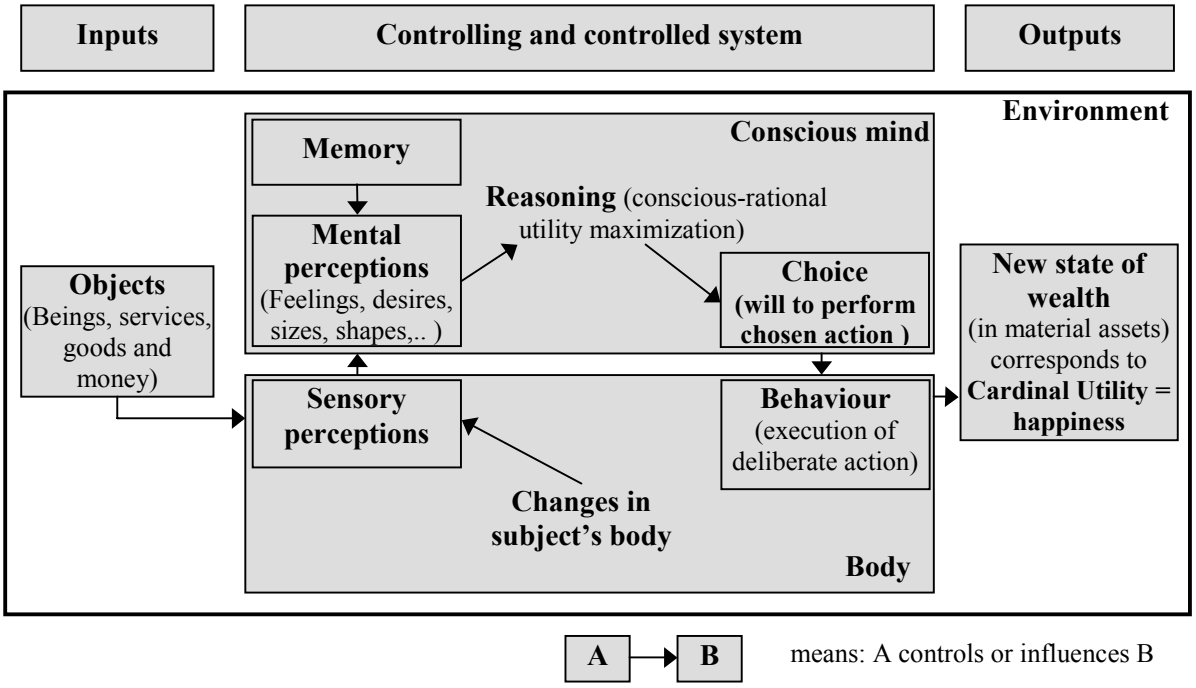


Figure A.2: The Rationalist's paradigm of choice and behaviour

One might note that the assumed causal relationships lack empirical validation. This holds, for example, for the conviction that a person's happiness (a mental experience) is proportional to her state of wealth in terms of materialistic goods. The diagram also shows other unsolved problems of how body and mind interact. The functioning of the subject as a whole requires some apparently unconscious transformation of the physical sensory perceptions of objects in the body's environment, into mental representations in terms of feelings and affective 'values'. Also the explanation of how the mind or will controls the behaviour of the body is missing.

A.2 The Behaviorist's paradigm (1900 – 1960)

The rise of behaviourism in psychology meant a drastic rejection of the Rationalist's paradigm. This paradigm shift was preceded by the successful application of a descriptive approach in the study of animal behaviour, based on objective observation in experimental and real-life circumstances. Another reason may be that neither psychology nor economics thus far were able to answer the fundamental questions about the co-operation of body and mind that arose when Descartes (1642) introduced the body-mind dichotomy. Behaviourism took a clear monist view of the mind-body relationship and disregarded mental phenomena.

A.2.1 Behaviourism

Watson (1913: 162; 165; 173), who started his career as a student of animal behaviour, was convinced that the study of the conscious mind by introspection had come to a dead end and stated: '*The time seems to have come when psychology must discard all reference to consciousness;*

Never use the terms consciousness, mental states, mind, content, introspectively verifiable, imagery, and the like; Psychology, as the behaviourist views it, is a purely objective experimental branch of natural science which needs introspection as little as do the sciences of chemistry and physics'. Inspired by the famous salivation experiments of Pavlov, psychologists started to study the observable response of animals to stimuli and found that after '*respondent conditioning*' a principally irrelevant stimulus, like ringing a bell, can initiate a reflex (e.g. salivation of a dog) even if the relevant stimulus, for example the scent of food, is not applied.

Skinner, who became the most cited psychologist of the 20th century, found that animals soon learned a particular behaviour (like pressing one particular lever out of two to obtain food) if they were rewarded (got food) when they showed the desired behaviour (pressing the right lever) and not rewarded (got no food) when they showed the wrong behaviour (pressing the wrong lever or not pressing any lever) (e.g. Skinner 1950). This '*operant conditioning*' can be conceived as '*habit formation by the method of "prize and punishment"*' (Konorski and Miller 1937: 264). Such findings from experiments reinforced the belief that free will is an illusion and that the environment determines all behaviour. Of course, the effectiveness of the stimuli depends on the innate '*preferences*' of the species at hand for different kinds of rewards. In the dominant Skinnerian interpretation of behaviourism choice is no longer the purposeful, goal-oriented selection of means to an end but purely a reactive response.

A.2.2 Decline and revival of Neoclassical Economics

Towards the end of the 19th century the neoclassical approach to economics lost influence, mainly because the unspecified, measureless utility concept and its connotation with the even vaguer, subjective happiness conflicted with the contemporary 'scientific' aspirations of the economic community.

In the wake of behaviourism neoclassical economists strove to '*develop the theory of consumer behaviour freed from any vestigial traces of the utility concept*' (Samuelson 1938: 71). In the 1930s this resulted in the '*ordinal utility*' concept of Hicks (1939) and the intrinsically equal '*revealed preference*' theory of Samuelson. Utility Theory was now stripped from cardinal utility with its hedonic and ideological connotation. Though the new neoclassical approach still assumed that the consumers maximise their utility (under budget constraints) and its 'diminishing marginal rate of substitution' principle reflected Bernoulli's (1738) diminishing marginal utility, adherence to these principles was now empirically demonstrable.

In this guise the Neoclassical Utility (or Consumer) Theory soon became the dominant approach in microeconomics. According to this theory consumers are assumed to maximize an ordinal utility corresponding to an idiosyncratic, predetermined rational preference order for quantities and attributes of any goods they perceive. These preferences are innate, temporally stable and independent of choice set composition, the way the alternatives are described, and other contextual influences. Expected Utility Theory and Game Theory, both developed in the 1940s by Von Neumann and Morgenstern (1944), to cope with probabilistic outcomes and negotiations between subjects, are founded on similar principles. Though these latter theories adhere to the cardinal utility concept, '*happiness*' is commonly expressed in money terms.

A.2.3 Synthesis: The Behaviorist's paradigm of choice and behaviour

One might note that the neo-classical concept of choice behaviour in microeconomics is a rather 'automatic' response of individuals to the goods and opportunities available in the environment. Consumers are assumed to rate the available alternatives rationally by

comparison with their 'innate', fixed preference order and to 'calculate' what alternative yields the highest expected contribution to their interests. This approach is close to the 'learned response' as conceived in Skinnerian behaviourism. Consequently, choice is not the consequence of situation-dependent, deliberate judgment and reasoning.

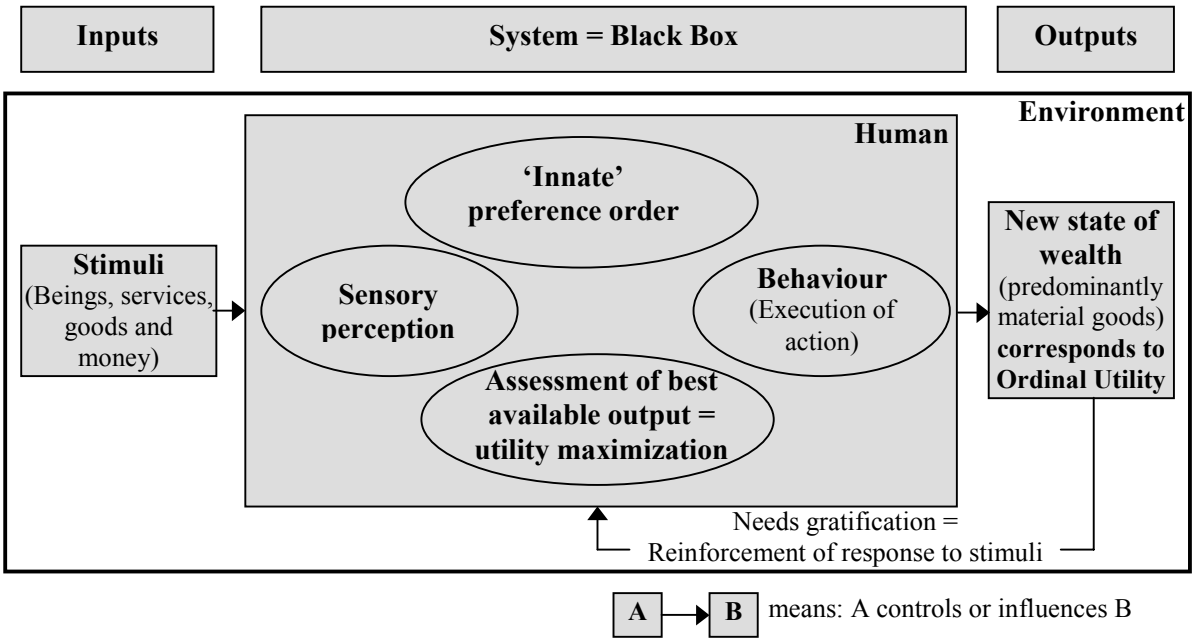


Figure A.3: The Behaviorist's paradigm of choice-and-behaviour

Thus the mind as controller and happiness as the final outcome disappeared in the 1950s in mainstream psychology as well as in microeconomics. In systems-theoretical terms, choice is a covert process in the black box that generates behaviour (see Figure A.3). This accounts for the transformation of stimuli in needs gratification. It is essentially an open-loop system, containing a reactive process of behaviour with a measurable output in terms of material assets.

A.3 The Cognitivist's paradigm (1960 – present)

Though behaviourism dominated economics and psychological science in the first half of the 20th century, several other approaches flourished as well. This period saw the birth of Psychoanalysis, that directed attention to the importance of the unconscious mind, Gestalt Psychology with its accentuation on mental perception and holism, Social Psychology that studied the behaviour of individuals in social environments, and Organizational Studies, concerned with individuals and groups of people within organizations. These movements and new sciences were heralds of the ever-increasing post-1950s surge of new disciplines, theories and schools within social and behavioural sciences.

A.3.1 Motivation theory

Even in the heyday of behaviourism several researchers of animal and human behaviour disagreed with the neglect of the purposeful nature of living beings by mainstream behaviourism. Based on his studies of the learning behaviour of rats Tolman (1938) demonstrated the context and motivation-dependent, purposeful nature of behaviour, although his attempts to put mental processes back on the Behaviorist's agenda were no match in those days for Skinner's power of persuasion (Skinner 1950).

Maslow (1954: 19, 3, 29 and 24), who started his career as a behaviourist[135], stated his guiding principles as follows: '*Our first proposition states that the individual is an integrated, organized whole*'. Contrary to psycho-analysis, he emphasized the complementary nature of conscious and unconscious mental processes: '*in the healthy human being, rationality and impulse are synergic, and strongly tend to come to similar conclusions rather than contrasting ones. The nonrational is not necessarily irrational or antirational; it is more often prorational. A chronic discrepancy or antagonism between conation and cognition is usually itself a product of social or individual pathology*'. He placed the context-dependant, goal-oriented nature of human choice behaviour on the drawing board of humanistic psychology: '*Behaviour is determined by several classes of determinants, of which motivation is one and environmental factors is another*'. Maslow thought that people are motivated to satisfy five classes of basic needs that are arranged in a hierarchy. All wants and desires that motivate behaviour in a particular context can be attributed to these basic needs. Once a person's behaviour results in the gratification of such a want there is a moment of happiness or joy but '*man is a wanting animal… As one desire is satisfied, another pops up to take its place*'.

There is little discussion about the primacy of Maslow's Physiological needs and Safety needs once any of these is severely unsatisfied, but though the satisfaction of the 'higher' needs (Belongingness & love, Esteem and Self-actualization) might strongly affect the happiness of any subject these are hardly considered in microeconomics and decision theory. Though his scientific research was strongly criticized by fellow psychologists, variations on his '*hierarchy of basic needs*' can be found in most modern textbooks of sociology and management science. In Decision Theory needs, motives and goals receive little attention but a listing of wants in a recent book review clearly reflects Maslow's hierarchy: '*decision makers want to be safe and healthy , …[have] fulfilling relationships, …to experience some successes in the domains of education, career pursuits, personal development, and leisure activities*' (Nickerson 2004: 203).

A.3.2 Microeconomics

Neo-classical Utility Theory has been the canonical choice behaviour paradigm in mainstream microeconomics from the 1940s to date. However, for discrete choices it was extended into Random Utility Maximization by allowing for interpersonal differences and unobserved attributes in the assessment of idiosyncratic preference orders. Many theoretical additions and improvements to these theories have been proposed but few have found their way into mainstream microeconomics. New findings from social sciences are commonly accommodated by calibrating model parameters to experimental findings.

Maybe influenced by Maslow, Georgescu-Roegen (1954) introduced the concept of a hierarchy of wants into economics. He associated it with a lexicographic preference order, which was further elaborated by Encarnación (1964). These views gained no hold in mainstream economics but in judgment and decision-making research several lexicographic decision rules were demonstrated.

One might consider that, instead of following context-independent preferences or ordered wants, people might trade-off their wants against the concurrent opportunities available in their environment to arrive at aspiration levels for their gratification. Focussing on such aspirations rather than demands, Simon (1955) posited that both humans and their

[135] As might be understood by the citations in this text and was stated by Maslow himself, he was much influenced by the Gestalt Psychology school that originated in Central Europe in the early 20th century.

organizations more often than not choose the first acceptable or satisficing alternative encountered instead of 'calculating' the highest preference or utility. He proposed a version of the non-compensatory, conjunctive elimination rule to implement this principle. Later on a host of particularizations and combinations of lexicographic and Attribute-based Elimination rules were proposed by other researchers. The application of such rules by individuals has been demonstrated in many choice experiments and from real-life behaviour, particularly in decision theory and marketing. Which rules are applied appears to depend on the context of the choice process, pressure of time and so forth.

After Von Neumann and Morgenstern (1944) had elaborated Expected Utility Theory for choosing between probabilistic alternatives it appeared that in some cases people violated the transitivity principle (e.g. Allais 1953). Markowitz (1952) demonstrated that this could be explained if people valued losses differently, i.e. more highly than gains of the same size. Savage (1954) attributed the observed violations to errors of the subjects. Later on, several empirical formulae that accounted for subjective probability weights were proposed (e.g. Machina 1987). The most well known is Prospect Theory in which Kahneman and Tversky (1979) combined weighted probabilities and loss aversion. They also showed that people frame their alternatives depending on the context of the decision, and do so in terms of changes with respect to a reference state. This theory was later extended to other choice categories (Tversky and Kahneman 1991; 1992) and became the backbone of behavioural economics.

A.3.3 Happiness revisited

In the 1960s some psychologists resumed the study of happiness. To allow for empirical research and to circumvent Bentham's (1789) problem of the quantification of the 'immeasurable' pains and pleasures, Bradburn (1969) investigated people's self-reports of happiness, which became the standard method for studies of '*subjective well-being*' in economics (e.g. Frey and Stutzer 2002), hedonic psychology (e.g. Kahneman *et al.* 1999a) and sociology (e.g. Veenhoven 2000). It is assessed as the individual's mapping of her overall happiness and/or life satisfaction on a qualitative scale. In the Eurobarometer surveys, for instance, the subjective well-being of representative samples of the populations of all member states is annually assessed as the answer to the question '*Taking all things together, how would you say things are these days – would you say you're very happy, fairly happy, or not too happy these days?*'. Following Veenhoven (2003: 128), happiness or subjective well-being, which implies fitness to survive, might be considered as the end or final outcome of the human choice-and-behaviour system as a whole: '*happiness is an outcome of life and distinct from preconditions for a good life*'.

It was repeatedly shown that on a societal level, income above a certain level hardly adds to happiness (Easterlin 1974; Hagerty and Veenhoven 2003). A widespread saying is that 'money can't buy happiness' but according to Myers (1993), to mention just one social psychologist who studied the matter, most people apparently believe that in their particular case a little more money will make them a little happier. These observations leave little doubt that in everyday choice and behaviour people are not striving to maximize their 'subjective happiness' or cardinal utility in Bentham's meaning, though some present-day authors propose reinstating this (e.g. Frey and Stutzer 2002; Ng 2003). Subjective well-being in terms of overall happiness or life satisfaction could be better considered as the final outcome rather than as an output of human choice behaviour. However, one might note that, aggregated to the national level, it fits perfectly with Bentham's '*greatest happiness*' objective of government policy.

The operational choice behaviour of humans appears to be rather opportunistic and myopic (see e.g. Payne *et al.* 1993; Benartzi and Thaler 1995; Slovic 1995; Payne *et al.* 1999). Individuals typically pursue the more myopic 'instantaneous' though transient pleasures, circumscribed by Myers (1993: 51-52) as: '*Better than a high income is a rising income. If we get a pay rise ... we feel an initial surge of pleasure. But if these new realities continue, we adapt*'. Obviously people will likewise try to prevent unhappiness caused by deteriorations. This change-oriented consideration of the expected consequences of behaviour is consistent with the view of many scientists, from Spinoza (1677) to Frijda (1988), the latter as cited by Myers (1993: 53): '*pleasure is always contingent upon change and disappears with continuous satisfaction*'.

The outputs of the choice-and-behaviour process in relation to the neo-classical interpretation of utility is thus better understood in terms of the value of the subject's assets, i.e. money, another medium (Hsee *et al.* 2003), services or material goods. The utility that results from a particular alternative is determined by the hedonic value of the change [136] in assets rather than by the value of the new state of assets. This is consistent with the change-oriented framing principle of Prospect Theory. Another finding from recent research is that, in addition to the hedonic experience of the change in assets, the experiences gained from the actions to acquire them also contribute to the happiness of the subject, see e.g. Argyle (1999: 364): '*The greatest satisfaction comes from activities where challenges are met by skills, producing a state of "flow"*'; see also popular reading (e.g. Metz 2002). There is ample psychological literature that these affective experiences are often better remembered than the associated changes in assets and therefore may influence both operational and strategic choice behaviour (e.g. Kahneman 1999; Slovic *et al.* 2002).

A.3.4 The rise and dominance of cognitivism

In the 1950s many scientists were fascinated by the promises that the fast development of computers implied for the future. This led to an approach in which humans were compared to information processing systems[137]. Roughly speaking, the senses are input channels for information that is transformed by mental operations, the results of which are stored in the memory that, when required, is also consulted for additional information to arrive at an output in terms of a response to the input signal. Together with some colleagues Herbert Simon, among others, developed computer simulations of several psychological processes.

Another important development was Noam Chomsky's findings from linguistic research that convinced him that humans have a genetically determined mental capability for the understanding and handling of language, though they are unconscious of these cognitive abilities. This conviction was reflected in his critical review of Skinner's behavioural theory of language (Chomsky 1959) that heralded the end of the dominance of behaviourism.

The cognitivist's approach assumes that cognition consists of mental representations that are manipulated according to rules or routines. These mental phenomena exist and should be studied, whether or not the subject is consciously aware of them. Cognitivism rejects the method of introspection as by definition this can only reveal a part of the cognitions. Like behaviourism, it starts from the belief that psychological research should only employ

[136] One might note that Bernoulli's 'verbal model' also draws on changes: the value of a risk should be determined by giving consideration to '*the utility of whatever gain accrues to the individual or, conversely, how much profit is required to yield a given utility*' (Bernoulli 1738: 24). It is only in his mathematical derivation that he considers solely the final state of assets.

[137] See, for example, the title of the article: '*The Mind as the Software of the Brain*' (Block 1995).

experiments, measurements, hypothesis formulation and other elements of the scientific method. In the late 20th century this paradigm dominated not only cognitive but also social psychology.

An important development in social psychology was the development of Attitude Theory and its successors (Fishbein 1963; Ajzen and Fishbein 1980; Ajzen 1991). These theories presume that people process the available information in a rational, systematic way to arrive at a consistent relationship between their beliefs about the outcomes of a course of action and the '*behavioural intention*' (e.g. 'I will stop smoking from now on') to perform the successive actual behaviour. One might conceive the behavioural intention as a deliberate strategic decision that influences many successive conscious or unconscious follow-up choices to put them into operation. A similar distinction between strategic decision making and operational choice is observed in several other fields like travel behaviour research (e.g. Gärling *et al.* 2002).

An example of the 'rules' by which mental representations are manipulated are the heuristic rules that were experimentally demonstrated in the 1970s (Tversky and Kahneman 1974). These are employed when people have no accessibility to adequate knowledge in a situation where they have to assess or judge the attributes of alternatives. This may cause biases in the judgment compared to rational assessments. Kahneman later described heuristics as the substitution of attributes of alternatives, for example when the average pain over a certain period is substituted by a similar attribute that is more easily recalled from memory, such as the highest experience of pain. In social psychology it was reconfirmed that in the judgment of alternatives and attributes feelings play an important role (e.g. Zajonc 1980). This may explain why the loss of an object that is in someone's possession is valued much more highly than the money she was once prepared to pay for its acquirement. Other scientists found similar violations of utility maximization principles in actual choice behaviour, like regret avoidance.

A.3.5 Management science

Until the 1960s the Rational Decision-Making model was the dominant concept for decision making in organisations. A typical materialization of it is the seven-step process described in the contemporary management textbook of Hellriegel *et al.* (1999): '*a. Define and diagnose the problem; b. Set goals; c. Search for alternative solutions; d. Compare and evaluate them; e. Choose among them; f. Implement the solution selected; g. Follow up and control*'. Several other versions of this model have been suggested, mostly involving the splitting up or combining of one or more steps. Originally, these steps should have been followed in a fixed order. In this classical normative interpretation it assumes an omniscient decision maker, who knows probabilities rather than experiences uncertainties, who has an unbounded computational power and has a stable preference-order of possible outcomes of decisions (Simon 1955). The Bounded Rational Decision-Making model of management science as proposed by Simon (1960) aims at a closer similarity between described and observed choices. It discerns three steps: '*i. Intelligence: finding occasions calling for a decision. ii. Design: inventing, developing and analyzing possible courses of action. iii. Choice: selecting a particular course of action from those available.*' It is not hard to see that these steps can be found by an aggregation of the steps in the rational model[138]. However, the steps may be taken in a partly iterative way, including a renewed search for information at any moment in the process when this seems required, as is often

[138] In later editions of this book Simon added a fourth step, '*Review*', that covers steps f. and g. of the rational model.

observed within organizations (e.g. Pen 2000[139]; 2002). Bounded rationality adheres to the idea that the manager may accept the first satisficing outcome: as soon as she discovers an alternative that meets this aspiration level it is chosen and the search for alternatives is stopped.

After Simon's seminal articles the traditional approach to what a manager should do was gradually extended with behavioural and system dynamical elements into the contingency approach which is the dominant viewpoint on management these days. Mintzberg (1989) observed American managers in the 1970s. He describes how they collect huge quantities of predominantly 'soft' information, and make a decision based on unconscious-intuitive synthesizing of this information rather than by logic-analytic reasoning.

A.3.6 Neuroscience

Originally, many cognitive scientists conceived that human information processing followed the 'rational' rules of logic, either by deliberate, conscious rational thinking or by unconsciously following rules or habits that were based on the automation of previously conscious deliberations. But from the 1980s onwards a growing number of social and cognitive psychologists became convinced that people employ at least one other kind of reasoning. Many of these 'dual-mode' hypotheses of reasoning were assembled by Stanovich and West (2000) in two mental 'systems', which they indicated as: '***System 1*** *is characterized as automatic, largely unconscious, and relatively undemanding of computational capacity ...* ***System 2*** *... encompasses the processes of analytic intelligence ... Construals triggered by System 1 are highly contextualized, personalized and socialized ... System 2's more controlled processes serve to decontextualize and depersonalize problems*.'

The impressive progress in neuroscience during the last decade, which, for example, made it possible to map the transformation of physical stimuli of the senses into mental representations almost completely onto the nervous system, yields increasing evidence for a System 1 – System 2 distinction (e.g. Bechara *et al.* 1997). Though evidence thus far is circumstantial rather than irrefutable, the systems seem to differ in the way in which information is processed (unconscious, automatic, parallel, …, versus conscious, controlled, sequential, …) and can be mapped onto physical and chemical processes and circuits in different parts of the brain (e.g. Lieberman *et al.* 2002). The new field of Decision Neuroscience aims to study the neurological processes of individuals engaged in choice tasks (Shiv *et al.* 2005). It may be just a matter of time before neuroscience has unravelled the neurological processes that constitute human choice behaviour.

Thus far, neuroscience appears to support the important role of feelings and unconscious System 1 reasoning compared to the complementary rather than dominant character of System 2 (e.g. Lieberman *et al.* 2002; Bechara and Damasio 2005), as earlier posited by many psychologists (e.g. Maslow 1954; Zajonc 1980). It also confirms the concepts of Spinoza (1677), Wundt (1874) and James (1890) who considered mental and bodily phenomena as two 'views' of the same process (e.g. Damasio 2001; 2003), at the expense of the body-mind dichotomy that dominated philosophy and psychology from Descartes (1642) onwards.

[139] Pen identified seven phases in a firm-relocation decision-making study of almost 200 firms in the Netherlands, of which *Identification and Diagnosis* might be attributed to Simons step i; *Search, Development and Evaluation* to step ii; and *Strategy and Implementation* to step iii. Firms discerned at least three and at most seven phases, and each firm followed one or more phases in each of Simon's three steps.

A.4 Synthesis: an early 21st century paradigm of choice and behaviour

When the recent findings about choice and behaviour are assembled in a systems-theoretical diagram one has to realize that both the mind-body dichotomy and the black box concept are too simple to characterize the functioning of the subject. On the other hand the knowledge about *how* conscious and unconscious mental, physiological, physical and chemical processes within the body interact is insufficient for a proper description. However, much information is available about *what* humans do in terms of choice and behaviour. Taking it for granted that mind and body are features of one organism that acts as one organized whole, one might discern several functions of it that are involved in choice and behaviour. One of these may be called mental perception, that transforms the essentially physical sensory information about the outside world and the body into mental representations and arranges for the communication (storage and retrieval) with memory. Another is strategic decision making that results in decisions (plans, scripts, behavioural intentions) with respect to operational choice behaviour. A third one is operational mental choice behaviour that precedes (or accompanies) the concrete actions of the body and judges and evaluates actual contextual information (the environment and body) and contextually relevant strategic decisions. When this is required for the progress of a particular choice process, whether concerning strategic decision making or operational choice behaviour, these functions can initiate an information search at any moment in the process. A fourth function is the concrete execution of the chosen actions. In connection these four functions and their interrelationships arrange for the interaction between the human being and the world.

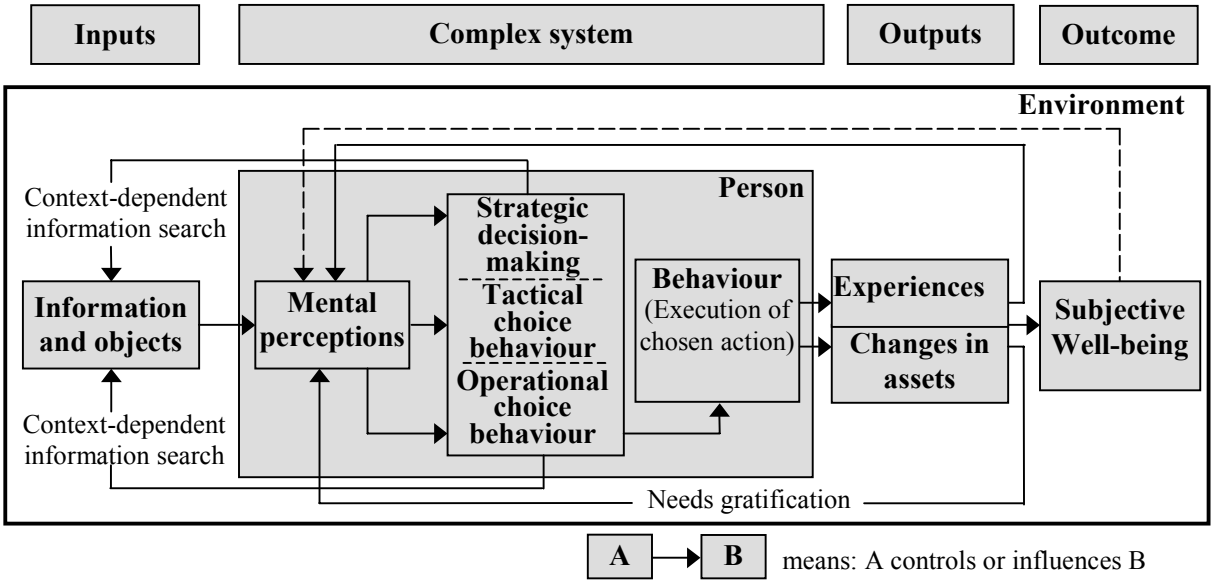


Figure A.4: The Cognitivist's paradigm of choice and behaviour

Improving its subjective well-being, which presupposes fitness to survive, is considered as the purpose or final outcome of this system. However, even though one might assume that there is weak feedback to mental perceptions it does not directly influence its concrete social and economic behaviours. Concrete decisions and choices are motivated by more myopic objectives, notably expectations of hedonic experiences. These are '*expected utilities*' or '*decision values*' due to changes in assets as well as experienced during the execution of the chosen action. During and following action completion the actual experiences are fed back to the subject by transformation into mental representations that are stored in memory. The

context-dependent search process, initiated during concrete decision making and/or choice behaviour, arranges for the feedback to the inputs.

The preceding notions are assembled in Figure A.4. The diagram depicts an actual interpretation of the Cognitivist's paradigm. In systems-theoretical terms, this view of human behaviour is conceived as a set of functions, executed by a complex system, which together account for the interaction between the organism and its environment. As far as one might speak of 'response' this is a stimulus-organism-response system that accounts for both the organism's needs and the environmental stimuli. From this it seems clear that any human behaviour is determined by the momentary state of the substructures of the organism as well as by its perception of the concurrent environment. This underlines the context dependency of human behaviour.

Annex B
Elicitation of decision rules from aggregated outcomes

This annex analyses whether it is possible to infer the use of different decision rules within a survey population from aggregated responses. The analyses draw on the postulate that most individuals are generally consistent in their within-context choice behaviour and thus will follow a once-chosen choice behaviour strategy as long as it works out well.

B.1 The stated choice survey results

The postulate is applied to the analyses of the stated inclinations of a representative sample of the Dutch grown-up population (1054 persons, age 18+) as expressed in nine consecutive choices. The choices were between staying with the incumbent provider or switching to another health insurance company, depending on the differences in the insurance conditions offered, as recently reported in a Dutch newspaper (Van Eijk 2004).

The correctness of the newspaper conclusions in view of the survey design is not the topic of discussion here. The responses to the different choice sets are considered as revealed choice decisions. Obviously one could make stronger inferences about the decision rules employed by respondents by analysing their individual response sequences. However, as often only aggregated information is kept from past surveys and in view of the primarily expository character of this annex no attempt was made to recover these individual responses. Moreover, it is assumed that all respondents interpret the measures Δe, Δq and Δp (see Table B.1) to be of equal magnitude though on different scales and that they assigned idiosyncratic decision weights to attributes to arrange for commensuration where appropriate. Of course, possible interpersonal differences in framing, valuation and the decision weights of attributes are considered.

Nine choice sets were presented to the survey population. Each consisted of the insurance package of the incumbent provider and a package of 'another' provider. The 'other' package differed in the extent and/or quality of the coverage and/or in the insurance premium. Table B.1 summarizes the choice decisions in terms of the stated propensities for nine bi-optional choice sets. All choice sets consist of the insurance package of the incumbent provider on the

one hand and a package of 'another' provider on the other. The packages differ in the extent and/or quality of the coverage and/or in the insurance premium. The choice sets are ordered according to increasing attractiveness of the incumbent provider. From the newspaper article it could be ascertained that 93% of the respondents were satisfied or very satisfied and 6% were dissatisfied with the present insurance; 6% had already considered switching to provider, although only 1% of these were dissatisfied with their present company.

Table B.1: Stated propensity of Dutch citizens to switch one's health insurance company

Choice set	Alternative conditions of 'other' insurance company			Number of respondents intending to switch to 'other' company (%)		
	Extent of coverage (Δe)	Quality of coverage (Δq)	Insurance premium (Δp)	Yes (Definite or presumable)	Indifferent	No (Definite or presumable)
1	Same (0)	Same (0)	Lower (+)	77	2	21
2	Lower (-)	Higher (+)	Same (0)	21	4	75
3	Lower (-)	Same (0)	Lower (+)	21	3	76
4	Higher (+)	Same (0)	Higher (-)	19	3	78
5	Same (0)	Higher (+)	Higher (-)	17	4	79
6	Higher (+)	Higher (+)	Higher (-)	16	4	80
7	Higher (+)	Lower (-)	Same (0)	9	3	88
8	Same (0)	Lower (-)	Lower (+)	6	3	91
9	Lower (-)	Lower (-)	Lower (+)	4	3	93

Adapted: translated, Δ/+/0/– signs added, definite and presumable categories combined etc. Source: TNS NIPO in NRC Handelsblad, 20 November 2004, Theme: Health Care, p.13.

B.2 Identification of applied choice behaviour strategies

For several combinations of framing, valuation principles and compensatory and/or non-compensatory decision rules the sequences of nine choices were assessed that would be found if a decision maker consequently followed that choice behaviour strategy. For each choice sequence the percentage of the population that could have chosen it was attributed to it. These responses were eliminated from those in Table B.1. Next, the weight factors of attributes and the loss aversion factor were varied to account for interpersonal differences in valuation. Subsequently the percentages of the population that chose consistent with the corresponding choice sequences were determined, attributed and removed until only the indifferent and 'inexplicable' responses remained. This process was repeated with any of the discerned choice behaviour strategies as a starting point. Clearly, many respondents that could have followed a certain decision rule might have arrived at the same choice by following another rule, thus percentages represent the upper limits. All percentages listed below refer to the survey population as a whole.

B.3 Status Quo bias, Loss aversion or Non-compensatory decision rules

Twenty-one percent of the population chose the incumbent alternative or status quo from choice set one. Though theoretically some of these people might have switched to an alternative in one of the subsequent choices this seems highly unlikely in view of the values of the attributes of those alternatives compared to those of the alternative in choice set 1. Thus

these respondents were considered to have chosen the incumbent from all the successive choice sets.
Such behaviour is intransitive within the assumptions of utility maximization in its strictest sense. However, '*people's judgments are not simply based on the information provided within the experiment, but also on the knowledge and initial impressions that subjects bring to the situation*' (Kaplan as cited in Maule and Svenson 1993: 7). Thus, one might consider that these respondents took hidden factors into consideration, like search and transition costs. One might conceive that these factors were valued as a 'status quo attribute' (value 0 for the incumbent, negative for the alternative packages and providers). If this value outweighs the lowering of the premium this restores transitivity under the utility maximization principles.

Under the assumptions of Prospect Theory this choice sequence will be found if people weighed all attributes more or less equally and applied a loss aversion factor above 2.0. Another explanation that fits within the assumptions of Prospect Theory might be that these respondents reframed the alternatives to take hidden factors like transition, search or hidden costs, regret avoidance, brand loyalty and other phenomena into account. When one assumes that these people framed the incumbent provider and its package as part of the reference state, these hidden factors would be framed as attributes with zero value for the incumbent's package and equal loss for all nine alternatives. This loss could presumably be judged intuitively using the affect heuristic. Even a loss aversion factor well below 2.0 would explain the choice sequence.

A third explanation is provided by the application of a non-compensatory decision rule. Of course, a Strong Lexicographic decision rule based on the hidden 'status quo' or 'affect'-attribute would result in this choice sequence. Also a conjunctive elimination rule (with the attribute levels of the reference state as cut-offs), followed by either a compensatory or lexicographic decision rule in which the hidden affect attribute dominates the premium attribute does the same job.

Though Prospect Theory, in connection with loss aversion provides the most 'natural' explanation for this choice behaviour one cannot reject these other choice behaviour strategies. Thus, as they do not discriminate decisively between most decision rules, these 21% of the respondents are not considered in the following analyses.

B.4 Maximal occurrence of the application of Utility Theory

The reference-independent valuation of attribute values, the Weighted Additive rule for the compensatory assessment of one value or utility per alternative, and the selection of the alternative with the highest value or utility from each choice set were considered as prerequisites for the identification of transitive choice behaviour according to Utility Theory. Within this framework interpersonal differences can only be accommodated by variations in the weight factors of the attributes. It appears that 16% of the respondents could have demonstrated transitivity under these assumptions if they valued $\Delta q > \Delta p > \Delta e$. If we allow for moderate loss aversion (in view of the generally presumed concavity of the utility function) another 5% might be added, though only under the not very likely presumption that these people valued Δq and Δp equally and Δe at approximately zero. The introduction of choice set independent hidden factors did not add more respondents. Thus, at most 21% might have used the utility maximization principles including transitive choice behaviour. Of the remaining population another 36% could have consistently applied the assumptions of Prospect Theory or an aspect-based elimination rule, see below. Disregarding the 21% 'Status quo' group an additional 20% remains unexplained by any other considered decision rule.

B.5 Maximal occurrence of the application of Prospect Theory

Prospect Theory with the Weighted-additive rule to wind up the choice process allows more room for interpersonal differences in valuation, such as variations in the loss aversion factor λ (value-of-loss/value-of-gain ratio) and alternative definitions of the reference state. Starting with the incumbent provider and his package as reference state and the well-known 'average' value $\lambda = 2.0$ yields 53% consistent respondents if $0.5*\Delta p < \Delta e < \Delta p$ *and* $0.5*\Delta p < \Delta q < \Delta p$. Another 4% might have been transitive if they applied the same reference frame for $\lambda = 2.0$ and $\Delta e < 0.5*\Delta p$ *and* $\Delta q > \Delta p$. Finally, if we assume that 6% of the respondents who were reported to be dissatisfied with the incumbent provider might have ascribed this in terms of a negative value on an affect attribute this could explain another 4% transitive respondents. Thus, at most 61% might have followed the principles of Prospect Theory. Disregarding the 21% 'Status quo' group the remaining 18% could not be explained by Utility Theory or by any of the other decision rules examined.

B.6 Maximal occurrence of application of the Strong Lexicographic rule

Strong Lexicographic rules might have been applied consistently by at most 20% of the population. For these rules it makes no difference whether attribute values – not necessarily commensurable here – are assessed according to Utility Maximization Theory or Prospect Theory. The evaluation of choice sets was attribute-wise, for all choice sets in the same sequence of attribute decision weight or importance, after which the alternative with the highest value on the most important attribute was chosen. In view of the many 'draws' of attribute characteristics between the incumbent and the alternative packages most people should attribute the highest weight to the quality attribute to arrive at 20% consistent choices. Of these, 4% might as well be attributed either to the Maximax rule or a Disjunctive rule with cut-off values just above zero. Of the remaining, about 40 to 45% of the respondents might have used either a compensatory rule following Prospect Theory or the Reference-Based Elimination rule (see below), leaving approximately 15 to 20% unexplained.

B.7 Maximal occurrence of the Attribute-Based Elimination rules

Finally, it is easy to see that an aspect-based elimination rule with threshold attribute values above zero, whether Conjunctive or Lexicographic or Evaluation-By-Aspects proper, will result in many empty choice sets and thus makes no sense in this analysis. However, a conjunctive Reference-Based Elimination rule that eliminates alternatives that do contain a 'non-satisficing' loss on any attribute, i.e. with values below those of the reference state, followed by a second stage compensatory decision rule might explain consistent choice behaviour of 53% of the population. The same result is found if a Lexicographic rule is followed in the second stage. Of the residual, 4% might be explained by the application of either a Maximax rule or a negative status quo value, and an additional 4% by the use of a Strong Lexicographic rule. This leaves about 15% unexplained.

B.8 Summary and discussion

The 21% of the population that systematically preferred the incumbent provider will most probably have followed a choice behaviour strategy drawing on loss aversion, either by loss-aversive valuation followed by a compensatory decision rule or by application of a conjunctive elimination rule with the attribute values of the present alternative as cut-offs. Other explanations like the Strong Lexicographic rule and the common Utility Theory, both with a high value for a hidden 'status quo' attribute, cannot be excluded but are highly unlikely.

Including these 21% as much as 82% of the responses could be explained from loss-aversive attribute valuation followed by a compensatory decision rule. Most of these (74%) might also be explained by using a conjunctive Reference-Based Elimination rule, followed by a compensatory evaluation where required. At most 42% of the responses might be explained by loss-neutral valuation and compensatory evaluation as well, of which only 21% seems plausible. At most 4% of the responses might be explained by the use of either the Maximax or the Disjunctive rule. For about 15% of the respondents it was not possible to infer any consistently followed choice behaviour strategy.

Evidently a similar analysis of the individual responses might reveal more intrapersonally inconsistent choice behaviour than inferred in this theoretical exercise. On the other hand it would enhance the discriminatory power of the elicitation process, and one could make allowances then for some stochastic errors. At a first glance, the high percentage of the population that, from the viewpoint of utility maximization, exhibited intransitive choice behaviour seems surprising, as does the high percentage of the people exhibiting loss aversion by following either a compensatory rule combined with Prospect Theory or the Reference-Based Elimination rule.

B.9 Conclusion

It appears possible to infer the use of particular choice behaviour strategies from the aggregated responses of this survey population, by assuming that most people will demonstrate intrapersonal within-context consistency and/or transitivity, and by taking non-stochastic interpersonal differences in valuation and choice behaviour into account. One could argue that the experimental context created a high accessibility of the status quo or reference state by confronting people with it in all successive choice sets. But one might also wonder if this is not what real-life decision making in general is all about. In this respect the large number of responses that could be explained by a conjunctive Reference-Based Elimination rule seems promising for further exploration in travel choice behaviour contexts.

Annex C
Car drivers' responses to the introduction of road pricing in Singapore

Before the Area License Scheme (ALS) was introduced in June 1975 most commuters in Singapore who went to work within or beyond the future Restricted Zone used their car, if they had one, for their daily commute. Most of them entered the city centre during the morning peak hours to arrive shortly before their work start time. They were thus destined to experience the consequences of the ALS. This annex aims to examine, on an aggregate level, how they responded to this abrupt structural change in their travel conditions. It starts with an assessment of the frequency of the pre-ALS distribution of the concerned commutes over different destinations and mode choices. Next, the changes that occurred in these frequencies were elaborated, starting from the frequencies that Watson and Holland (1978) extrapolated in agreement with the development of travel choices found from the household travel survey. As the changes in traffic flows that follow from these estimates differ from the observed ones an alternative estimate is made based on a comparison of pre-ALS and post-ALS traffic flows. This annex concludes with a listing of the frequency of the different travel choices as a response to the ALS introduction.

C.1 Pre-ALS modal split of car owning commuters

This subsection offers an overview of the pre-ALS modal split of travellers who entered the future Restricted Zone in the morning, either for work or other purposes within that zone or on their way to a destination beyond it. Information about these modal shares as collected in the extensive World Bank household travel survey was compiled by Watson and Holland (1978), together with traffic data and more general information and is further elaborated here.

C.1.1 Early 1975 trips by members of vehicle-owning and non-vehicle-owning families

The main distinction that Watson and Holland made among the participants in the household survey was between non-vehicle-owning and vehicle-owning households. In 1975 59% of Singapore's households had no motorized vehicle at their disposal. From the household survey it appeared that 42% of the non-vehicle owning household members commuted to the Restricted Zone and 6% to work beyond it. This amounts to about 105,000 trips with a

destination within the Restricted Zone and an additional 15,000 trips with a destination beyond it. Taking into account that about 10% of the population and about 24% of the total employment was concentrated in the centre of Singapore this leaves about 80,000 commutes by vehicle-owning family members to work in the Restricted Zone. This agrees with the final outcomes of Watson and Holland's more detailed assessments of vehicle-owning households that, taking car occupancy rates into account, yield 77,000 commutes to and 41,000 through the Restricted Zone. Members of non-vehicle-owning households used almost exclusively (88 to 90%) the bus for work trips to and through the Restricted Zone, leaving a few percent for other modes such as the bicycle, walking, taxis and occasionally a car passenger. About 55% of the members of vehicle-owning families commuted by car, either as driver or passenger, while 33% took the bus and almost 10% used a motorcycle or scooter. In connection these data yield an overall pre-ALS modal share[140] of 65% for transit, 24% for private cars and 3% for motorcycles in all commutes with a destination in the Restricted Zone.

C.1.2 Travel modes of members of vehicle-owning families in early 1975

According to traffic counts, between 7:30 and 10:15 a.m. 42,800 cars crossed the cordon around the to-be-restricted zone on each working day in March 1975. Watson and Holland used the answers given by vehicle-owning family members to the household survey to estimate the distribution of these car trips over destinations and trip purposes. Here, a further subdivision was made. For the assessment of the number of solo drivers it was assumed that the great majority of drivers who took passengers carried only one member of a car-owning family to the same destination and for the same trip purpose. It is worth noting that passengers travelling in a car for purposes that were not the same were not recorded in the household survey, which may also explain the seemingly low occupancy of four-person carpools, particularly those bound for work beyond the Restricted Zone. The estimates are presented in Table C.1. Additional indications about the distribution of car drivers over solo car drivers and passenger carriers can be found from the modal shifts of Restricted Zone-bound travellers. For the pre-ALS modal shares this analysis confirms by and large the 50-50 distributions of Restricted Zone-bound car drivers over solo drivers and passenger carriers found there.

C.1.3 Early 1975 car owners' modal shares

The topic at hand in this annex is to assess the responses of car drivers to the introduction of the ALS. This requires knowledge about how car owners used their car before the change in question. 'Car owner' is defined here as the person who takes care of a car that is continuously at the disposal of her family, by driving it along to some activity location or by leaving it at home. It is assumed that this deployment may imply its use for the daily commute, as solo-driver or while carrying a family member or a paying co-worker, but also leaving it at home, for example to save running costs or parking fees.

Watson and Holland defined vehicle-owning households as families that had at least one motorized vehicle at the disposal of its members, which includes company cars for the daily commute, for example. They also reported that 143,000 cars and 83,000 motorcycles and scooters were registered in 1975 and were 'owned' by 41% of the households. Spencer and

[140] Note that Gomez-Ibanez and Small (1994) as cited by Evans *et al*. (2003) erroneously compared the 1975 and 1976 modal shares of commuting vehicle-owning household members with the 1983 and 1988 modal shares for all commuters to the Restricted Zone. The suggested long-term impact of the ALS introduction on the modal shares, from 56% by car and 33% by bus in 1975 to 23% by car and 66 to 69% by transit almost completely disappears when the pre-ALS 24% – 65% ratio as assessed here is taken as the starting point.

Sien (1985) assessed the number of private and company cars, with the exception of tuition and government registered cars, at about 140,000. Taking into account that a few percent of the families might have had more than one car at their disposal, about 30% of the 430,000 households might have owned at least one. This implies that at least 25% of the vehicle-owning households in the World Bank Survey were not 'car-owning'. This percentage might also hold for the car passengers and bus riders in Table C.1. But the share of motorcycles and scooters in the total motorized traffic in the considered period was 17% for destinations in the Restricted Zone and 25% for destinations beyond it. If the share of workers from vehicle-owning households that did not own a car had been the same for destinations within and beyond the Restricted Zone, up to about 30% of the Restricted Zone-bound travellers who did not drive a car may not have had a car at their disposal but only a motorcycle or scooter. This would leave about 21,000 bus riders and 'other travellers' from car owning families.

Table C.1: March 1975 modal shares of travellers from vehicle-owning households

Destination and purpose	Work within future RZ	Other activities within future RZ	Work beyond future RZ
Average number of vehicles entering the RZ between 7:30 and 10:15 a.m.			
All passenger cars	25,600	1,000	16,200
Carpools carrying ≥ 4 occupants	2,300	100	700
Other cars	23,300	900	15,500
Motorcycles and scooters	5,300	200	5,300
Average number of travellers entering the RZ between 7:30 and 10:15 a.m.			
Car drivers (total)	25,600	1,000	16,200
Carpool drivers	2,300	100	700
Solo car drivers	11,700	100	11,400
Car drivers carrying one passenger	11,600	800	4,100
Carpool passengers	6,900	200	1,100
Other car passengers	11,600	1,000	4,100
Motorcycle and scooter riders	5,300	200	5,300
Bus passengers	24,800	1,400	12,900
Other (bicycle, taxi, walking)	3,000	1,000	1,200

Explication: RZ = Restricted Zone. Travel flows rounded off to multiples of 100, based on traffic counts for cars as attributed to destinations by Watson and Holland (1978: Table 4.2 and Figure 6.1). Modal shares based on the distribution of trips by vehicle-owning household members (Watson and Holland: Tables 4.4 and 4.7; Figures 5.1, 5.8, 5.14 and 5.15).

The reason for the high share of car drivers who took along passengers may have been due to the fact that 24% of Singapore's jobs were concentrated in the Central Business District, so finding others travelling in the same general direction would not have been difficult. Of course, differences in work start time and large distances between each other's workplaces may have left a fair number of family members of solo car drivers who worked in the Restricted Zone as 'captives' of another travel mode. Other workers from car-owning households may have been forced to use the bus transit to the Restricted Zone because the car was used for the partner's commute to work outside the Restricted Zone. Considering the estimated 21,000 workers from car-owning households who went to the Restricted Zone by

bus, taxi or 'slow mode' compared to about 12,000 solo car drivers, there were thousands of car owners who deliberately left their car at home. Of all trips to work in the Restricted Zone by members of vehicle-owning households, 28% had a destination in the Restricted Zone (Watson and Holland 1978: Table 5.2), so one might assume that the same percentage holds for all car owners. Taking days off, repairs etcetera into account this might yield about 35,000 entries each day. This is about 7,000 more than the observed number of car entries in Table C.1 with an additional number of entries of about 7% either before 7:30 or after 10:15 a.m. For commuters working beyond the Restricted Zone, the much lower number of bus riders compared to solo car drivers implies that no more than a few car owners left the car in the garage and chose to take the bus.

Taking into account the different annotations to the modal shares as listed in Table C.1 enables the estimation of the modal split of the car owners that went to or through the future Restricted Zone within the future restricted period (Table C.2).

Table C.2: Estimated March 1975 modal shares of car owners

Destination and purpose	Work within future RZ	Other activities within future RZ	Work beyond future RZ
Average number of trips entering the future RZ between 7:30 and 10:15 a.m.			
All car owners	32,600	1,000	16,200
Solo car drivers	11,700	100	11,400
Car driver with 1-2 passengers	11,600	800	4,100
Carpool driver (≥ 3 passengers)	2,300	100	700
Bus passengers	7,000	-	-

RZ = Restricted Zone. Numbers are estimates based on the figures in Table C.1, adapted for supplementary information presented in the text and rounded off to multiples of 100.

The numbers presented in Table C.2 are not meant to be exact assessments but rather indicate order-of-magnitudes. It shows that the greatest majority of car owners used their vehicle for their daily recurrent trips while for a distinct minority the expenses apparently did not counterbalance the travel time savings.

C.2 Responses to ALS enforcement as extrapolated from pre-ALS traffic

Watson and Holland (1978: 152-153) estimated the responses of car drivers who were confronted with the ALS enforcement by extrapolation of their pre-ALS travel behaviour proportionate to the changes in behaviour found from the pre-ALS and post-ALS waves of the household survey. This section follows their approach and refines it where appropriate.

C.2.1 Responses of car drivers as retrieved from the household survey

Watson and Holland (1978: 152-153) presented a table with their final inferences concerning the responses of car drivers who were confronted with the ALS enforcement. After elimination of the pre-ALS carpools and rounding-off to multiples of 100 trips this overview contained 23,300 commuters, 900 other car drivers with a destination in the Restricted Zone and 15,500 commuters with work beyond the Restricted Zone who, before ALS enforcement, passed the cordon between 7:30 and 10:15 a.m. (see Table C.1). For the assessment of their responses to the ALS enforcement they distinguished three destination and trip purpose combinations: commutes to the Restricted Zone, other trips to the Restricted Zone and

commutes beyond the Restricted Zone. Other distinctions were: two trip schedule classes: cordon passage during the restricted period and in the adjoining hours; four travel modes: bus rider, other non-driving mode, carpool driver and other car driver; and, for destinations beyond the Restricted Zone, two routes: through the Restricted Zone or a detour over the ring road. Extrapolation of the mode, schedule and route changes reported in the pre-ALS and post-ALS household travel survey yielded a distribution of the post-ALS car traffic over these categories. As about 90% of the 1,000 pre-ALS car trips with an 'other', mostly discretionary, motive were either cancelled, redirected to destinations outside the Restricted Zone or rescheduled for the afternoon or evening, these are disregarded from now on. Following a similar approach as Watson and Holland the remaining trips will be subdivided further over pre-ALS solo drivers and drivers who carried a passenger, over different transit alternatives and over some relevant combinations of departure time changes and staggering of the official work start time.

C.2.2 Solo driving, ride sharing and carpooling

Undoubtedly it was easier for family members, neighbours or colleagues who were accustomed to sharing their trips to establish a carpool than for solo riders. Two couples travelling together might have been one of the easiest ways to arrange a four-person carpool. For solo drivers, this alternative was only feasible if the commuter was happy to give up the privacy and comfort of her 'own' car and if she found fellow travellers who lived in her neighbourhood, who worked or had other engagements at or close to her office location and who could arrange approximately the same work or activity start time. The examination of the microanalysis data from Watson and Holland revealed a 1:4 ratio between the numbers of former solo drivers and former passenger-carrying drivers who had joined a Restricted Zone-bound carpool after ALS enforcement. This ratio yields modal shifts of 800 Restricted Zone-bound solo car drivers and 3,000 passenger-carrying drivers to carpooling. Application to destinations beyond the Restricted Zone implies that 800 of the 1,000 shifts to carpooling concerned drivers who already carried one or more passenger.

C.2.3 Transit, express bus services and park-and-ride

Watson and Holland's estimated 4,200 car drivers who changed to bus transit for their commute to the Restricted Zone included the car drivers who chose for the new Blue Arrow or Air Conditioned Coach express services. In the fall of 1975 the Blue Arrow ridership was about 1,200 and the Air Conditioned Coach service 150. The most plausible explanation for the limited success of the Blue Arrow and Air Conditioned Coach services seems to be their 'reach' in terms of the limited number of routes and coach stops. Presumably only a small minority of the commuters lived and/or worked sufficiently close to the bus stops for these express buses, as well as having home departure and work start time demands that fitted with the timetable. It is assumed here that half of the passengers of the Blue Arrow service were pre-ALS bus riders as it offered a considerably faster trip for a 25% fare increase which is very low compared to the increase in the ALS fee. In view of this relatively low fare a proportionate distribution of the remaining passengers over former solo and rideshare drivers is assumed. The high fare of the Air Conditioned Coach services will have attracted almost exclusively former solo drivers. After subtraction of the shifts to the express bus services 3,500 shifts to conventional buses remain. The microanalysis data suggest a similar low share of solo drivers in the shift to bus riding as for carpool joining.

In addition to these shifts to transit the change of driving to park-and-ride should be considered. The initial utilization of the fringe car parks was 600. It soon dropped to below 500, after the shuttle buses were allowed to call at some residential areas as well. As this will

have worsened the overall travel time for those who used it for park-and-ride the former number is adopted here. It is assumed that solo drivers, who apparently benefited the most, almost exclusively used this service.

C.2.4 Departure time adjustment

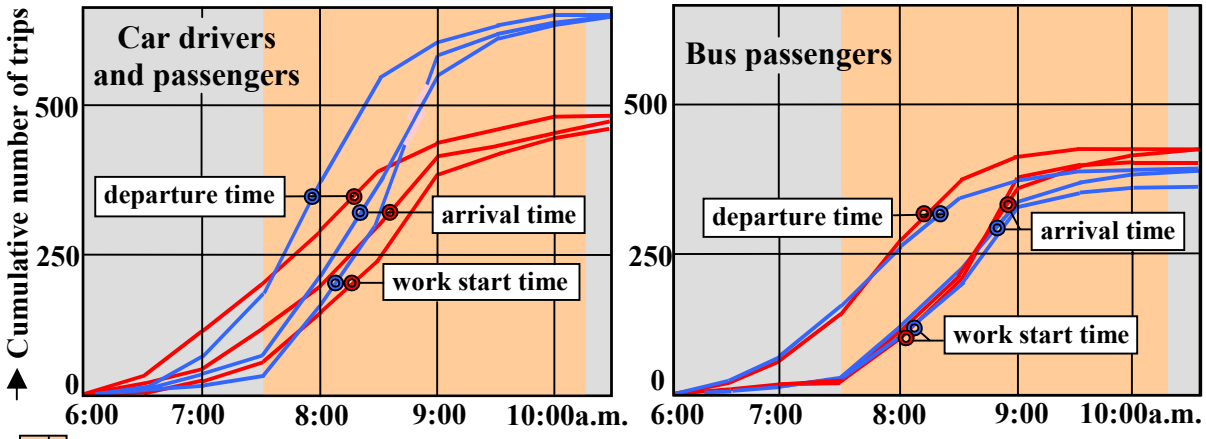
An obvious way to avoid payment of the ALS fee was to advance or postpone the home departure time to such an extent that the cordon was passed before 7:30 or after 10:15 a.m. Watson and Holland reported that 4% of the Restricted Zone-bound car driving commuters postponed their home departure till after 10:15 a.m. whilst 14% advanced it to the hours before 7:30 a.m. Attributing this ratio to the 4,300 departure time adjustments yields 1,000 postponements of crossing the cordon until after 10:15 a.m. Obviously, the postponements of home departures went together with a postponement of work start time until 10:30 a.m. or later. Watson and Holland (1978: 88) *'assumed that changes in the proportions of people who reported starting times up to 7:30 a.m. were adequate indications of changes in the proportions who actually entered the Restricted Zone before 7:30 a.m.'*. These advancements include those accompanied by advancements in the work start time and increases in the earliness of arrival at work. As the average travel time of car drivers is about half an hour this includes commuters who either had a work start time of about 8:00 a.m. or advanced it to 8:00 a.m. or earlier.

Figure C.1 offers insight into the corresponding changes in home departure time, arrival time at work and work start time of commuters who worked in the Restricted Zone. The cumulative distributions show that bus riders kept to their schedule whilst more than 10% of the car occupants who originally arrived at work before 8:00 a.m. advanced their home departure. The distributions show that most car users who departed earlier from home did not advance their work start time.

Watson and Holland (1978) observed that most of the respondents to the World Bank Survey rounded off their departure and arrival times to the nearest quarter of an hour. To cope with this imbalance they aggregated them to half-hour intervals. The cumulative distributions in Figure C.1 are based on these aggregated data and thus assumed an equal distribution over half-hour intervals. However, the actual reported departure and arrival times might be better conceived as the median values of a more or less equal distribution over quarter of an hour intervals. The reported work start time was apparently the nominal one, as several respondents reported arriving at work after this time. For a sub-sample of the World Bank survey population Wilson (1988b) presented diagrams of arrival and work start times on a five-minute instead of a half-hour base. These latter peaked at half and whole hours and their cumulative distributions might thus better be drawn as step functions. The cumulative distributions in Figure C.2, derived from these diagrams, are drawn according to the aforementioned principles.

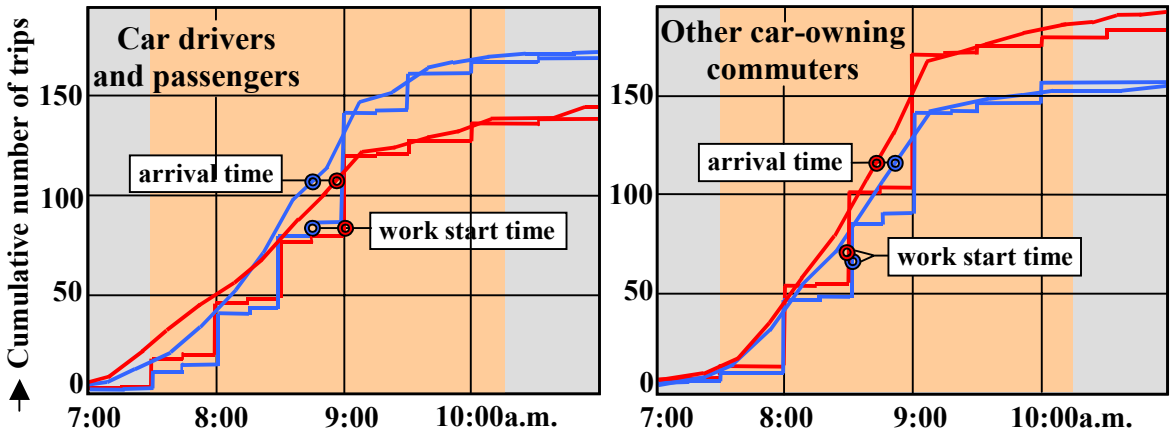
Figure C.2 shows a large dispersion in arrival times, from about 30 minutes before until a few minutes past the official work start time. For car occupants the average earliness was about a quarter of an hour, half their average trip duration. Transit passengers, who had an average travel time of about 40 minutes (see Figure C.1) arrived on average ten minutes before their work start time. The average earliness of bus riders is on the low side compared to that of the transit passengers and car users who commuted in the morning to Pittsburgh's Central Business District (Hendrickson and Plank 1984). For them an average 40 minutes trip time and an average arrival time of twenty minutes early were reported. The dispersion of earliness across Singapore's commuters was about the same as in Pittsburgh as follows from

Hendrickson and Plank's diagram that shows a staggering of early arrivals from zero to 35 minutes by the 42% of the commuters with an official work start time of 8:00 a.m. Figure C.2 thus apparently offers a plausible description of the early arrivals of commuters in Singapore's Restricted Zone.



Adapted from frequency distributions of 1170 trips before and 1026 after ALS enforcement, as reported by Watson and Holland (1978: 126-127)

Figure C.1: Cumulative frequency of car owners' trip schedule components



Assembled from information in Wilson (1988b: 197-201)

Figure C.2: Cumulative frequency of car owners' early arrival time

Wilson's detailed information of the arrival times of car-using commuters showed, on balance, an 8% increase[141] in the half hour around 7:15 and 7:30 a.m., hardly any change around 7:45 a.m., a 7% decrease at 8:00 a.m. and smaller decreases for the following quarters.

[141] Percentages in the main text relate to the number of car users who, before ALS enforcement, left home between 7:30 and 10:15 a.m.. Compared to the corresponding pre-ALS arrivals those at 7:15 a.m. were 1.65 times as high and at 7:30 a.m. 1.9 times while they remained almost the same at 7:45 a.m., were halved at 8:00 a.m. and fell by 30% in the following quarters. Note that the 8% increase of arrivals before 7:31 a.m. do not include car drivers with a WST at 7:45 or 8:00 a.m. who advanced their home departure to pass the cordon before 7:30 a.m. and arrived at work shortly after that time.

The diagrams of work start time show an on-balance increase of almost 4% at 7:30 and 0.5% at 8:00 a.m., no change at 7:15, 7:45 and 8:15 a.m. and a 5.5% decrease at 8:30 a.m. All increases in the work start time of bus riders correspond to almost equal decreases of car users, except for those with a work start time at 7:30, 8:00 and from 10:00 a.m. onwards. The remaining decrease in car users' work start time during the restricted period appeared to be equal to the net increase in commutes by car in the adjoining periods plus the compensation for modal shifts. Taking all the information together, about 1,300 of the 3,300 car drivers who advanced their home departure to the hours before 7:30 a.m. might have advanced their work start time as well while the remaining may have advanced their home departure without adjusting their work start time.

For destinations beyond the Restricted Zone, Watson and Holland estimated that about 800 drivers changed to a non-driving mode, predominantly to carpooling and hardly if anyone to transit, while the number of carpool drivers increased by 200. They assessed that 3,000 adjusted their home departure time. No information was found about the work start time of commuters who changed their home departure. Watson and Holland mentioned that before ALS enforcement 50% of the car drivers and a majority of the other commuters started their trip before 7:30 a.m. The average duration of the car trips was slightly over half an hour. Assuming a similar peaking of work start time at full and half hours as in the Central Business District indicates a very high percentage of work start times of 8:00 a.m. This may reflect a higher share of workers with an early work start time in the large harbour and industrial areas around the Restricted Zone compared to the Central Business District with its many shops and offices. For the Restricted Zone, Wilson (1988a) reported a work start time of at or before 8:00 a.m. for 40% to 48% of the skilled, semiskilled, unskilled, transport and communication and service workers compared with 21% to 28% for professionals, clerical and sales workers. Taking this distribution into account it seems reasonable to assume that about 40% of the workers beyond the Restricted Zone had a work start time of 8:00 a.m. The larger distance between cordon and workplace compared to jobs within the Restricted Zone implies that smaller advancements of home departure are required to avoid the license obligation. In connection with the high share of car drivers with a work start time of 8:00 a.m. this makes advancements without work start time adjustments more profitable than for commutes to the Restricted Zone. It also implies that the urge to advance the work start time to 7:30 a.m. will have been less while work start time advancements from 8:30 to 8:00 a.m. are relatively more interesting than for Restricted Zone-destined trips. However, the number of trans-Restricted Zone workers with a work start time of 8:30 a.m. will have been lower than for work within the Restricted Zone. Watson and Holland's analysis of the starting time for the trip back home also revealed a small absolute advancement (3% of pre-ALS car drivers) to the 4:01-4:30 p.m. period. Finally, the relatively early work start times compared to commuters who worked within the Restricted Zone suggests a lower share of work start time advancements. Overall, the number of work start-time postponements might be assessed at well below 500 whilst about the same number might have advanced their home departure as well as their official work start time, mainly to 8:00 a.m.

C.2.5 Combinations of work start time and travel mode adjustments

Watson and Holland (1978: 126-130) also analysed the work finishing, work departure and home arrival times. They found that '*There is no evidence of a change in the times at which respondents by any mode arrive home. Thus, it may be concluded that the staggering of the times at which trips are started is a morning-only phenomenon*'. This might mean that the advancement of work start time resulted in an extension of the daily working hours. But re-examination of their histograms of work finishing time showed a clear increase of work finishing hours

before 4:00 p.m. amounting to at least 50% of the respondents who advanced their work start time to 7:30 a.m. Nevertheless Watson and Holland's finding that no advancement of home arrival time after ALS implementation could be retrieved was confirmed. Apparently the 'time gain' of the advancement of work start time was lost during the afternoon commute, at least at this aggregated level. This would imply that it yielded no value for the concerned commuters.

About half of the car-using commuters who advanced their morning schedule[142] travelled as car passengers or in carpools whilst after the ALS introduction about 6% of them went back home by bus. It is also worth noting that, in 1975, Singapore was '*a city where going home for lunch is prevalent practice*' (Watson and Holland 1978: 268), a phenomenon that in the mid-20th Century was also common in the Netherlands, for example. These particulars might indicate several alternative responses to the ALS introduction: A car driver may continue starting work at 7:30 a.m. and take a passenger or drive a carpool to the Restricted Zone, maybe to please a friend, thus asked by her employer or for the benefit of a small fee; another car driver may continue starting at 7:45 or 8:00 a.m. and take three passengers to qualify himself for the exemption of the ALS fee; both may continue going home for lunch, but without the nuisance of taking passengers, and commute back and forth to work in the afternoon as a solo car driver; to do so, they may stick to a longer lunch break than average, resulting in a work finishing time that is still advanced but unnoticeably submerged in the host of post-4:00 p.m. finishing times. By and large these individuals will stay close to their reference state. Other car drivers may advance their work start time to 7:30 or 7:45 a.m., thus avoiding the ALS fee, and may or may not take passengers. Still others, for example those with a set home arrival time, may advance their work start time to join a solo driver or carpool, and use the corresponding advancement of work finishing time to accommodate their return trip by bus within the home arrival constraint.

It follows, therefore, that there is every reason to believe that advancement of the work start time did yield additional value or utility for the commuters who chose to do so, in addition to avoidance of the ALS fee. Several feasible responses that would be profitable for the individual would not result in a significant advancement of the afternoon home arrival. The aggregated nature of the available data might easily conceal the remaining effect of work start time advancement on home arrival time. For the formation of many carpools these advancements may have been a necessary condition. The retrieved information does not allow the splitting-up of work start time advancements over the different feasible modes and ride-share arrangements.

C.2.6 Summary of the extrapolated responses of car drivers to ALS

The previous assessments resulted in 32,100 post-ALS commutes that could be related to pre-ALS car trips. This leaves a decrease of 6,700 car trips between the spring and fall of 1975. In the absence of other explanations, Watson and Holland considered that this decline was mainly caused by decreasing employment, high taxes on vehicle ownership and the decentralization of activities in the Restricted Zone. They are combined here with the changes from car driving to carpool passengership, under the heading 'cancelled trip or shifted to non-driving mode'. After rounding-off to multiples of 100 trips the previous assessments are listed in Table C.3 under 'Extrapolated from pre-ALS traffic'.

[142] Neither Watson and Holland (1978: Figure 5.18) nor Wilson (1988b) distinguished between different categories of car occupants in their arrival and work start time frequencies but Watson and Holland did so in the home departure time distributions as depicted in their Figures 5.4 , 5.5 and 5.6.

Table C.3: Actual travel choices by car drivers after ALS enforcement

Estimated number of car drivers' responses to ALS enforcement	Actual travel choices			
	Extrapolated from pre-ALS traffic		Retraced from post-ALS traffic	
	Solo driver	Ride-share	Solo driver	Ride-share
Commuters on their way to work within the Restricted Zone				
Pre-ALS total	11,700	11,600	10,200	10,000
Cancelled trip or shifted to non-driving mode	2,300	4,200	3,500	4,700
Shifted to conventional bus	800	2,700	700	2,300
Shifted to Blue Arrow or ACC service	400	300	400	300
Accepted Park-and-Ride	600	-	600	-
Advanced home departure, same WST	1,200	800	600	300
Advanced home departure and WST	800	500	400	200
Postponed home departure and WST	600	400	300	200
Kept to pre-ALS mode and schedule	5,000	2,700	3,700	2,000
Commuters on their way to work beyond the Restricted Zone				
Pre-ALS total	11,400	4,100	9,600	3,900
Cancelled trip or shifted to non-driving mode	2,700	1,700	3,700	2,100
Shifted to conventional bus	-	-	-	-
Detoured over ring road	4,600	1,400	3,900	1,200
Advanced home departure, same WST	1,600	400	500	100
Advanced home departure and WST	400	100	200	100
Postponed home departure and WST	400	100	100	100
Kept to pre-ALS mode and schedule	1,700	400	1,200	300

Numbers relate to pre-ALS non-carpool drivers who entered the future Restricted Zone between 7:30 and 10:15 a.m., rounded off to multiples of 100. Empty cells indicate that less than 100 car drivers chose that option. WST = work start time. ACC = Air Conditioned Coach

C.3 Responses to ALS enforcement as retraced from post-ALS traffic

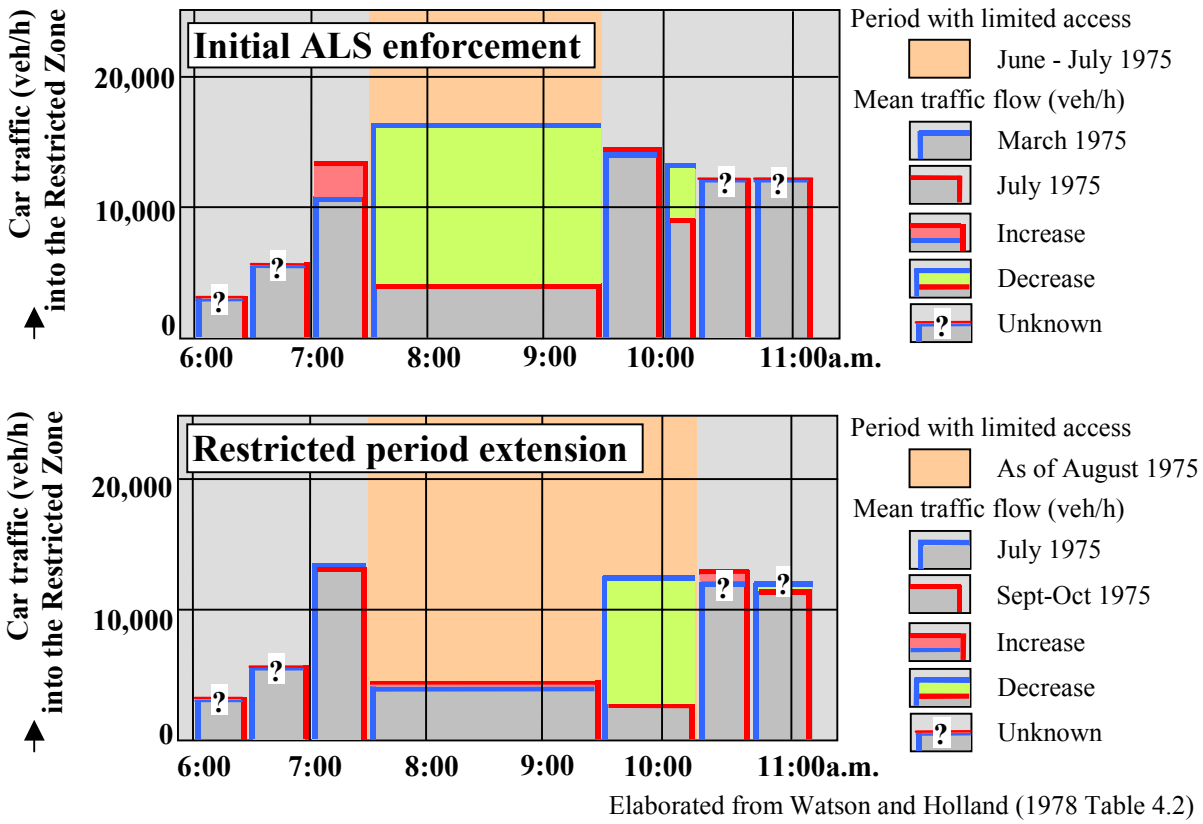
Watson and Holland apparently did not compare the impact of the estimated frequency on traffic flows with the actual development of car traffic. A check of the changes in trip frequencies as listed in Table C.3 under 'Extrapolated from pre-ALS traffic' and the observed changes in traffic densities revealed significant differences. The present section starts with an overview of the ALS-induced changes in traffic flows, followed by alternative estimates of responses based on the post-ALS traffic counts.

C.3.1 Effect of ALS on traffic flows

After the enforcement of the ALS, the number of motorized vehicles that entered the Restricted Zone each day during the restricted period dropped dramatically from 74,000 to 41,000 entries (see Figure 13 on page 193). Consequently, congestion within the Restricted Zone diminished strongly during the restricted period, resulting in an increase in average traffic speeds from 27 km/h before to about 33 km/h after the introduction. However,

particularly on parts of the ring road around the Restricted Zone the circulation deteriorated and a new peak in inbound traffic after 9:30 a.m. arose. To ensure that the impact of the ALS on the retail trade was minimal, the restricted period was soon extended[143] to 10:15 a.m. After the effects of that measure materialized, the traffic flows in and around the Central Business District did not decrease significantly during the remaining months of 1975.

A closer look at the changes in the traffic flows that entered the Restricted Zone revealed that the number of buses, motorcycles and scooters hardly changed. However, the number of goods vehicles more than doubled, to over 10,000 entries. All these categories as well as taxis were exempted from the license fee. As mentioned above, the traffic of taxis initially increased at such a pace that it was feared that it would undermine the effects of the scheme. Once they were brought under the license obligation their number dropped to less than 4,000, which is 35% of the pre-ALS level. As these decreases and increases in commercial vehicles counterbalanced each other, the reduction in total traffic was almost completely caused by a decline in car traffic (see Figure C.3). Within this category, there was a 50% increase in car pools carrying at least four individuals, which were also exempted from the license fee. In the period from 7:30 to 10:15 a.m. traffic into the Restricted Zone of cars carrying less than four occupants declined from about 40,000 to slightly over 7,000 entries.



Elaborated from Watson and Holland (1978 Table 4.2)

Figure C.3: Impact of ALS on all car traffic into Singapore's Restricted Zone

The changes in traffic flows that took place after ALS enforcement also reveal the popularity of departure time advancements and, to a much lesser extent, postponements. While total car

[143] According to Phang and Toh (1997), the Restricted Period was extended on 23 June 1975. However, several texts in Watson and Holland (1975) in connection with their analysis of traffic data suggest that this was not effectuated until the first of August 1975. This was confirmed by Ng and Li (1996).

traffic to the Restricted Zone decreased to 25% of the pre-ALS level Figure C.3 shows a clear increase of 25% in the half hour before the restricted period and a small increase in the half hour after it, at least after the initial introduction.

C.3.2 Differences between extrapolated and observed car traffic

The extrapolated post-ALS car traffic into and through the Restricted Zone as listed in Table C.3 amounts to 9,800 non-carpool cordon crossings during the restricted period. This reveals a discrepancy with the 7,100 non-carpool car entries counted in the same interval. A similar 'overestimation' is found for the extrapolated 5,800 advancements of car departures in the period before the restricted hours. In July 1975 the number of non-carpool car entries counted between 7:00 and 7:30 a.m. was only 1,300 above the pre-ALS level. One might consider attributing these differences to the 6,100 that were already attributed to trip cancelling due to decreasing employment, high taxes on vehicle ownership and the decentralization of activities. However, both employment and car ownership (see Spencer and Sien 1985) in Singapore decreased by less than 1% in 1975 and there are no indications that employment locations changed much faster. These phenomena might explain at most a few percent decrease in traffic, which is already much too small to explain the drop in extrapolated car trips, let alone the additional drop as observed from the post-ALS traffic counts.

A better explanation for the observed decline might be a change in the vehicle definitions as applied in the traffic counts. Watson and Holland reported an unexplained increase, between March and July 1975, of goods vehicles entering the Restricted Zone. During the restricted period the entries of these vehicles, which were exempted from the license obligation, increased by 5,500. The authors reported that separate traffic counts within the Restricted Zone, in which light vans were classified together with cars, showed no increase in traffic with medium-sized goods vehicles and heavy trucks. They assumed that the overall increase in traffic by goods vehicles was caused by an error in the March data. In agreement with this assumption one could imagine that the Public Works Department, which was responsible for the traffic counts, might have accentuated the distinction between goods vehicles on the one hand and passenger cars on the other once the ALS was enforced. This could imply that the number of pre-ALS passenger cars entering the Restricted Zone was overestimated. As the household travel survey did not distinguish between passenger cars and vans, extrapolation of the overestimated pre-ALS car traffic based on the survey results would also overestimate the advancements and postponements of trips to the hours before and after the restricted period. Another explanation might be a large shift from commutes by passenger cars to light vans. As this assumption would have largely the same effects on the difference between observed and extrapolated traffic flows it is not elaborated hereafter.

C.3.3 Observed responses of car drivers as retraced from post-ALS traffic

Starting from the post-ALS traffic counts one can assess the possible impact of the alternative explanation for the 'disappeared' car trips on the actual travel choices. While in July 1975 6,000 non-carpool drivers entered the Restricted Zone between 7:00 and 7:30 a.m., the corresponding pre-ALS number was 4,700 and the concurrent 'increase' in goods vehicles was 800. Considering that this increase concerned light vans, which in March 1975 might have been wrongly identified, this resulted in an increase of 2,100 non-carpool cars, which could be attributed to the advancement of home departure times. One might consider that some of the pre-ALS early morning car trips were cancelled and that several drivers may have joined a carpool or taken the bus. The traffic data presented by Watson and Holland show no strong modal shifts for early morning car drivers. As an upper limit one might assume an additional 300 advancements to compensate for the reductions in early morning car trips due

to mode shifts and trip cancelling for other reasons. This would yield a total of 2,400 departure advancements compared to the 5,800 found from the 'extrapolation' approach.

The same process as for the early morning commutes, applied to the half hour directly after the restricted period, showed an initial increase of about 1,500 car trips in the 9:30-10:00 a.m. period. After the restricted period was extended the inbound car traffic in the half hour after 10:15 a.m. was about 500 trips lower than in the 9:30 to 10:00 a.m. period before the extension. Though this suggests fewer postponements after the extension of the ALS than after the initial introduction, a solid traffic-counts based assessment is not possible as the pre-ALS traffic flows after 10:15 a.m. could not be recovered. As cordon crossings after 10:15 a.m. imply increases in starting work at 10:30, 10:45 or 11:00 a.m., the extent of schedule postponements should be equal to these increases. For car-using commuters who worked in the Restricted Zone Watson and Holland's diagrams (1978) show a 1.5% increase in work start time between 10:01 and 10:30 a.m. while those of Wilson (1988b) yield 1.7% between 10:01 and 11:00 a.m., both as a percentage of all car users with a pre-ALS work start time between 7:31 and 10:15 a.m. Taking some overlap into account this indicates at most about 500 postponements. The smaller group of car drivers who worked beyond the Restricted Zone had, on average, a much earlier work start time. Under the assumption of similar relative increases in late work start time as for the Restricted Zone-bound commuters, about 200 of them might have postponed their work start time. This yields a total of 700 retraced compared to 1,500 extrapolated work start time postponements.

After correction for the possible misidentification of goods vehicles and subtraction of the car trips with 'other' purposes the total March 1975 number of non-carpool cars that entered the Restricted Zone between 7:30 and 10:15 a.m. becomes 33,700 instead of the 40,200 as estimated by Watson and Holland. The Public Works Department counted only 7,200 non-carpool cars entering the Restricted Zone in the Fall of that year, slightly above the average 6,600 issued licenses and far below the 9,700 entries as extrapolated by Watson and Holland. Because no counter-indicative information was found Watson and Holland's extrapolation results were adopted to assess the numbers of shifts to transit and detours via the ring road. To account for the lower number of trips from which these were extrapolated the actual numbers were multiplied by the ratio between the 33,700 retraced and 40,200 originally observed pre-ALS car trips. Taking the counted post-ALS car drivers and the advancements and postponements as assessed above as a fact yielded again a number of 'missing' trips when the same household survey results were used to disaggregate the March 1975 car trips. One should consider that, in addition to a few percent cancelled trips and another few percent that changed to a non-motorized mode, increased occupancy rates of the light vans, which will have been owned predominantly by employers who might have promoted ride sharing, might explain a significant part of this reduction.

The results of this alternative assessment of actual travel choices by car driving commuters are listed in Table C.3 under 'Retraced from post-ALS traffic'.

C.4 Conclusions

Both the retraced and extrapolated responses show the high shares of passenger-carrying drivers in the shifts to carpooling and bus riding which lead, in turn, to the high numbers of solo drivers who kept to their mode and schedule. As might be expected in the light of the discussion above there are conspicuous differences between the retraced and extrapolated numbers of commuters who adjusted their home departure time. The outcomes of the

retracing process might be considered more plausible as they match the changes in observed traffic flows more closely.

Annex D
Travel conditions around the introduction of road pricing in Singapore

This annex assesses the travel costs and time spent for different feasible trips that car owners might choose for their morning commute in Singapore, before and after the introduction of road pricing in 1975. It is predominantly based on the elaborations of the characteristics and travel choices reported in the World Bank household survey in connection with speed and traffic measurements (Watson and Holland 1978). To improve its readability this reference is not further cited in this annex. The findings of Watson and Holland are supplemented with information from other references and completed with additional analyses to arrive at sound assessments of the attribute levels of the alternatives that are considered in Sections 7.4 to 7.7 of this book. In agreement with the adopted perspective on the individual's choice behaviour only the levels of time and monetary cost attributes are assessed. It is assumed that attributes like comfort or alternative-specific hidden factors can be approximated by stochastic interpersonal variations in the Value of Travel Time Savings (VTTS).

D.1 Fees and fares

Obviously, the license fee is the most discriminating cost attribute. The fares for cars were S$3 for a single day license and twenty times that amount for a monthly license. Right from the start about 80% of the licences valid for a particular day were monthly tickets. License costs are converted to daily expenses here, assuming that individuals make about twenty 'licensed' trips per month. This yields S$3.00 per day for entrance to the Restricted Zone during the restricted period, and zero costs for entrances during the rest of the day and before the introduction of the Area License Scheme (ALS).

Before the ALS implementation, a ticket for whole-day parking in the core of the Central Business District for a month cost S$50 and between S$30 and S$50 per month in the rest of the zone. Full day parking on an hourly basis was at least twice to three times as expensive and was only incidentally observed, at least in the public car parks in that area. After ALS introduction the monthly fares increased to at least S$70 in the core and at least S$60 in the remaining part of the Restricted Zone. Following the same approach as for the license fee, pre-ALS parking costs are estimated at S$2.50 per day, increasing to S$3.25 per day after

ALS introduction. The 'official' park-and-ride alternative offered ample parking space and a bus shuttle to three locations in the Restricted Zone at S$1.50 a day. For destinations to work beyond the Restricted Zone no information about parking fees was available. Plausible ranges may be: fees of S$1.50 per day increased by S$0.50 per day after ALS enforcement, for commuters working in the fringe of the Central Business District; and zero parking expenses for people working at larger distances from the Central Business District. Comparing the travel times of commuters who worked in and beyond the Restricted Zone as presented by Watson and Holland suggests that most of the latter group worked in the fringe of the Central Business District. Hereafter, S$1.00 and S$1.30 per day are adopted as pre-ALS and post-ALS 'average' estimates.

Watson and Holland mentioned S$0.30 to S$0.40 for a standard single town bus trip and an equivalent S$0.40 fare for a conventional bus trip equivalent to the Blue Arrow service. Wilson (1988b) stated that standard fares ranged from S$0.30 to S$0.60 per trip. Both sources give no details about the lengths of such trips. As a compromise, average one-way prices of S$0.40 and S$0.50 are assumed hereafter for trips to and beyond the Restricted Zone, respectively. In accordance with Watson and Holland, a flat S$0.50 one-way fare is assumed for the express 'Blue Arrow' bus services, and S$1.00 per trip is adopted for the high comfort air-conditioned coaches.

D.2 Travelled distances and travel times before ALS implementation

From the pre-ALS survey Watson and Holland found an average travel time of 29 minutes for car drivers who commuted in the morning to what later became the Restricted Zone, compared to 41 minutes for bus riders. There was no difference found between the travel time of bus riders from vehicle-owning households and those from households without a vehicle. Car drivers and passengers needed on average one minute to walk from their origin to their car and two minutes to walk from their car park to their destination. Bus riders needed on average six minutes to walk from their origin to the bus stop, eight minutes to wait at the bus stop and five minutes to get off and walk to their destination. The average in-vehicle times were thus 26 minutes for car drivers and 22 minutes for bus passengers. At the start of their trips car drivers probably needed an additional minute or two for traversing and driving out of the low-speed residential area, and possibly another two minutes for traversing the tertiary roads in the business area, entering the parking lot, manoeuvring and parking. The average period during which they travel at cruising speed was thus almost the same as the average in-vehicle bus trip duration.

For the morning commute, Watson and Holland estimated pre-ALS speeds for cars on the inbound radial roads, the ring road and the roads within the Restricted Zone. The average was 27 km/h, the same as measured during the evening rush hour on the outbound radials, ring road and roads within the Restricted Zone. The corresponding average speed of buses was 21 km/h. The difference might have been caused by the slowing down, getting in of passengers and acceleration at bus stops and by some additional retardation compared to cars at intersections and in congested traffic, due to the lower acceleration rate of buses. For outbound radial roads an average speed of 35 km/h for cars and 27 km/h for buses was found. The area in which the speeds were measured lay within four km of the city centre. The same cruising speeds are assumed in the more remote areas, in view of the poorly developed network of through-roads at that time (e.g. Willoughby 2000). Combining all this information, the average one-way distance covered by pre-ALS car drivers who went to the city centre is estimated to be 10 km compared to 8 km for pre-ALS bus passengers. If the 'average' car trip was made by bus, the additional two kilometres travelled requires an extra 6 minutes travel

time, making the total bus trip time 47 minutes. Conversely, the hypothetical equivalent car travel time for the 8 km bus trip would be 25 minutes. The traffic speed evidence indicates that there are no important differences between the morning and afternoon travel times.

The average pre-ALS travel times for commuters who passed through the Restricted Zone on their way to a workplace beyond it were 33 minutes for cars and 48 minutes for bus passengers. Taking the 35 km/h speed on outbound radials for the additional four minutes travel time by car compared to destinations within the Restricted Zone yields an overall distance of 12 km for car drivers, with a corresponding 52 minutes travel time if the same trip was made by bus.

Watson and Holland found that many car-driving commuters, who passed the Central Business District before the ALS came into operation, made a detour over the Ring Road to circumvent it. For commuters who traversed the Restricted Zone close to the sea, in a northeast-southwest direction, the required detour amounted to almost four kilometres but for other traverses the detour was only one kilometre. Here, an average of 2.5 km is assumed. Taking the differences between pre-ALS car speeds in the Restricted Zone and post-ALS speeds on the Ring Road into account, the additional travel time ranges from three to eleven minutes with an average of seven minutes.

D.3 Running costs

There is some doubt about the extent to which car-driving commuters take their running and capital costs into consideration in travel choice behaviour. Wilson (1989: 360) assessed the distance-related costs from earlier engineering estimates for fuel, oil, replacements (tyres, batteries…), maintenance and depreciation, for 1975 car travel in Singapore. He assessed the depreciation costs to be S$3.48 per km and the sum of the remaining distance-related costs, which by transport researchers are commonly conceived as running costs, to be S$9.96 per km. In an earlier survey vehicle owners were asked whether they perceived the different distance-related costs. All vehicle owners mentioned fuel but only 15 to 18% mentioned other running cost components and 5% mentioned depreciation. Wilson multiplied the km-related cost components with the shares of private car owners who perceived them. These ‘perceived running costs’, which include the weighted depreciation costs, amounted to S$0.085 per km. They are close to the average fuel costs of S$0.0805 per km and may, from a hedonic valuation view, be considered a better measure for the ‘expected running costs’ than the much higher theoretical unweighted sum of fuel, oil, replacements and maintenance. That is why in this book Wilson’s perceived distance-related costs are adopted as behaviourally the most appropriate measure for the car-owners’ running costs. Within the Extended Prospect Theory paradigm these running costs might be conceived as ‘routine expenditures’ that for many car owners may not be subject to loss aversion (Tversky and Kahneman 1991; see also differences in the valuation of toll fares and running costs in Hensher 2001b and Nielsen 2004). However, for the simplified assessments in this book changes in these costs are treated in the same way as changes in fares and fees.

As inferred above, the average distance covered by car drivers before ALS enforcement was 10 km for destinations in the Restricted Zone and 12 km for destinations beyond it. This yields average one-way running costs of S$0.85 and S$1.00, respectively. The 2.5 km detour via the ring road implies an increase of S$0.20 in running costs.

D.4 Solo drivers and ride sharing

Before ALS was enforced many car drivers carried a passenger. Watson and Holland provide detailed information about the modal shifts of car drivers and passengers for the microanalysis sample of commuters who made the same trips both before and after ALS enforcement. They inferred these modal shifts from the morning commutes reported in the travel diaries of 719 commuters who kept the same home address and the same destination in the Restricted Zone after ALS enforcement. These comprised 224 pre-ALS car trips (excluding 4+ carpools) with 117 passengers. While eleven car drivers became car passengers the same number made the reverse change, suggesting continued alternate drive arrangements. Eight car drivers became carpool passengers while another eight car passengers became carpool drivers, suggesting a similar type of pre-ALS arrangement. 43 Car drivers and 38 car passengers became bus riders, while 35 drivers and 28 passengers joined a carpool as driver and passenger, respectively. Only 31 car passengers kept to their mode while 123 car drivers did so. These data make it very likely that most ALS-induced modal shifts to transit and carpool concerned complete car crews. Particularly for carpool formation this makes sense: the easiest way to arrange for a four-person carpool may be for two couples to travel together. It also suggests that before the enforcement of the ALS hardly any non-carpool driver took more than one passenger.

If one assumes that passenger-carrying drivers took on average one passenger with the same destination and trip purpose, half of the car-driving commuters going to the Restricted Zone did so, as did about a quarter of those who went through the Restricted Zone to a workplace beyond it. It is worth noting that several of them might have taken a family member who travelled along for another purpose. This kind of passenger is not recorded in the household survey but may help to explain the seemingly low occupancy rates of four-person carpools, particularly those bound for work beyond the Restricted Zone, as suggested by Watson and Holland's modal share diagrams.

Watson and Holland did not discuss family relationships but in 1975 the average number of workers per household was only slightly below two, which makes it plausible that many married couples travelled together long before ALS enforcement loomed. Colleagues and neighbours might also have shared their rides daily, from the moment that one of them started to travel by car, maybe on an 'exchange' basis with another family. Moreover, the absolute number of car drivers who became car passengers was the same as for the reverse change, which suggests a number of arrangements where two car owners took it in turns to drive. For the latter type of rideshare one might assume that the ALS fees and parking fees of the car trip were shared, whilst only half of the running costs are incurred. If the passenger was a paying colleague, one might assume that she paid the driver less than half of the running costs and fees and kept her bus ticket saving. Family members who shared a ride might have attributed the fees and running costs to one of the members and have considered the free trip of the other as a bonus, or may have attributed them equally to both commutes. Overall it seems realistic to assume that the running costs, parking and license fee expenses of passenger-carrying car drivers are slightly above 50% of the corresponding expenses of solo drivers. Here they are tentatively estimated at 60%.

The microanalysis revealed large differences in average pre-ALS travel time between the car drivers who kept on driving after ALS enforcement and those who changed to bus riding. Those who kept on driving reported an on average one minute shorter pre-ALS travel time than the average for all car drivers, while those who became bus passengers reported a two minutes longer than average pre-ALS time. However, the post-ALS bus trip of the modal shifters took on average only nine minutes more than their pre-ALS car trip. Apparently a

longer travel distance did not cause the longer pre-ALS travel time. The explanation might be that those who changed after ALS implementation had less car accessibility either at home and/or at the office than the average pre-ALS car driver, and better access to bus transit at home and/or at the office than the average bus passenger. If this was true, the shift would lead to an improvement in the average waiting and/or walking times of both car drivers and bus passengers. This was actually confirmed by an on average 20% decrease in the home-end walking time of car drivers, and 4% decreases in both the home-end and office-end walking times of bus passengers plus a 20% decrease in waiting time at the bus stop. Though the absolute differences in these averages are small one should consider that the shifters accounted for only about 20% of the pre-ALS drivers. There are no indications to assume another average trip length for the shifters than the average 10 km that was found for all car drivers with destinations in the Restricted Zone.

The analysis of modal shifts within the microanalysis sample as discussed above clearly shows that few solo drivers became transit passengers while over 90% of the shifts from car driving to bus riding involved drivers who had carried a passenger. The observed differences in access and egress travel times between the 'shifters' and 'mode keepers' imply differences in the average pre-ALS travel times of solo drivers and drivers who carried passengers. Taking these into account the average pre-ALS travel time of solo drivers was assessed at 29 minutes and the equivalent trip by bus 48 minutes. For drivers who carried a passenger these travel times were 30 and 45 minutes respectively. These differences hold for destinations within the Restricted Zone. For destinations beyond it no clues were found that suggested similar differences between solo and passenger-carrying drivers.

D.5 Travel time changes caused by the ALS

As discussed in the previous subsection the traffic conditions during the morning commute changed greatly following ALS enforcement, with important reductions in traffic density during the restricted period and increases in the periods directly before and after it. The impact of these changes on the travel times are discussed here, again drawing on the information revealed in Watson and Holland complemented by additional analyses where required. As after ALS-enforcement the traffic densities during the evening commute hardly changed, the same times are adopted for the afternoon trips home as before ALS implementation.

After the introduction of ALS both the 'full' survey and the microanalysis sub-sample revealed an on-average one-minute increase in commuting time to work in the Restricted Zone. Based on travel time measurements, Watson and Holland found an increase in average car speed in the Restricted Zone of about 20% , from 27 to 33 km/h, when the ALS regime applied. For inbound radials the increase was slightly less, for outbound radials there was no difference and on the ring road the average speed went down from 25 to 20 km/h. In the hours after 10:15 a.m. the speeds were typically lower, even lower than between 7:30 and 10:15 a.m. before ALS introduction. Early morning speeds were not assessed. These data seem to contradict the observed travel time increase for Restricted Zone-bound commutes. In view of the size of the Restricted Zone, the measured speeds and the location of the main roads, one would expect a decrease of about one minute travel time for commutes that enter the Restricted Zone between 7:30 and 10:15 a.m. and a few minutes increase in both the half hour before and after the restricted period, as a consequence of the strongly increased traffic flows during the latter periods.

In an effort to explain these findings, Watson and Holland analysed the differences in travel time before and after ALS enforcement as reported by the same commuters. About a quarter of them reported the same travel times, and two slightly larger groups (each about 35%) reported either increases or decreases of five minutes and beyond. For many these changes in travel time may have been the result of travel time variability, which would leave a few travellers for whom the travel times as found from the pre and post-ALS diaries differ systematically. Of those commuters who acquired a license, 23% experienced a travel time decrease of over five minutes compared to 14% who experienced an equal increase. This is in agreement with the findings from the speed measurements and supports the expected decrease in average travel time during the restricted period. Of the commuters who advanced their departure to the period before 7:30 a.m. 50% saved at least five minutes while 30% lost at least that time. The authors offered no explanation for this seemingly counter-intuitive observation. Disregarding the small groups of car drivers who, before and after ALS enforcement, reached the Central Business District long before or after the restricted hours the different observations can be reconciled by assuming three groups of car drivers:

i. A large group of car drivers who traversed the Central Business District between 7:30 and 10:15 a.m., and kept to their schedule. They experienced a decrease in traffic density (see Figure D.1). According to the outcomes of the speed measurements they would gain, on average, one minute travel time;

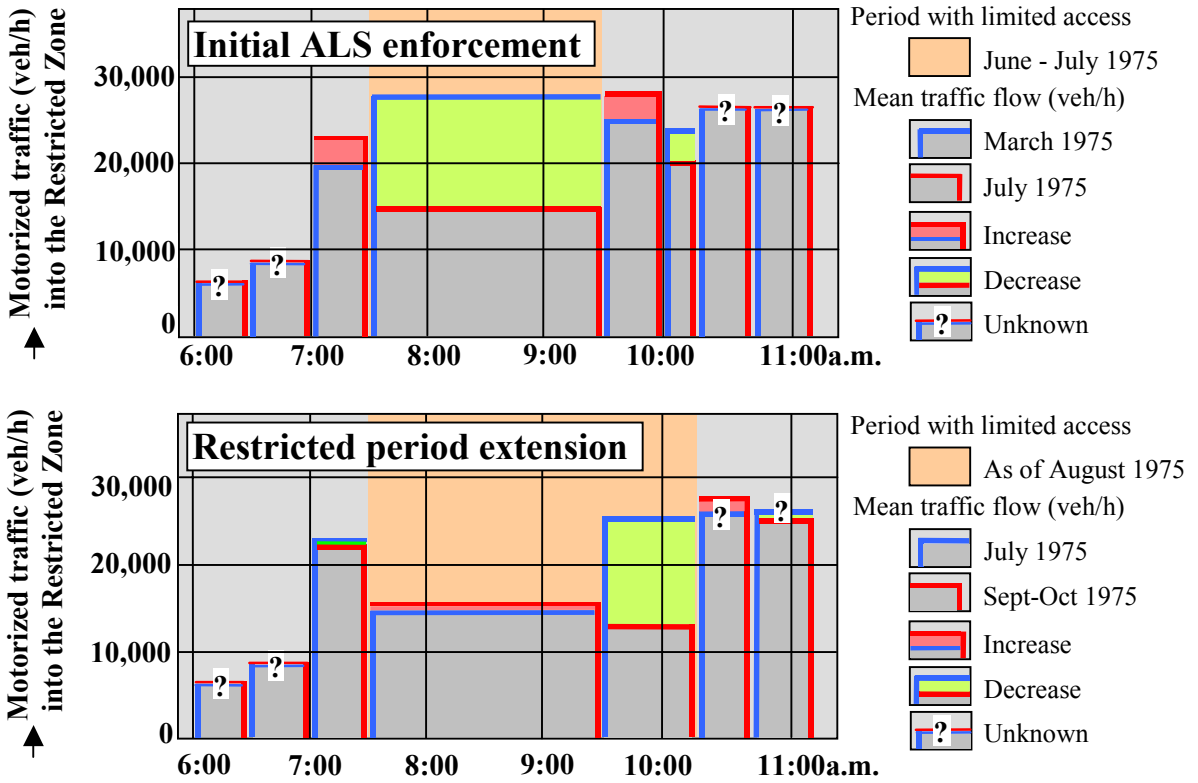
ii. A small group that shifted their home departure time and thus traversed the Central Business District before 7:30 a.m. instead of between 7:30 and 8:30 a.m. They experienced a decrease in traffic flows from about 27,500 to 23,000 vehicles per hour and have gained on average over half a minute; and

iii. A sizeable group of drivers who, before ALS enforcement, entered the Restricted Zone at about 7:30 a.m. and advanced it slightly to the new half hour peak before 7:30 a.m. They experienced an increase in traffic flows from 19,500 to 23,000 vehicles per hour. Taking the on-average one minute increase of all car travel times and the sizes of the different groups into account, the average travel time loss of this group would be five minutes.

For bus transit, Watson and Holland reported an average travel time gain of 0,5 minutes for passengers from vehicle-owning households and 1.2 minutes for passengers from non-vehicle-owning families from the overall analysis, while a 0.6 minute increase was found from the microanalysis. As few schedule adjustments were reported for bus passengers who predominantly travelled within the Restricted Period an average one-minute gain is adopted here in view of the agreement with increased traffic speeds.

The Blue Arrow service offered less than 60 morning trips into the Restricted Zone, a tiny fraction of the about 4,000 buses that each day entered the zone between 7:30 and 10:15 a.m. Taking the service frequency to be every fifteen minutes this implies that at most eight bus routes were serviced. The Air Conditioned Coach service offered just 12 inbound trips daily, presumably along different routes. Apparently its reach was less than that of the Blue Arrow service. As these services offer time gains due to fewer halts, for most potential clients waiting and walking times will be larger than for conventional buses that operate in the same corridor. This diminishes or even removes completely the maximum achievable time gain, which has to be found by a reduction of the pre-ALS in-vehicle time. Considering the 28 minutes in-vehicle transit time assessed above for the equivalent average trip by car, a reduction of five minutes might be the most one might attain. This advantage in

travel time compared to the conventional bus services will only have been accessible for a small minority of commuters.



Elaborated from Watson and Holland (1978 Table 4.1)

Figure D.1: Impact of the ALS introduction on traffic to the Restricted Zone

The World Bank survey revealed an average one-minute decrease in travel time after ALS-implementation for commutes to work beyond the Restricted Zone. This same decrease follows from the ALS-induced speed changes as measured in and around the Restricted Zone.

No information was found about the timetables of the bus services from the approximately 12 fringe parking lots to workplaces, let alone travel times. As the provision of these park-and-ride facilities were the most important and costly policy measure aimed to mitigate the effects of the ALS, insights into their effect on the travel times of those who chose to use them is a prerequisite for an appropriate ex-post evaluation. A map of the original plan is presented by Watson and Holland (1978: 282) and shows the location of fourteen car parks and a network of shuttle bus services that connects them with three core areas within the Restricted Zone. They mention that 90 buses served the lots, offering eleven bus lines to the three core areas of the Restricted Zone. The distance from the fringe car parks to the core areas of the Restricted Zone ranged from two to seven km. To realise a high average speed the buses only stopped in these core areas. Assuming about four shuttle bus stops per core area, the average distance from the bus stops to the offices would be about 200 m, requiring a one-minute longer walk to the office than the average reported by pre-ALS car drivers. Such an arrangement of bus stops might have been connected by round trips of about 10 to 15 km, depending on the location of the fringe car park in question. Taking into account bus speeds that reflect the express character in addition to realistic times for the halts this would make cycles of 30 to 35 minutes possible. With an average of eight buses available per parking lot and disregarding slack time

this would allow a frequency of about one shuttle bus every five minutes. For the average 'shifting' car driver this might imply an average four minutes for walking from the parking lot to the bus stop and waiting for the first shuttle to leave. In addition to these losses, the park and ride alternative will have caused a considerable increase in travel time compared to the 'optimal' route by car, due to the halts at the bus stops in the three core areas and the detour needed to serve them all. This accumulated in-vehicle travel time loss would have ranged from at least two to over ten minutes. An alternative shuttle schedule might have offered direct connections from each parking lot to each of the three core areas. This would limit the additional in-vehicle times compared to the optimal car trips to about four minutes. As it would imply a reduction in the frequency of departures at the parking lots to one per eight minutes the average time 'lost' at the fringe car park would increase to about six minutes. For each alternative shuttle service this yields an increase of at least seven and quite often up to fifteen minutes in one-way travel time compared to the pre-ALS car trip, depending on the adopted layout of the bus routes. Taking the previous estimates into account the additional travel time is conceived to be normally distributed with an average of eleven minutes and a standard deviation of two minutes.

D.6 Overview of adopted attribute values

The attribute levels that were assessed in this annex can be considered as averages over the groups of travellers for whom the alternative to which the levels apply are feasible options. They are assembled in Table D.1.

Table D.1: Attribute levels for trips to and trough the Restricted Zone

Pre-ALS trip attribute (averaged over all concerned travellers)	Post-ALS trip attribute(averaged over all concerned travellers)	Spring 1975	Fall 1975
Trips to the Restricted Zone (RZ)			
Fee for car entering RZ	Fee for car entering during RP [1]	S$0.00	S$3.00 [2]
Fee for whole-day parking	Fee for whole-day parking	S$2.50 [2]	S$3.25 [2]
	Fee for park-and-ride services		S$1.50 [2]
Fare for one-way common bus trip	Fare for one-way common bus trip	S$0.40	S$0.40 [3]
Running costs, car trip	Running costs, car trip	S$0.85 [2]	S$0.85 [2]
Running costs, 8 km car trip [4]	Running costs, 8 km car trip [4]	S$0.70 [2]	S$0.70 [2]
Travel time, car trip during RP	Travel time, car trip during RP	28 min [5]	27 min [5]
	Travel time, park-and-ride trip	29 min [5]	36-44m [5]
Travel time, car trip before RP	Travel time, car trip before RP	26 min [5]	31 min [5]
Travel time, 8 km car trip during RP [4]	Travel time, 8 km trip during RP [4]	25 min [5]	24 min [5]
Travel time, average bus trip	Travel time, average bus trip	41 min [6]	40 min [6]
	Travel time, Blue Arrow/ACC trip [7]	41 min [6]	≥ 35mn [6]
Travel time, 10 km bus trip [6]	Travel time, 10 km bus trip [8]	47 min [6]	46 min [6]
Trips to and beyond the Restricted Zone (RZ)			
Fee for car traversing RZ	Fee for car traversing during RP	S$0.00	S$3.00 [2]
Fee for whole-day parking	Fee for whole-day parking	S$1.00 [2]	S$1.30 [2]
Fare for one-way common bus trip	Fare for one-way common bus trip	S$0.50	S$0.50
Running costs, average car trip	Running costs, average car trip	S$1.00 [2]	S$1.00 [2]
	Running costs, detoured car trip		S$1.20 [2]
Running costs, 10 km car trip [4]	Running costs, 10 km car trip [4]	S$0.85 [2]	S$0.85 [2]
Travel time, average car trip	Travel time, average car trip	33 min	32 min
	Travel time, detoured car trip	33 min	40 min
Travel time, 10 km car trip [4]	Travel time, 10 km car trip [4]	30 min	29 min
Travel time, average bus trip	Travel time, average bus trip	48 min	47 min
Travel time, 12 km bus trip [7]	Travel time, 12 km bus trip [8]	52 min	51 min

[1] RP = Restricted Period from 7:30 to 10:15 a.m. [2] For rideshare drivers: 60%. [3] Blue Arrow express buses: 0.50 S$; Air Conditioned Coach service: 1.00 S$. [4] Calculated hypothetical value for a car trip with the same distance as an 'average' bus trip. [5] Drivers who carried a passenger: plus one minute. [6] Plus one minute for former solo drivers, minus two minutes for former drivers who carried a passenger. [7] ACC = Air Conditioned Coach service. [8] Calculated hypothetical value for a bus trip with the same distance as an 'average' car trip.

Annex E
Shape parameters of the VTTS distributions of Singapore's commuters

In Subsection 7.4.8 it was found that a lognormal function might approach the Value of Travel Time savings (VTTS) distribution over a population closely. Disregarding some minor sources of its dispersion this distribution might be estimated from the product of the underlying lognormal distributions of household income and inverse discretionary available time. This subsection draws on these findings and the available information about the household income of different groups of travellers to estimate the shape parameters of the distributions that apply to those groups. In Section 7.5.3 these shape parameters are applied to estimate the average VTTS of these groups.

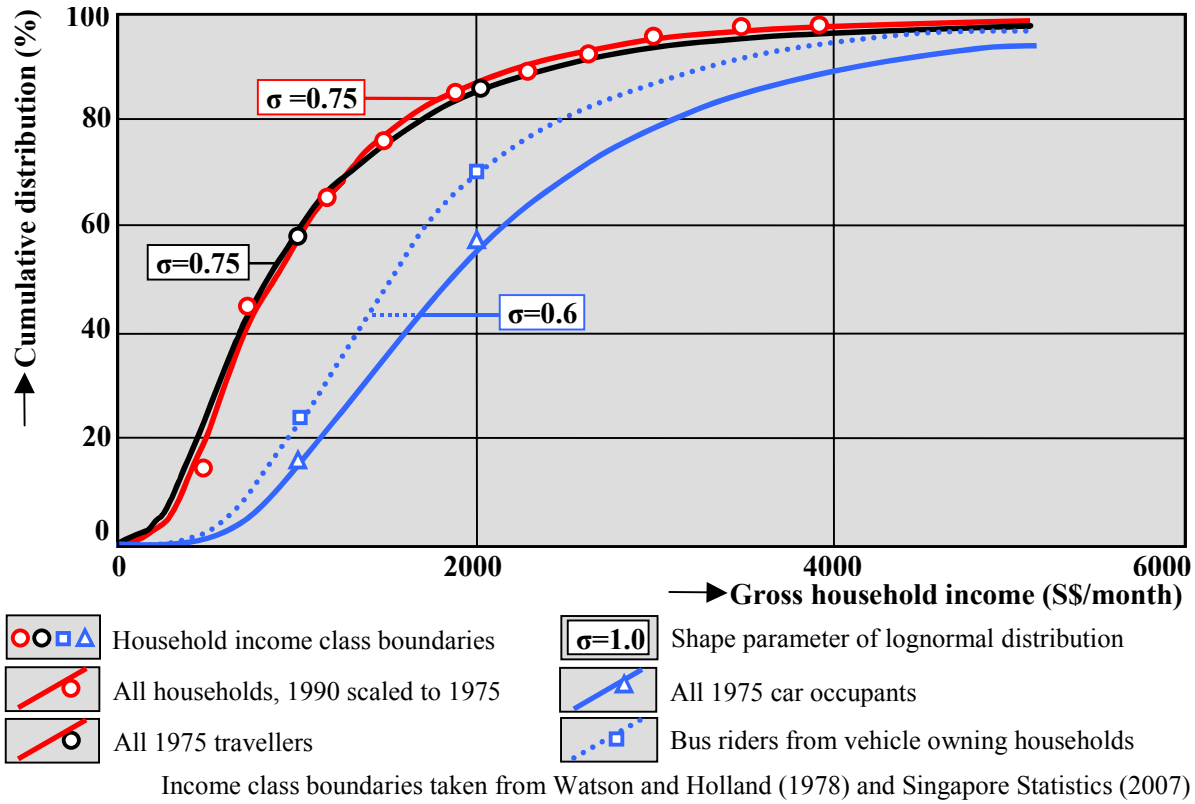
E.1 Travellers' household income distributions

The year nearest to 1975 for which household income distributions for Singapore's population could be retrieved was 1972 (Rao and Ramakrishnan 1980). The best fitting lognormal approximation yields an average of S$600 per month and a shape parameter $\sigma = 0.7$. The next year for which a distribution was recovered was 1990, with an average household income of S$3,080 per month (Singapore Statistics 2007). The lognormal approximation yields an average S$3,070 per month and a shape parameter $\sigma = 0.75$. The shape parameter for the household income distribution of all Singapore's 1975 commuters will thus have been about 0.75.

For the travellers confronted with the ALS enforcement Watson and Holland (1978) discerned three monthly household income categories: below S$1,000, from S$1,000 to S$2,000, and above S$2,000. For the participants in a public opinion survey they found an average household income of S$1,100 per month. The distribution over the income classes of all participants in this survey was 52:34:13. For the car drivers and passengers involved it was 18:43:30 and for bus passengers 63:29:8. They also offered income distributions for members of vehicle-owning families as observed for a microanalysis sample of the household travel survey. These distributions were 20:41:39 for all passengers, 19:38:43 for car drivers and passengers and 24:46:30. This signifies the much higher average incomes of vehicle-owning families, whether they used the car for their commutes or took the bus.

Combining the different data reported by Watson and Holland yields for all travellers an approximate distribution of 58:28:14 across the three classes. The best fitting lognormal distribution has an average household income of S$1,150 per month, slightly above the average S$1,100 per month for the participants in the public opinion survey and well above the average of S$850 per month for the population as a whole. This might have been caused by an over-representation of higher incomes among the visitors to the centre of Singapore where the public opinion survey was held. The shape parameter of the best-fitting distribution was $\sigma = 0.75$. Scaling back the 1990 lognormal distribution to the average income found from the public opinion survey (scale parameter = average 1975 / average 1990 = 0.36) yields a distribution that almost coincides.

The lognormal approximation of the household incomes of car owners as inferred from their distribution over the three income classes yielded an average of almost S$2,050 per month and a shape parameter $\sigma = 0.6$. For those members of vehicle-owning households who used a car for their daily trips, as driver or passenger, an average household income of S$2,150 per month and a shape parameter $\sigma = 0.60$ was assessed. For those who left the car at home and took the bus the average was S$1,750 per month, again with virtually the same shape parameter. Some of the distributions are depicted in Figure E.1.



Income class boundaries taken from Watson and Holland (1978) and Singapore Statistics (2007)

Figure E.1: Lognormal household income distributions in Singapore

The average household income for all 1975 car owners appeared to be about 80% higher than the average for all travellers. This is somewhat below the factor 2 that Li (1999) reported for the ratio between the average 1990 wage rates of car owners and all workers. The strong increase in taxes and fees for car ownership and road use from early 1975 onwards may explain this difference. The higher mean income of the participants in the public opinion survey compared to the national average may offer an alternative explanation. In any case the

lognormal approximations of the income distributions of the different groups of travellers thus yield plausible results.

E.2 Distributions of the inverse of travellers' discretionary available time

In Subsection 7.4.8 a shape parameter $\sigma = 0.55$ was found for the inverse of the discretionary time available per week in the Dutch 1988 stated choice survey. As indicated there the corresponding shape parameter in Singapore would presumably be higher due to the on average larger share of the workers with a very long working week. It was also discussed there that income is approximately proportionate to the inverse of the discretionary time available. Using the same ratio as for the income distributions yields shape parameters for the inverse discretionary time of about 0.7 for all travellers and about 0.5 for car drivers and for car owners who commuted with transit.

E.3 Distributions of travellers' VTTS

It was shown in Section 7.4 that the product of the underlying distributions of household income and inverse discretionary time available might approach the distribution of VTTS. The product of two lognormal distributions is a lognormal distribution with a shape parameter equal to the root mean square of the shape parameters of the underlying distributions. Multiplication of the household income and inverse discretionary time distributions results in an estimated shape parameter of $\sigma \approx 1.0$ for the VTTS distribution of all commuters who passed the future ALS cordon in the morning and of $\sigma \approx 0.75$ for the car owners among them who took the bus, for the solo car drivers and for those who took a passenger.

E.4 Discussion and conclusion

One should consider that the shape parameters are assessed to hold for 1975 commuters with a destination in or beyond the Restricted Zone. As the average income of these travellers was about 20% higher than for the population as a whole the dispersion in their income will presumably have been lower. This may partly explain why the shape parameter $\sigma_{VTTS} \approx 1.0$ for all travellers lies well below the value ($\sigma_{VTTS} = 1.3$) found from the 2001 stated choice results in Richardson (2003). More importantly may be the increase in the shape parameter of the household income distribution, due to a nationwide increase in income disparity. That shape parameter grew from almost 0.75 in 1975 to 0.89 in 2000. For the car driving population segment Richardson's data show a small decrease of the shape parameter. This may have been caused by a decreasing dispersion of income within this group but no solid information was recovered to support this explanation.

Taking the potential impacts of the differences in income distributions into account there appears to be a fair agreement between the 1975 and 2001 VTTS dispersion across the commuting population and its segments. A shape parameter $\sigma \approx 1.0$ may thus be adopted for the VTTS distribution of all travellers while for the homogeneous subgroups of car owners who commuted by bus, as solo driver or rideshare driver $\sigma \approx 0.75$ may be assumed.

Annex F
Trade-offs of alternatives to commuting by car in Singapore

The main question that car drivers in Singapore had to answer when they were confronted with the introduction of the Area License Scheme (ALS) was whether they were prepared to pay the fee or would rather adjust their daily trip planning to avoid it. If they they wanted to adjust their trip planning, many different alternatives were feasible (see Annex C). Obviously, the attractiveness of the different alternatives depended on the travel conditions of the commuters (Annex D) and on their socio-economic circumstances and personal preferences. The frequency with which each alternative is chosen is conceived as the consequence of the choice behaviour of 'representative' individual car drivers. This annex applies the models developed in Section 7.4 to a series of bi-optional trade-offs of the feasible alternatives, for different manifestations of loss-aversive and loss-neutral appraisals. Most bioptional trade-offs are followed by observations of the descriptive ability of the Utility Theory (UT) and Extended Prospect Theory (EPT) paradigms. The annex finishes with some preliminary conclusions. A more thorough comparison of EPT's and UT's predictive performance, against the observed choices from multi-alternative choice sets, will be made in Subsection 7.6.3.

The considered algorithms for the model calculations in this annex cover: LA(2,2), i.e. application of a loss aversion factor 2.0 to both time and money losses; LA(2,1), application of the loss aversion factor 2.0 to time losses and loss-neutral valuation of money expenses; and LA(1,1), a loss-neutral appraisal of the time and money changes. These different manifestations of loss aversion are conceived as interpersonal choice behaviour strategies that can be described by substitution of the concerned factors in the value function derived in Section 7.4.9. The application of these fleshed-out functions to the bi-optional choice sets yields a prediction of the lowest or highest idiosyncratic Value of Travel Time Savings (VTTS) at which the concerned car drivers are considered to prefer one alternative to the other. A comparison with the dispersal of idiosyncratic VTTS values over the different groups of travellers (Subsection 7.5.3) allows a prediction of the extent to which each choice would be made. These are assessed in agreement with the EPT paradigm, which is simplified to a 70-30 distribution of choice behaviour strategies over LA(2,2) and LA(2,1), and UT, which assumes that all travellers follow the LA(1,1) strategy.

F.1 Trip cancelling and car pooling

An obvious operational choice alternative that prevents payment of the license fee is to skip trips, or to move them to another time of the day or to a destination outside the Restricted Zone. It is easy to see that, where this alternative is feasible it dominates all travel alternatives. Skipping and moving were common practice for the about 1,000 trips to the Restricted Zone with a discretionary purpose, like shopping, social and recreational activities. Car drivers who carried a passenger made almost all these trips.

Trip cancelling for other reasons than coping with the ALS fee is discussed extensively in Annex C. Clearly these changes in car traffic are not the result of operational travel choices by car driving commuters. A shift to non-motorized travel modes and employment of light vans for commuting might have had similar impacts on the reduction of car traffic after ALS enforcement. The consulted literature offered no leads for an assessment of the trade-offs that resulted in such choices.

Carpools were exempted from the license fee, provided that the car had at least three passengers in addition to the driver. Some carpools took people for shopping or other purposes or even picked up passengers at bus stops. On balance this eagerness caused a small shift from bus transit to carpooling in the morning. However, in the afternoon over 20% of the carpool passengers went back home by bus. This behaviour was already observed before ALS enforcement, but at a smaller scale. Obviously, they left vehicles that did no longer comply with the four-person carpool criterion and thus increased the populations of car drivers and car passengers compared to carpool participants, but this did neither affect traffic flows nor license fees.

As discussed in Annex C the great majority of new carpools were formed by car passengers and the drivers who carried them. The household survey showed that pre-ALS car drivers who, post-ALS, joined a carpool as driver or passenger kept about the same travel time. One does not need calculations to see that carpooling was a dominant alternative for them, particularly if the pool shared the travel costs. It is not hard to conceive that many car drivers who considered potential carpools would expect at least a few minutes additional travel time for picking up passengers. As any information about such 'would-be' travel time losses is lacking, the reference-dependent trade-offs of joining a carpool versus other feasible alternatives cannot be made here.

F.2 The 'keep your mode and schedule' and bus riding alternatives

Following the ALS introduction, car drivers could not stick to their reference state[144] when they considered visiting or traversing the Central Business District in the restricted period. For solo car drivers with a destination in the Restricted Zone the 'keep-to-your-mode-and-schedule' alternative (further referred to as 'KYMS') incurred a license fee of S$3.00 and an increase of S$0.75 in parking expenses on a daily basis (see Table D.1 on page 357 for these and successive attribute levels). Solo car drivers who passed through the Restricted Zone to a destination beyond it had to pay the same S$3.00 license fee plus an average S$0.30 increase in parking expenses. For car drivers who took passengers along, the monetary costs were estimated at slightly more than half these amounts. The increased speeds in the Restricted Zone implied a small one-minute travel time gain compared to the pre-ALS circumstances. The KYMS alternative is considered as the 'default' alternatives for pre-ALS car drivers who

[144] As four-person carpools did not fall under the license obligation, the responses of pre-ALS carpool drivers to the introduction of ALS are disregarded in this chapter.

were not able to find a cheaper alternative that complied with both their constraints and idiosyncratic minimum VTTS-thresholds.

The most obvious default alternative for car drivers who were not able to find a faster alternative that complied with both their constraints and idiosyncratic maximum VTTS-threshold was to switch to bus transport. For the average solo car driver who worked within the Restricted Zone this cost an additional nineteen minutes travel time in the morning and twenty in the afternoon, plus a loss of comfort and the expense of two S$0.40 bus tickets. For destinations beyond the Restricted Zone, the travel time increases would be eighteen and nineteen minutes, and the bus tickets would cost S$0.50 twice. The mode shifters would gain the running and parking costs for their trip.

According to the value function discussed in Section 7.4 and disregarding differences in comfort, a pre-ALS solo car driver who went to work in the Restricted Zone would after ALS enforcement, prefer the KYMS alternative to a change to bus riding if:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * 0 + 1\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-3 - 0.75) + 0\}[\text{S\$}] > VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-18 - 19) + 0\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.4) + 2 * 0.85 + 2.5)[\text{S\$}]$$

Solo car drivers who applied LA(2,2) would prefer the 'low travel time' KYMS alternative if their VTTS was slightly above S$8/h. Comparison with the VTTS distribution of pre-ALS solo car drivers as found according to the corresponding LA(2,2) appraisal yields that this holds for 77%[145] of the solo drivers who went to the Restricted Zone daily. For LA(2,1) the break-even VTTS lies well below S$6/h, and according to the corresponding pre-ALS VTTS distribution 65% of them had a higher VTTS and would therefore be expected to choose KYMS. The assumed 70/30 distributions of these choice behaviour strategies under the EPT paradigm yields that 75% of the solo car drivers should keep to their pre-ALS mode. The break-even point according to LA(1,1) lies above S$11/h. Comparison with the corresponding VTTS distribution yields that 30% of them would be better choosing the KYMS alternative while the others should switch to bus riding. The corresponding frequencies for Restricted Zone-bound drivers who carried passengers were virtually the same as for solo drivers. A similar assessment for solo car drivers who worked beyond the Restricted Zone yielded frequencies of 85% for EPT and 45% for UT. The corresponding frequencies for drivers of rideshares were 90% and 60%.

The ratio of solo car drivers to the Restricted Zone who actually kept on driving during the restricted period to those who became conventional bus passengers was about 5:1 (see Table C.3 on page 344). This ratio is higher than the 3:1 ratios that were predicted according to the reference-dependent trade-offs discussed above. The reference-independent, loss-neutral appraisals predicted a ratio 1:2.3 for solo drivers. For rideshare drivers the actual ratio was about 1:1 whilst EPT also predicted 3:1 and UT about 1:1. Obviously, for commutes to the Restricted Zone the reference-dependent predictions offer better approximations of the actual observed choices of solo drivers than the reference-independent ones.

[145] In view of the highly aggregated data on which the assessments of the lognormal frequency distributions were based this and similar percentages should not be considered as exact measures of the size of population segments but as order-of-magnitude estimates. To prevent the pretence of exactitude they will further be rounded off to multiples of 5%.

For drivers of rideshares the reference-dependent predictions suggest that their calibrated VTTS values might have been too high, while the reference-independent one suggests that their VTTS distribution was too low. A more plausible explanation for the relative underestimation of the shift to bus riding might be that the assumed 40% share of the passengers in all travel costs, including the increased parking fees and the ALS fee, was too high. When considering the choice behaviour of these passenger one should take into account that their median VTTS, assessed as described in Subsection 7.5.3, was 40-50% below that of their drivers. A similar assessment as described above for the solo and rideshare drivers revealed that 45, 45 and 80% of the car passengers would prefer a change to bus riding over KYMS according to the LA(2,2), LA(2,1) and LA(1,1) algorithms, respectively. About 50, 55 and 85% of their drivers would also prefer the bus, if they had to pay the whole license fee and parking cost increase, while only 20, 35 and 70% would do so if their passengers were willing to pay 40% of these cost increases. Taking this into account the predicted modal split of pre-ALS rideshare drivers comes closer to the observed travel behaviour. A more solid comparison of the validities of the reference-dependent and reference-independent paradigms requires the assessment of the choices for other alternatives than KYMS or conventional bus transit.

About 1,500 car drivers who traversed the Restricted Zone while on their way to work beyond it kept on car driving according to their schedule while very few of them shifted to bus transit. According to EPT 85 to 90% of the car drivers would prefer KYMS over bus riding against 45 to 60% according to UT. The share of the car passengers who might have preferred a change to transit over paying 40% of the license fee was 20% according to LA(2,2) and LA(2,1) and 50% according to LA(1,1), indicating that their choices might cause a few percent additional shifts to transit. For the car trips with destinations beyond the Restricted Zone the findings from the reference-dependent assessments are thus much more plausible than from the reference-independent ones.

F.3 The ‘make-a-detour’ alternative

Car drivers who only traversed the cordon on their way to a destination outside the Restricted Zone might choose the few kilometres detour that circumvented it in the morning and might keep on traversing the Restricted Zone in the license-free afternoon. For the average solo driver this results in a S$0.20 increase in distance-related running costs, a seven minutes travel time loss and a S$0.30 increase in parking costs, all compared to the pre-ALS reference. Substitution of the appropriate attribute levels in the value functions yields the following trade-off against the KYMS alternative:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-7)\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-0.2 - 0.3) + 0\}[\text{S\$}]$$
$$> VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (0) + 1\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-3 - 0.3)[\text{S\$}]$$

Applying LA(2,2) yields that for individuals whose VTTS was below S$21/h it would be worth making such a detour to avoid the license fee. For LA(2,1) this value was S$10/h and for LA(1,1) S$20/h. Comparison with the corresponding VTTS distributions showed that according to the reference-dependent appraisals 65-70% of the solo drivers would be better making the detour than sticking to KYMS, whilst according to a loss-neutral valuation 90% of them should do so. For drivers carrying passengers these percentages were the same.

The comparable formula for the trade-off with a shift to bus riding reads:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-7)\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-0.2 - 0.3) + 0\}[\text{S\$}]$$

$$> VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-18-19) + 0\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.5) + 2 * 1 + 1)\}[\text{S\$}]$$

Car drivers who follow loss-aversive appraisals with respect to travel time changes would prefer the detour if their VTTS was above S$1/h to S$3/h. This held for 95 to 100% of them. The corresponding percentages according to the UT paradigm were 70% for the solo drivers and 85% for those who carried passengers.

On balance, according to EPT 65% and following UT 65-70% of all car drivers would prefer the average seven-minute detour over KYMS and over a change to bus riding. Similar percentages were assessed for smaller and larger detours, within the range discussed in Annex D. When a three-minute detour was needed 95% would choose this according to EPT and 75-90% according to UT. When the detour required ten minutes additional driving the propensity to choose it was 30% for EPT and 30-45 for UT. Under the assumption of a normal distribution of the detour distance (mean 2.5 km and standard deviation 1.5 km) across the drivers concerned all appraisals indicate that a majority would choose for the detour option if only KYMS and bus transit were available alternatives. According to EPT less than 5% of the car drivers would prefer a change to bus riding over a detour while about 30% would choose KYMS. Following UT about 25% would change to bus riding and about 10% would keep on driving. According to Annex C a negligible number of car drivers changed to bus riding while the number of drivers who kept to their schedule and mode was only one-third of those who made the detour. The loss-neutral appraisal obviously overestimated the change to bus riding.

F.4 The Blue Arrow and Air Conditioned Coach alternatives

The Blue Arrow and Air Conditioned Coach express bus services were initiated to provide a ‘comfortable’ alternative for car drivers. With a single trip fair of S$0.50 it offered a service every fifteen minutes for two hours in the morning and 2.25 hours in the afternoon. The Air Conditioned Coach service was another alternative offered to persuade car drivers to take the bus. At S$1.00 for a single trip with a luxurious coach, it offered transfer to the Restricted Zone in the morning and back in the afternoon.

As discussed in Annex D these services might offer a travel time gain of up to five minutes compared to a conventional bus service for a minority of about 10% of the commuters. Traded off against a conventional bus trip the Blue Arrow service would be chosen by car drivers with a VTTS of more than S$0.5/h to S$1.0/h, which holds for almost 100% of the pre-ALS car drivers. Virtually all pre-ALS car drivers for which it offered this level of service would thus reject the conventional bus in favour of the Blue Arrow. The threshold VTTS where the Blue Arrow service would be preferred to KYMS lay 10 to 20% above that for the conventional bus service. These findings hold for both solo drivers as well as drivers who took passengers, and according to all the paradigms considered. It makes the Blue Arrow service attractive for 35-55% of the drivers if they followed a loss-aversive appraisal and for about 80% of those who are loss neutral. The more expensive Air Conditioned Coach service would only be chosen over KYMS and the common bus by a few percent of the solo car drivers. All these preferences for the express buses assumed a trip five minutes faster than that offered by the existing conventional bus services.

Similar trade-offs were made between the continued use of conventional buses by car owners and a switch to the new express services. About 90% of the pre-ALS bus riders had a VTTS that made the five minutes time gain per trip offered by the Blue Arrow more attractive than the additional S$0.10 extra expenses. For 10 to 15% of them the Air Conditioned Coach

service was also worth the associated additional expenditure. These outcomes were found according to all the algorithms considered.

In the VTTS threshold assessments above the differences in 'comfort' between the considered services were disregarded. If comfort had more than a marginal impact on operational travel choices, a switch to the on-average more moderate and less crowded Blue Arrow express buses should have been attractive for many passengers of the conventional bus services even if they offered no travel time gains at all. However, the few changes of bus riders to the Blue Arrow service could easily be explained by the expected time gain. A similar observation holds for the switch to the Air Conditioned Coach services by the more wealthy pre-ALS transit passengers and the pre-ALS car drivers who shifted to public transport. Their limited attraction suggests that most travellers did not value the additional comfort of the Air Conditioned Coach and Blue Arrow services as a counterbalance for more than a few minutes additional travel time.

F.5 The Park-and-Ride alternative

The 'official' park-and-ride alternative offered ample parking space and a bus shuttle to three locations in the Restricted Zone at S$1.50 a day. According to the overview in Annex D the S$2.50 daily parking costs are saved and the ALS fee does not have to be paid. Twice a day it adds at least seven minutes travel time to the car trip, while for less lucky travellers the additional travel time might amount to about fifteen minutes. Solo car drivers who valued both travel time and cost changes loss aversively would prefer park-and-ride with seven minutes additional travel time over KYMS if their VTTS was below S$14/h but would take the bus instead of park-and-ride if their VTTS was below S$4/h. This holds for 50 and 5% of them, respectively. The corresponding percentages for the EPT paradigm were almost the same, for the UT paradigm they were 85 and 60%. Overall, this yields percentages of between 45 and 50% of the solo drivers for whom park-and-ride was the best option, according to all paradigms. These percentages applied only to those travellers for whom park-and-ride offered the best achievable travel time increase compared to driving. At increasing travel times the percentages dwindle to 10% for the average eleven minutes time loss and become zero from twelve minutes onwards, when no one would choose it, again according to all paradigms.

Assuming that the additional travel time compared to the car trip was seven minutes, for car drivers who carried a passenger park-and-ride would be an interesting option for 5-10%, depending on the paradigm considered. An increase in travel time of less than a minute suffices to make it unattractive according to all the valuation algorithms considered. For these assessments it is assumed that both car passengers and their drivers had to pay S$1.50 per day for the shuttle service. If all car occupants were allowed to travel on one ticket one would find similar percentages as for the solo drivers.

If KYMS, bus transit and park-and-ride were the only feasible alternatives for travel to the Restricted Zone and a normal distribution is assumed for the additional travel time for park-and-ride compared to car driving, only 15% of the solo car drivers would choose for park-and-ride. All different valuation rules yielded this result. This implies that between 1,000 and 1,500 of the 10,000 lots in the fringe car parks would be occupied. In practice the park-and-ride scheme was even less successful: only 600 places were actually used. The Singapore business community anticipated this lack of popularity even before the enforcement of ALS: '*There was agreement that the Park-and-Ride Scheme would probably not be popular: first, time would be lost in the transfer process; second, the cars would be left exposed and unused in the fringe parking lots; and third, the cost did not compare favourably with other forms of public transport*'

(Watson and Holland 1978: 214). The time loss and relative cost considerations are supported by the appraisals above. These appraisals might have overestimated the actual employment of the parks. The disinclination to leave the car behind in the fringe car park might have explained this difference between prediction and observation. It could have been simulated by adding a dummy variable to the value function of the KYMS alternative, as this offers the same car parking conditions as the reference state. However, before jumping to conclusions one should consider the other feasible alternatives to the ALS fee.

F.6 Advancing home departure time without changing work start time

An obvious way to avoid payment of the ALS fee was to advance the home departure time to such an extent that the cordon was passed before 7:30 a.m. Compared with the pre-ALS reference, advancement of the home departure implies a loss of discretionary time spent at home. If the work start time cannot be advanced it causes a 'useless' early arrival at work. In the present tactical choice frame the early arrival is considered to be valued at the same rate as travel time, i.e. as the discretionary time lost due to the earlier home departure. Essentially, this follows Gaver's '*linear cost of headstart*' model that he considered '*more reasonable* (than the currently common schedule-delay approach) *under many circumstances, for here the headstart time is completely wasted even if the traveller arrives early*' (Gaver 1968: 175). A traveller who, before ALS enforcement, passed the ALS cordon after 7:30 a.m. and intended to cross it a quarter of an hour earlier to avoid the license obligation would thus lose that quarter of an hour at home. As discussed in Annex D, the post-ALS traffic density just before 7:30 a.m. may imply an increase in travel time of five minutes, which should be added to the advancement. Compared to the pre-ALS reference the increase in parking fees should be added to this time loss. For home departure advancements up to half an hour, most drivers would have experienced the same increase in travel time in the area around the cordon if they choose to arrive at work at the same time as before. Their KYMS alternative should then contain a five minutes time loss as well. Substitution of the relevant attribute levels for a solo car driver who works within the Restricted Zone yields that the commuter might have preferred such an advancement above KYMS if:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-15 - 5)\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.75)\}[\text{S\$}]$$
$$> VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-5)\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-3 - 0.75)\}[\text{S\$}]$$

A solo driver who exhibited LA(2,2) would prefer this advancement alternative over KYMS if her VTTS was below S$12/h. The trade-off with bus riding yields a VTTS > S$6/h. About 30% of the solo drivers and 20% who drove a passenger had a VTTS in between these thresholds. Loss-neutral valuation of changes in monetary expenses leaves no drivers between the thresholds, both according to LA(2,1) and LA(1,1). According to similar assessments with the LA(2,2) algorithm, advancements of fifteen and ten minutes would be chosen by 55% and 85% of the solo car drivers who applied LA(2,2) and by almost the same percentage of the other drivers. If they followed LA(2,1) these percentages would be 30 and 65%, and LA(1,1) would yield 25 and 45%. No paradigm explained advancements of 25 minutes or more. For destinations beyond the Restricted Zone the corresponding marginally acceptable advancements were about five minutes greater all along the line. The previous assessments indicate that the choice between the advancement of home departure and either bus riding or the KYMS alternative strongly depends on the commuter's usual pre-ALS interval between arrival at work and work start time. The degree of earliness in arrivals at work compared to work start time has thus to be assessed before a prediction of the expected number of advancements can be made.

According to the analyses of the data of Wilson (1988b) in Annex C, about 35% of the commuters with a pre-ALS work start time at 8:00 a.m. arrived at work around 7:35 a.m. or earlier. For them, advancements of five minutes would suffice for a timely crossing of the cordon. Following the reference-dependent appraisals discussed above such small advancements dominate KYMS. According to EPT they are also more attractive than a shift to bus riding for 85-95% of all drivers according to EPT and for 50-55% following UT. Another 15% of the commuters arrived around 7:40 a.m. The required ten minutes advancement would be chosen by 80% and 45% of the solo drivers according to the EPT and UT paradigm, respectively. At about 7:45 a.m. 15% more arrived, requiring advancements of about fifteen minutes. This would be worth it for 45% of them according to EPT and for 25% according to UT. The 15% of the drivers who arrived at about 7:50 a.m. and were valued according to LA(2,1) or LA(1,1) would reject the advancement in favour of KYMS or a shift to bus riding. Only 30% of the solo drivers who chose according to LA(2,2) would choose for advancement. For the remaining 20% of commuters, who were used to arriving less than ten minutes before 8:00 a.m., advancement without adjustment of the work start time was not an attractive alternative, whatever the applied choice paradigm. The same holds for workers with a later work start time. The application of the previous percentages to the 1,500 car drivers with a work start time of 8:00 a.m. yields 800 advancements of home departure time without adjustment of work start time according to EPT and 400 according to UT. To these figures should be added at most a hundred commuters with a work start time of 7:45 a.m. The numbers according to EPT largely agree with the 900 ‘retraced’ actual advancements as listed in Table C.3 (page 344) while those in agreement UT underestimate these.

Car drivers who went to work beyond the Restricted Zone might have needed ten or more minutes to cover the distance between the ALS cordon and the workplace. If one assumes that they kept to a similar pattern of early arrivals as shown in Figure C.2 (page 341) for the 8:00 a.m. work start time in the Restricted Zone, about 50% of the drivers who arrived before 7:45 a.m. had already passed the cordon by 7:30 a.m. For them, a few minutes advancement to cope with the increased pre-7:30 a.m. traffic would be sufficient to avoid the license obligation. Most will not have contributed to the increase in pre-7:30 traffic counts and their advancement will not have been noticed in the household survey. These advancements should thus be disregarded for the predictions aimed at a comparison with the actual observed travel choices. The other drivers who started work at 8:00 a.m. would need to leave between ten and twenty minutes earlier. Assessments according to all considered paradigms yield that 40-55% of these workers would be better advancing their home departure and early arrival times to a sufficient extent than sticking to KYMS or changing to the bus. Applying the relevant percentages to the 40% of drivers with a work start time of 8:00 a.m., as estimated in Annex C, predicts 1,200 advancements according to EPT and 1,100 according to UT. These predictions are both clearly above the 800 retraced advancements as listed in Table C.3 (page 344). The UT paradigm performs slightly better.

F.7 Late arrivals and reliability

According to the starting points for the present assessments (Subsection 7.4.5) commuters limit the chance of late arrival at work to a certain idiosyncratic extent that is assessed at a higher level of the strategic-operational choice hierarchy, notably the employment contract decision level. They are well acquainted with the day-to-day variation in their commute duration and will primarily adjust the ‘discretionary’ or ‘home’ side of their journey when they are confronted with changes in the travel time distribution. Large interpersonal differences in the acceptable chance of late arrivals at work should be expected, depending on employment status and/or position in the work place hierarchy. These hypotheses therefore

imply that the distribution of early and late arrivals at work should not change significantly as a consequence of the enforcement of the ALS, unless advancement or postponement is required to avoid passage of the ALS cordon during the restricted period.

The cumulative distributions of the arrival and work start times of commuters who work in the Restricted Zone provide a broad outline of the appropriateness of these assumptions. The most conspicuous observation might be the difference in the extent of early versus late arrivals between car using commuters and transit passengers (see Annex C). Car drivers and their passengers arrived on average about fifteen minutes early, and bus[146] riders ten minutes. This might be caused by differences in the way in which commuters deal with travel time unreliability in relation to arrival time. The traffic situation in Singapore city was congestion-prone, with average traffic speeds below 20 km/h before and just above 30 km/h after ALS-implementation. In the absence of motorways and in view of the many intersections this will have caused a considerable scatter in travel times. Under such conditions and with an average trip duration of about 30 minutes by car and 45 minutes by bus, both bus passengers and car occupants might commonly experience delays of five minutes and should take much higher incidental peak delays into account. A similar pattern of travel time variability during the morning commutes was found in comparable situations elsewhere in the world (e.g. Small 1982; Hensher 2001b; Hollander 2006). Unreliability might also be an explanation for the large and seemingly stochastic differences between pre-ALS and post-ALS travel times from the same origin to the same destination: Watson and Holland (1978) found that 17% of the car drivers reported a decrease of more than five minutes whilst 19% reported an increase of the same size. They reported corresponding percentages of 21% and 30% for bus riders. If pre-ALS early arrivals were conceived as a margin to cope with unreliability in travel time, Watson and Holland's findings suggested that bus riders should arrange for a higher rather than a lower margin compared to car drivers. However, one should consider that most car drivers will have been well aware of the uncertainty in travel patterns and might generally have felt themselves responsible for an appropriate trip schedule to cope with it. Therefore, they might find no excuses for late arrivals as a consequence of departing too late. Bus passengers buy a journey that may be assumed to follow an appropriate timetable and might hold the bus company responsible for an arrival time according to that schedule. Thus they could blame the bus company for arrivals after the work start time.

Interpersonal differences in dealing with travel time uncertainty may also explain the conspicuous reduction of the margin between arrival and work start times from 9:00 a.m. onwards, that holds for bus riders as well as car occupants (see 1C.2 on page 345). This pattern is similar to that found by Hendrickson and Plank (1984) for the morning commute to Pittsburgh's Central Business District, for example. If the apparent dispersal in arrival times for the same work start time is conceived as the consequence of differences in dealing with unreliable travel time, a significant number of the respondents arrived several minutes after their work start time. The decreasing early arrival margin for later work start times might be attributed to changes in the composition of the travelling population. Wilson (1988a) analysed the effect of the profession on work start time in Singapore. Almost 45% of his respondents with a work start time of 9:00 a.m. onwards were professionals or sales personnel, 18% were 'blue-collar' workers[147] and the remaining were clerical workers. Professionals and sales personnel numbered only 34% of the respondents with a work start time before 9:00 a.m. while 31% were blue-collar workers and 35% clerical workers. The share of white-collar

[146] Almost all Wilson's '*other car-owning commuters*' were bus passengers.
[147] This term is used here to cover the skilled/semiskilled, unskilled and service workers and workers in transport and communication as discerned in Wilson (1988a).

workers and/or individuals who are high in the work-place hierarchy apparently increased with a late nominal work start time. This may explain the corresponding decline in unreliability margin, as it is a well established fact that these employees are less likely to be challenged for arriving late (e.g. Small 1982; Fujii and Kitamura 2004).

The enforcement of ALS caused an increase in traffic flows directly before and after the restricted period (see Subsection 7.2.2). Most post-ALS car drivers with a work start time up to 8:00 a.m. thus experience a longer travel time and less reliability than the pre-ALS car drivers with the same work start time. They also arrived, on average, two minutes earlier. However, this advancement might be better explained by the intention to cross the cordon before 7:30 a.m. Traffic conditions also worsened after 10:15 a.m. and the diagram for post-ALS car users indicates a strong decrease in earliness, which might be explained by the urge to pass the cordon after the restricted period and the supposed high position in the work-place hierarchy of this group. The survey sample on which these indications are based is, however, much too small to be able to draw firm conclusions. The average earliness of car commuters with a work start time between 8:01 and 10:15 a.m. remained virtually unchanged. As most shifters will have had a higher position than the pre-ALS bus riders this may explain the small over-all decrease in earliness of the 'other' post-ALS commuters.

The preceding observations yield strong indications for non-stochastic effects of travel mode as well as job characteristics on the probability of late arrival at work due to travel time uncertainty. Based on the recovered aggregated survey results, most bus passengers and employees that are higher in the work-place hierarchy seem to accept a higher risk of late arrivals than car drivers and workers in the lower strata of the workforce. The observed changes in earliness and lateness of arrival times after ALS enforcement might be explained by these phenomena and by the aim to pass the ALS-cordon before or after the restricted period. No indications were found that travellers adjusted their early arrival margin after ALS enforcement to cope with the changes in travel time and reliability. One would need an econometric analysis of the individuals' pre-ALS and post-ALS reports of departure, arrival and work start times in connection with other socio-economic characteristics to reject this behaviour beyond doubt.

F.8 Advancement of the work start time

Part of the introduction of the ALS was a national programme launched by the government of Singapore to promote and encourage staggered working hours, to mitigate the effects of the ALS implementation. Ex-post interviews of business managers showed that '*the majority of respondents were in favor of staggered work hours. Several had staggered their own hours so that their business activities would not be affected by the traffic restraint scheme*' (Watson and Holland 1978: 218). It is assumed here that all employees who wanted to advance their work start time by up to half an hour were allowed to do so. Of course work start time advancement to 7:45 or 7:30 a.m. would suffice to pass the cordon before the restricted period. Taking the travel time from cordon to work plus an early arrival margin into account, work start time advancements to 7:45 or 8:00 a.m. and keeping the same early arrival margin might also have enabled many car drivers to avoid the license obligation.

A car driver who advanced their work start time from 8:00 to 7:30 a.m. and advanced her home departure time by the same amount would experience about the same or slightly better travel conditions, as the post-ALS traffic conditions before 7:30 were less congested than in the build-up to the heavily congested pre-ALS peak between 8:00 and 8:30 a.m. Disregarding the possible small time gain yields a loss of 30 minutes spent at home in the morning

compared with the pre-ALS reference and a gain of 30 minutes in the afternoon. Obviously, the post-ALS rise in parking fees should be taken into account but the expense of the ALS fee is prevented. For solo drivers the trade-offs against KYMS and bus riding are thus:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * 0 + 1\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-3 - 0.75) + 0\}[\text{S\$}]$$
$$> VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-30) + 30\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-0.75) + 0\}[\text{S\$}]$$
$$> VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-18 - 19) + 0\}[\text{min}] / 60[\text{min/h}]$$
$$+ \{\lambda_{\text{money}} * 2 * (-0.4) + 2 * 0.85 + 2.5)\}[\text{S\$}]$$

The loss-aversive solo driver ($\lambda_{\text{time}} = \lambda_{\text{money}} = 2$) would choose the advancement if S\$6/h < VTTS < S\$12/h, which holds for 30% of this group. However, over 80% of those who are also sensitive to time losses but consider changes in money expenses loss-neutrally would prefer to take the bus instead and almost all others would choose KYMS. When both time and money changes are treated loss neutrally, the advancements of home and work departure times compensate each other and thus the advancement of work start time dominates KYMS. It would also be preferred to bus riding by 60% of the solo drivers. The percentages of rideshare drivers who choose the work start time advancement were about 5% smaller. It is easy to see that, according to loss-neutral assessments, the dominance of advancement over KYMS holds for work start time advancements of any size. According to the LA(2,2) and LA(2,1) assessments, nobody would choose advancements of 45 minutes and more.

Most car drivers with a work start time of 8:00 a.m. might have compared the consequences of the half hour advancement of work start time with an advancement of home departure without adjustment of their work start time. According to EPT, car drivers who were used to arriving at work around 7:45 a.m. or earlier would prefer advancement without an adjustment of their work start time while those arriving at 7:50 a.m. and later would prefer to advance their work start time as well. As the latter group comprises about 35% of the 1,500 car drivers who had a work start time of 8:00 a.m., about 200 car drivers would choose the work start time advancement to 7:30 a.m., according to the EPT-appraisal. The previous loss-neutral trade-offs indicate that work start time plus departure advancement dominates advancements without work start time adjustments of all sizes. This yields 1,000 advancements of travellers with a work start time of 7:45 and 8:00 a.m. but it reduces the predicted number of departure advancements without work start time adjustment to zero.

Advancements of the work start time from 8:15 and 8:30 to 7:45 or 8:00 a.m. combined with advancement of the home departure time to pass the cordon before 7:30 a.m. implied a shift away from the pre-ALS traffic peak in which 29,900 vehicles per hour entered the Restricted Zone to the less congested new peak before the restricted period (23,000 vehicles per hour). This might yield a few minutes travel time gain compared to the pre-ALS trip but the KYMS alternative would yield an even greater improvement in traffic circumstances. Compared to the additional travel time required for a shift to transit these gains, which only apply to the morning commute, are rather insignificant. The difference in travel time between advanced departure time and KYMS is further disregarded here. One might further consider that the drivers needed at least five minutes to cover the distance from the cordon to the office. A home departure advancement of 30 minutes would thus suffice for those who were used to arriving at or before 8:05 a.m. and persevered in their early arrival behaviour, and would offer 30 minutes discretionary time gain in the afternoon. According to LA(2,2), 30% of the solo car drivers would prefer this to a change to taking the bus as well as to the KYMS alternative. The corresponding percentage was zero for LA(2,1) and 60% for LA(1,1). For drivers who took along a traveller the corresponding percentages were 5 to 10% lower. Car drivers who

arrived at 8:10 a.m. would have to depart 35 minutes earlier to gain 30 minutes in the afternoon. According to LA(2,2) and LA(2,1) this would be the best alternative for 10% and none of the concerned solo drivers drivers respectively. Drivers who were used to arriving after 8:10 a.m. would find no work start time advancement option preferable to KYMS as well as bus riding.

Before ALS enforcement almost 30% of the about 5,000 car drivers with an official 8:30 a.m. work start time and 80% of the 300 with a work start time at 8:15 a.m. arrived at or before 8:05 a.m. while 15% arrived at about 8:10 a.m. Under the assumption that every commuter was allowed to advance her work start time at will, EPT predicts 400 work start time advancements and UT 3,000. After addition of the advancements by drivers with a work start time of 7:45 and 8:00 a.m. EPT predicts 600 work start time advancements, which is close to the 700 listed in Table C.3 (page 344). The 4,000 advancements as found following the UT paradigm overestimates this heavily.

Car drivers who travelled to work beyond the Restricted Zone will have needed at least ten minutes to arrive at work after they passed the cordon, instead of five minutes for those with a destination within the Restricted Zone. About 40% of them might have started work at 8:00 a.m. According to the LA(2,2), a half hour advancement of work start time to 7:30 a.m. would be preferred to KYMS and bus riding by about 40% of the solo drivers and 30% of the rideshare drivers. The same holds for about 25% of both groups according to LA(2,1) and for 85-95% according to LA(1,1). However, an ‘average’ detour via the ring road would be more profitable. According to all reference-dependent appraisals, departure advancements up to almost twenty minutes without work start time adjustments appear more profitable than a half hour advancement of departure plus work start time, whilst following UT the departure time plus work start time advancement would be preferred above all but the smallest advancements without work start time adjustment. Assuming the same distribution of earliness as for the car drivers who worked within the Restricted Zone, EPT predicts about 200 work start time advancements and UT about 2,000.

Car drivers who worked beyond the Restricted Zone and started work at 8:30 a.m. might have advanced it to 8:00 a.m. A home departure advancement of 30 minutes would thus suffice for a timely crossing of the cordon by the drivers who were used to arriving at work at or before 8:10 a.m. Following similar appraisals and trade-offs with other feasible alternatives, EPT predicts another 200 advancements and UT 2,000. Altogether EPT predicts about 400 advancements of work start time by car drivers who crossed the Restricted Zone on their commute to work beyond it and UT over 4,000. The latter paradigm strongly overestimates the 300 retraced actual travel choices and the reference-dependent appraisals do the same, though to a much lesser degree.

F.9 Combined work start time adjustments, carpool joining and other travel modes

Watson and Holland observed that the advancement of work start time could not be found again in an on average earlier home arrival time. This implies that it yielded no value for the concerned commuters, at least at this aggregated level. However, for many travellers it might have been advantageous to use different travel modes and schedules for the morning and evening commutes (Annex C). Some of these alternative tours are considered here.

One tour alternative was a 30 minutes advancement of work start time by a solo car driver to comply with a carpool’s schedule that she could join for free, followed by a 30 minutes earlier

return home by bus, for lunch or in the afternoon. The additional travel time due to the slower bus trip reduces the travel time gain in the morning. According to the reference-dependent appraisals this schedule advancement-carpool-bus transit alternative appeared to be dominant over whole-day bus transit for any VTTS and was preferred to KYMS by a distinct majority of all car drivers. According to the reference-independent appraisal this holds for almost 100% of them.

The same trade-off, but with a half hour postponement instead of advancement adds the additional bus travel time to the discretionary time lost in the morning. A reference-independent, loss-neutral evaluation yields the same almost 10% preference for this alternative as for the previous one but reference-dependent appraisals now yield that only a few percent would prefer this to a 'complete' shift to bus ridership.

When the same half hour work start time adjustment-carpool joining alternatives are considered from the perspective of a pre-ALS bus passenger, a work start time advancement reduces the loss of discretionary time in the morning with the decrease in travel time caused by the shift from transit to carpool while postponement increases the gain. According to a reference-dependent evaluation, joining the carpool in the morning in combination with an half hour advancement would be preferred over continuation of whole day bus ridership by 25% of the car-owning bus riders while only 2% of them would choose it in combination with the same postponement. A reference-independent evaluation yields no difference and shows that any degree of work start time adjustment combined with a shift to carpooling in the morning dominates whole-day bus riding.

Looking at the previous reference-dependent assessments, joining a carpool appears attractive for many car occupants as well as bus riders, even at the cost of a 30 minutes forward shift of work start time. According to the reference-independent appraisals, carpool joining in the morning dominates the continuation of both car driving and bus riding, irrespective of the kind and degree of work start time adjustment that is required. Relative distributions of car occupants' work start time before and after ALS enforcement, based on the data presented in Watson and Holland (1978) as well as Wilson (1988b), show an on balance increase up to and including 8:30 a.m., followed by an on balance decrease thereafter. This agrees well with the relative increases, following ALS enforcement, in the home departure times of car drivers between 6:00 and 7:00 and of carpools between 7:00 and 8:00 a.m. (Watson and Holland 1978: 94). These changes go together with similar changes in work finishing times before and after 5:01 p.m. They show that advancements of work start time were much more frequent than postponements and thus support the better descriptive performance of a reference-dependent compared to a loss-neutral evaluation of the choice contexts discussed in this annex.

It is hard to imagine that the many thousands of commuters who joined carpools after ALS enforcement would all have been able to do so without adjustment of their work start time. Staggering of working hours might have been an important success factor for the huge increase in car-pooling from 16% to 35% of all pre-ALS commutes by car. Its effect on the reduction in Restricted Zone-bound car traffic during the restricted hours might have been of the same order of magnitude as on the shift of car drivers to the period before 7:30 a.m. An econometric re-analysis of the individuals' reports of schedule adjustments along the lines discussed above might have yielded a more solid assessment of the extent of these effects. As mentioned above, the required personalized data could not be recovered for this study.

F.10 Postponing the work start time

Immediately after the ALS came into operation the number of cars that entered the Restricted Zone between 9:30 and 10:00 a.m. increased by about 1,500. As the traffic densities in the half hour after the restricted period were about the same as between 8:30 and 9:30 a.m. before the ALS was enforced, the drivers who delayed their schedule will have kept virtually the same travel time. Substitution of the relevant attribute levels of a solo car driver who works within the Restricted Zone in the value function yields the following comparison with the KYMS alternative:

$$VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (-30) + 30\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * 2 * (-0.75) + 0\}[\text{S\$}]$$
$$> VTTS_{\text{solocardr.}}[\text{S\$/h}] * \{\lambda_{\text{time}} * (0) + 1\}[\text{min}] / 60[\text{min/h}] + \{\lambda_{\text{money}} * (-3 - 0.75) + 0\}[\text{S\$}]$$

As in the present time discretionary time changes in the morning have the same value as in the afternoon this is the same trade-off as for an advancement of work start time from 8:00 to 7:30 a.m. According to the LA(2,2) algorithm the postponement would be preferred over KYMS by solo drivers with a VTTS < S$12/h, which holds for 40% of them. The corresponding trade-off with a modal shift to transit yields VTTS > S$6/h, applying to 90%. This leaves 30% of the solo drivers who would have preferred this postponement. An appraisal according to LA(2,1) shows that, depending on the driver's VTTS, all would prefer either KYMS or bus riding over postponement while LA(1,1) yields 55%. Consequently, the EPT assessment shows that about 20% of the drivers would prefer the postponement, less than half of the 55% predicted by UT. For drivers who carried a passenger the percentages are up to 5% lower. Assessments following the EPT paradigm show that a smaller fifteen minute schedule postponement would be attractive for an additional 40 to 50% of the drivers while nobody would choose a 45 minutes delay. The UT paradigm yields the same percentages as for a half hour postponement, as the reference independency and loss-neutral principles make the trade-off independent of the size of the schedule adjustment.

The aim of postponing the work start time was, of course, to avoid payment of the ALS license by passing the cordon after 9:30 a.m. In agreement with the previous assessments it is assumed that people arrived at the office about five minutes after crossing the cordon and that they stuck to their pre-ALS early arrival margin. Commuters with a 9:30 a.m. work start time arrived at work between 9:05 and 9:35 a.m. (see Figure C.2 on page 341), thus about 20% passed the cordon after 9:30 a.m. and needed no work start time postponement at all while for about half of them a quarter of an hour would be sufficient. The remaining needed needed half an hour's postponement. Application of the results of the postponement trade-offs above to the 11.5% of the pre-ALS car users with this work start time (Wilson 1988b) yields almost 1,000 postponements according to EPT and 1,200 for UT. About 600 of these would be postponements to 9:45 a.m. Although Wilson's data suggest that starting work a quarter of an hour before or after the hour was not popular the corresponding increase in the share of car users' work start time from 0.2% to 4.2% is not implausible, as in early 1975 4.3% of the car users had a work start time at 8:45 a.m. To the predicted number of postponements should be added another 100 postponements by drivers with a work start time of 9:15 a.m. Before ALS only a few percent of the approximately 8,000 drivers with an official work start time of 9:00 a.m. arrived more than five minutes after that hour these might add far less than 100 to the predictions. The resulting 1,200 and 1,400 delays in work start time as predicted by EPT and UT are below the 1,500 as retraced from the July 1975 traffic counts. One might consider that although the number predicted according to UT approaches the observed delays more closely they would grow to a multiple of it if the arbitrary restriction of work start time adjustments to at most half an hour, adopted solely for this paradigm, were dropped.

The increase in traffic after 9:30 a.m. motivated the government to extend the restricted period to 10:15 a.m. The reference-dependent algorithms showed that work start time postponements of 45 minutes were unattractive for all drivers, thus only individuals with a work start time of 9:45, 10:00 or 10:15 a.m. would adjust their work start time. Before ALS, the percentages of the car occupants with one of these work start times were 0.2%, 3.7% and 0.0%, respectively. It is worth considering whether the drivers who postponed their work start time to 9:45 or 10:00 a.m. following the initial ALS introduction might have postponed their start time again after its extension. Such a recurrent trade-off should be expected in agreement with the 'instant endowment' notion (e.g. Tversky and Kahneman 1991) as discussed in Chapter 4. As only a few percent of the less than 1,000 drivers with an initial or adjusted work start time of 9:45 a.m. will have arrived late enough to make a half hour delay sufficient to save the license fee their contribution to postponements will be negligible. The appraisals according to EPT predict that 300 of the estimated 1,200 drivers with an original or postponed work start time of 10:00 a.m. delayed their work start time. This is only 60% of the 500 actual postponements. The assessments in agreement with the UT paradigm resulted in 1,400 drivers with a work start time of 10:00 a.m. shortly before ALS extension, of whom 800 might have delayed it. The latter number is 60% more than the actual number of postponements. Again, the prediction according to UT is dominated by the arbitrary restriction of work start time adjustments to at most half an hour.

Similar calculations for car drivers who commuted to work beyond the Restricted Zone yielded almost one hundred postponements according to EPT. This is much lower than the prediction for destinations inside the Restricted Zone because of the lower overall number of car drivers who made that trip, the smaller share of them with a relatively late work start time and, more importantly, the attractiveness of a detour via the ring road. Here, too, EPT underestimates the approximately 200 actual postponements. According to the reference-independent appraisals work start time postponements of any size were just as attractive as equal advancements, as long as they enabled avoidance of the license fee, and also appeared to be much more attractive than any detour. Consequently UT predicts 900 postponements, or a multiple of it if the arbitrary 30 minutes maximum work start time delay constraint was dropped. This is far more than both of the actual work start time postponements.

Combining the predictions for commutes to and beyond the Restricted Zone yields 400 work start time-postponements according to EPT and at least 1,700 according to UT. Thus, if all employers allowed all car drivers to stagger their work start time without limits, the reference-dependent appraisals predict almost 60% of the 700 retraced delays while UT predicts more than twice that number. From the interviews with business managers held a few months after ALS enforcement and its extension it appeared that '*most respondents felt that they could not allow staff to start after 10:15*' though '*several had staggered their own hours so that their business activities would not be affected by the traffic restraint scheme*' (Watson and Holland 1978: 218). The 400 postponements predicted by EPT constituted about 25% of the drivers with an initial work start time of about 10:00 a.m. and 1% of all car-driving commuters. A large number of them may have been business managers or very high-ranking employees who were free to choose their office hours at will. Only a small part of the predicted postponements might thus have been cancelled for lack of employer's consent. The work start time postponements as predicted in agreement with UT constitute about 60% of the drivers with a work start time of 10:00 a.m. and about 5% of all car driving commuters. It seems reasonable to assume that only a minority got their employers' consent to start work after 10:15 a.m. The simplifying assumption that 'all employers consent in staggering of work hours' might thus be inappropriate for delays and could explain the overestimation of predicted compared to actual

delays. As the same evidence from the business interviews on which this explanation is based indicates few restrictions for work start time adjustments before 10:15 a.m. this also underlines the strong overestimation in the prediction of work start time advancements by the appraisals in agreement with UT.

F.11 Conclusions

The ranges of idiosyncratic VTTS values at which people would prefer a certain alternative that are assessed in agreement with EPT are most often well in line with the observed relative frequency of behavioural responses to ALS enforcement. Many assessments in agreement with UT approach these frequencies less closely. The most conspicuous difference concerns the propensity of drivers to pay the license fee and keep to their schedule rather than to switch to transit by bus. Averaged over solo and rideshare drivers and over trips into and through the Restricted Zone, the retraced trips in Annex C follow a 70:30 ratio where application of the EPT assumptions yields 75:25 and UT suggests 30:70. The propensity to continue driving the car to work beyond the restricted zone instead of making a detour or switch to transit were also better explained by the EPT implementation than by UT. An interesting finding is that the strong increase in carpooling was presumably facilitated by many limited adjustments of work start times, which consisted predominantly of advancements of up to half an hour. This preponderance of advancements over postponements is confirmed by the observed shifts in work start times as examined in Annex C. These appeared attractive for many car drivers

The different behavioural responses to the ALS enforcement as discussed in this annex clearly shows that the great majority of travellers only adjusted their behaviour to a small extent. For example, most car drivers who joined four-person car pools already carried a passenger, and small advancements of home departure time were more popular than large advancements of home departure and work start time, even if the earlier departure time due to the small advancement was completely wasted in waiting until work started. EPT took the adaptive character of human choice behaviour as one of its constituent principles. This apparently offers a better explanation and prediction of the behavioural responses of Singapore's car drivers to the ALS implementation than the principally constituent, context independent UT-paradigm.

Annex G
Long-term development of car use and income in Singapore

In the past decades the welfare of Singapore's inhabitants has grown enormously and the land-use pattern and transport system has changed to a comparably large degree (Section 7.2). These dramatic developments have obviously led to important changes in the traffic flows and travel conditions during the morning commutes. Section 7.8 explores the extent to which Extended Prospect Theory and Utility Theory are able to predict the changes in the travel behaviour of car owners elicited by these long-term developments. This annex aims to establish the exogenous variables for the prediction models and the actual observed changes in travel behaviour. It describes the assessment process that yields the relevant quantitative contextual information about the morning commute of car owners with a destination in the Restricted Zone, for the years in which important changes in the road-pricing regime were brought into operation. These years and changes are: 1980, Area License Scheme (ALS) fare increase; 1989, cutback in ALS fares, extension of charging to carpools, goods vehicles and motorcycles and extension of the restricted hours; 1994, further extension of the restricted hours; 1998, replacement of the manually operated ALS by Electronic Road Pricing.

The introduction of the ALS in 1975 was unique because of the availability of the very detailed outcomes of the World Bank Survey. A re-examination of the travel choice behaviour from 1976 onwards has to rely predominantly on traffic observations – most often with no distinction in the different categories of motorized vehicles and the number of occupants per vehicle – and aggregate socio-economic and travel data for Singapore's population. Published information about the morning commute concerns either the commuting population as a whole or the commuters with a destination within and/or beyond the Restricted Zone. Most recovered information from the first decade after the 1975 ALS introduction relates to the latter category. From the last decade mainly nationwide information was retrieved.

The following sections successively list the recovered information about car ownership, car deployment, and the cost of travelling and household income. Each section starts with the information about the national level followed by the assessment of the information about the commuters who worked within or beyond the centre of Singapore, either as found in the

available literature or as inferred from interpolation or estimation of other relevant information.

G.1 Actual development of car ownership among commuters

Information about the motorized vehicles that were registered in Singapore was found in Spencer and Sien (1985), Willoughby (2000) and LTA (2007). Through comparison and combination of these data a reconstruction of the total number of private, company and hire cars in Singapore between 1975 and 2005 was possible. The 141,000 cars that were registered in 1975 declined by 5% during the 1975-1977 recession. Since then there has been continuous, robust growth, to 284,000 in 1990 and 441,000 in 2005, 3.5 times the 1996 number. This growth was interrupted by recessions in 1985-1986, 1998 and 2002 when it stagnated at 1.75, 2.9 and 3.0 times the 1976 number. Due to the concurrent strong population growth and decrease in family size the average number of cars (including company and hire cars) per household increased from 0.30 in 1976 to 0.35 in 2005[148]. The relative growth in percentage of the labour force was similar, from 15% in 1976 to 19% in 1990 and 2005.

From the analyses in Annex C it appears that in 1976 about 33,000 car owners worked in the Restricted Zone, equal to 16% of the jobs in that area and to almost 25% of all the car owners in Singapore. According to Willoughby (2000), between 1975 and 1978 the Restricted Zone provided 24% of the national employment. In connection with the long-term stability of the distribution of car ownership over the population it seems sound to assume that the car ownership of commuters who worked in the Restricted Zone developed at about the same pace as for the population as a whole. For a long time Singapore's land use policy has been to decentralize commercial and other economic activities through the development of regional centres (LTA 1996). This explains the decrease in the Restricted Zone's share of employment since 1983, when it reached 25%, via 21% in the 1986 recession year to 19% in 1996 (Willoughby 20001). Assuming a continued decrease at about the same pace yields a 17% share in 2005. Taking the nationwide growth of employment into account (Table 9 on page 191) this implies a growth of car-owning commuters with a job in the Restricted Zone to about 80,000 in 2005, which equals 20% of all jobs. Similar numbers for the years in which the ALS regime was changed were estimated by interpolation.

G.2 Deployment of cars for commutes to the Restricted Zone

G.2.1 Development of modal shares

From 1980 onwards, five-yearly assessments of the usual mode of transport to work were available for all commuters in Singapore, from population censuses and household expenditure surveys (Willoughby 2000; Singapore Statistics 2007). Between 1980 and 2000 the share of all commutes that were covered by private cars slowly but steadily increased from less than 14% to almost 24%, after which it slightly decreased to 23% in 2005. At the same time the share of transit (bus plus rail) decreased. The data for other modes are influenced by

[148] The highest car ownership ratios were found in the period from 1990 (0.38) to 1995 (0.39). In the intervening years ratios of 0.38 (1989 to 1994) and 0.39 (1994 to 1997) were attained. After that a decrease to 0.35 followed during the 1998 recession. All these ratios were assessed by dividing the registered numbers of private plus company plus rental cars by the estimated number of households, including non-residents. According to the 2003 Household Expenditure Survey report 30% of households possessed a car in 1988, 31% in 1993 and 35% in 1998 as well as 2003 while in an advanced data release of the 2000 census 28% was reported for 1990 and 31.7% for 2000 (Singapore Statistics 2007). These percentages might not include company and rental cars, which account for about 10% of all cars. They confirm the growth in average car ownership per household until 1998 and the stagnation after that year. They also show that few households possessed more than one car.

some changes in definitions but show a steady decrease in the share of walking, a small increase in taxi riding and stable shares of motorcycles and 'other motorized'. During all surveys bus, rail and private car together accounted for about 70% of all motorized commutes. The ratio between the number of commutes by car and by transit increased from 1:4 in 1980 to 1:2 in 2000 and 2005. The increase in commuting by car (drivers plus passengers) was much stronger than the increase in the average number of cars per commuter. This means that over the years a significant group of travellers, who commuted by transit while they already owned a cars, switched to commuting by car.

For travellers who worked in the Restricted Zone the analyses in Annex C showed pre-ALS 24:65:11 ratios for commuting by car, bus and other modes. After the enforcement of ALS the car-transit-'other' ratio changed to about 22:70:8. The 1976 fare increase caused a further decrease of the car share to about 21%. Compared with the national average, the car apparently accounted for a much larger share of the commutes to the Restricted Zone in the 1970s. This might have been facilitated by a higher occupancy rate of the cars that, in turn, might have been supported by the concentration of jobs in the Restricted Zone. From home interview data Gomez-Ibanez and Small (1994), cited by Evans *et al*. (2003), found a 23:69:8 ratio for 1983 and a 23:66:11 ratio for 1988, implying a small increase of the car: transit ratio. Although the increase is in line with the national trend[149] discussed above the growth rate is much smaller.

G.2.2 Development of car occupancy rates for commutes to the Restricted Zone

In the policy document that proposed the Area License Scheme and was annexed to Watson and Holland's (1978) report, '*A plan for the relief of traffic congestion in the city*', an average car occupancy of commuters in Singapore of 1.3 was mentioned. For commuters with work in the Restricted Zone a pre-ALS car occupancy rate of 1.6[150] follows from the modal share diagrams presented by Watson and Holland, increasing to 1.7 after ALS enforcement. For work beyond the Restricted Zone a 1.35 rate was found, both before and after enforcement. At the same time the share of 4^+ carpools in the total car traffic that entered the Restricted Zone during the restricted hours increased from 7% to 37%. After the 1976 fare increase this share increased further, to 49% in August 1976, which indicates a further increase in the average car occupancy rate to almost 1.8. According to Evans *et al*. the 4^+ carpool share in the total car traffic during the restricted hours peaked at 54% in the early 1980s and decreased to 34% in 1988, suggesting a car occupancy rate of almost 1.7. In 1989 the exemption of the license obligation for 4^+ carpools came to an end. No information is available about how this affected its share in the car traffic. Some indication about its effect on car occupancy is offered by Li (1999) who in the passing of a study on the appropriateness of the ALS fee mentioned an average 1.43 car occupancy rate for 1993. Taking into account the lower occupancy for destinations beyond the Restricted Zone this indicates car occupancy rates slightly below 1.5. It suggests a sudden drop, by maybe 0.1 to 0.2 commuters per car, in the average car occupancy as a consequence of bringing the 4^+ carpools under the license obligation. This drop apparently adds to a gradual decrease in average car occupancy for commutes to the Restricted Zone since the early 1980s. Extrapolation of this trend indicates an average

[149] Evans *et al*. found a strong decrease in the modal share of cars after 1976 but they mistakenly took Watson and Holland's data for the 1975 and 1976 vehicle owning population. The present analysis takes the modal choices of the non-vehicle owning households into account.

[150] One should note that only commuting passengers are considered in this annex. The actual car occupancy will definitely have been higher than the figures mentioned in this section.

occupancy of 1.3 to 1.4 in 2005. This is about the same as the pre-ALS rate for the country as a whole.

Some additional support for the sudden 1989 decrease in car occupancy follows from a comparison of the morning and afternoon commute. Evans *et al*. cite from a 1988 survey that in the afternoon only 3.6% of the car traffic by commuters consisted of 4^+ carpools while during the morning restricted hours this share was 34%. Watson and Holland's data indicate afternoon car occupancy rates of 1.45 before and 1.6 after ALS enforcement, which is 0.1 to 0.15 below the corresponding morning figure. For work beyond the Restricted Zone they found a stable 1.3 rate, also below the 1.35 rate found for the morning. Apparently, many carpools lost commuting passengers in the afternoon. A common explanation is that many carpool drivers picked up casual passengers at bus stops outside the Restricted Zone to comply with the criterion for ALS fee exemption (e.g. Evans *et al*. 2003). As the difference in car occupancy over the day already existed before the ALS was introduced avoidance of the license fee might only explain a part of it. Several 'frugal' activity scheduling strategies might explain the remaining. In addition to the fading out of 'occasional' carpools the 1989 decrease in average car occupancy was thus apparently realized by breaking up a sizeable number of stable rideshare arrangements.

Where the general increase in car ownership (see previous section) thus mainly affected the modal share of public transport it might have resulted in levelling out the initially high car occupancy rates for destinations in the Restricted Zone to about the national average, leaving just a few percent change in the modal split between transit and car.

G.2.3 The 1976 modal shares and schedules of car owners who commuted to the Restricted Zone

For the months following the July 1975 introduction of the ALS an elaborated 'retraced' estimate of the travel behaviour of the 33,000 car-owning commuters with a destination in the Restricted Zone was made in Annex C. These assessments were based on the numbers and categories of cars that, before the ALS was enforced, entered the Restricted Zone between 7:30 and 10:15 a.m. After allowing for the changes in traffic caused by the 1976 fare increase this estimate yields about 8,500 car entries during the Restricted Period, about 1,500 car trips that were advanced to the hour before the restricted period and 500 that were postponed until the hour after it, and about 7,000 cars that were not affected by the ALS enforcement because they kept on entering the Restricted Zone in the hours before and after the restricted period. Another 11,500 car-owning commuters went to work by transit and about 4,000 did so as a car passenger.

In 1976 about 4,000 of the 8,500 car owners who went by car to their work in the Restricted Zone during the restricted hours drove 4+ carpools. About 3,000 were solo drivers and 1,500 carried a passenger. Another 2,000 drivers crossed the cordon during the restricted hours on their way to work beyond the zone. The data in Watson and Holland show that on an 'average' 1976 weekday 3,100 privately owned and 1,700 company cars had acquired the ALS license. The 'missing' 700 cars might belong to categories that were exempted from the license fee, like tuition and Government-registered cars and hire cars (Spencer and Sien 1985). The number of car entries as inferred from different sources thus fit with one another.

G.2.4 The development of private car traffic during the restricted hours

McCarthy and Tay (1993) cited Menon *et al*. (1992) as the source for a diagram that depicted the development of the number of cars that between 1975 and 1990 entered the Restricted Zone during the morning restricted hours. After the drop to 25% of the pre-ALS level in 1976 this number increased to 20,000 in 1990, half the pre-ALS level. Except for small declines in 1977, 1986 and 1987, which may be attributed to economic recessions, the number of incoming cars grew each year. The growth in 1980, when the ALS fare was increased, was the same as in both the year before and after. In 1989, when 4^+ carpools and several other vehicle categories were brought under the license while the fare was strongly reduced, the increase was about 20% higher than in the preceding and succeeding year.

The development of car traffic as depicted in the diagram in McCarthy and Tay's article was compared with the overview of government income from the sales of Area Licenses between 1975 and 1994 as reported by Willoughby (2000). Taking into account the fares for the different vehicles that fell under the license obligation and assuming a slightly decreasing number of ALS-obliged company cars after 1976 (see Spencer and Sien 1985) enables an estimation of the number of license-obliged private cars that entered the Restricted Zone up to 1989 to be made. When the development in the percentage of 4^+ carpools (see above) is considered and a small number of hire car entrances are added this yields almost the same inbound car traffic as inferred from McCarthy and Tay's diagram. Obviously, the government income from ALS sales increased suddenly after the 1989 ALS regime change. About 50% of the increase could be explained by an increase in car traffic. If the total rate of increase in government income from ALS between 1990 and 1993 was used to extrapolate the 1990 car traffic this would yield almost 27,000 car trips by commuters during the morning restricted hours in 1993. This seems unrealistic as extrapolation proportionate to the national growth in car ownership yielded only 22,000 trips. As a compromise these figures are averaged hereafter.

From 1993 onwards only information about the total motorized traffic that entered the Restricted Zone each day could be retrieved. Phang and Toh (1997) reported that 47,800 motorized vehicles entered the Restricted Zone between 7:30 and 10:15 a.m. in May 1993. This means about 23,000 goods vehicles, taxis and motorcycles in addition to the cars used by commuters. For May 1994, after the extension of the ALS to include the period between the morning and evening restricted hours, Phang and Toh reported 60,200 entries. There is, however, no reason to assume that more than a marginal part of this increase concerned commuters. More sensible explanations for this increase include adjustment of the schedules for shopping and business trips, stock replenishing and so on that co-occurred with a strong decrease in inbound traffic during the hours that were brought under the license obligation. Taking the average overall growth in car ownership into account this reasoning yields 26,000 car trips by commuters for 1994.

Similar considerations to the 1994 ALS regime change might apply to the 16% reduction in registered traffic during the 7:30 to 9:30 a.m. morning peak-hour that Menon (2000) reported for 1999, as the drivers' response to the change from ALS to Electronic Road Pricing in 1998. This change meant that instead of the flat S$3.00 fare for the whole period from 7:30 to 10:15 a.m. the payments of individual drivers varied from S$1.00 to S$5.00, depending on the traffic and the gantries that were passed before the cordon was reached. Menon found that 95% of the drivers continued their trip as usual, 2% abandoned it and 3% new drivers compensated for this decrease. He found no modal shift from driving to transit. The bulk of the reduction could be explained by a reduction of the average number of Restricted Zone

entries per vehicle, either by making less trips to the zone or by planning the routes more carefully to avoid more than one passage of the cordon. Obviously, such adjustments in trip planning might have been feasible for taxi drivers, for stock replenishing operations and for shopping and leisure trips. The impact of the change in the road-pricing regime on the total number of commutes by car who passed the road-pricing cordon during the 7:30 to 10:15 a.m. period was thus negligible, though several drivers quite definitely adjusted their schedule within that period to some extent to avoid peak payments (Olszewski and Xie 2005). A combination of the data presented by Phang and Toh, Menon and Olszewski and Xie yields an increase between 1994 and 1998 of about 15% in motorized traffic during the 7:30 to 10:15 a.m. period to the Restricted Zone. At the same time car ownership in Singapore increased by 14%. Averaging both figures yields 30,000 commuting car trips in 1998. Adopting the successive national car ownership increase up to 2005 as an approximation yields about 35,000 car trips into the Restricted Zone between 7:30 and 10:15 a.m.

G.2.5 The development of private car traffic in the periods before and after the restricted hours

Data for the total inbound motorized traffic in the half hour before the restricted period (7:00-7:30 am) were recovered for 1975, 1976, 1993, 1994 and 1998. After ALS enforcement the traffic increased by about 1,000 trips to 11,000 in late 1975, and then remained the same during 1976. In the 1990s the number was about 8,500, indicating a decrease by 2,500 trips. The development in the number of inbound cars was only recovered for 1975 and 1976. This showed the same on-balance increase of 1,000 trips. As discussed in Annex C, the increase might be explained as the balance of a general decline in car traffic that was overcompensated by 1,500 advancements of home departures by car owners who worked in the Restricted Zone and an additional 800 advancements by car drivers who worked beyond it, thus compensating the general decrease in car traffic due to the economic recession. The 2,500 lower traffic flow density in the 7:00-7:30 a.m. period, as observed in the 1990s, might be caused by a shift back to the pre-ALS trip schedules of commuters who worked in the Restricted Zone in combination with the diversion of through-traffic from the Restricted Zone to the expressways that in the 1980s were put into operation and circumvented it. Both changes in travel planning presumably occurred for the major part in the 1980s and might have been completed after the 1989 fare decrease.

The total inbound motorized traffic flow in the half hour after the restricted period (10:15-10:45 a.m.) varied from 14,000 just after ALS enforcement to 11,000 after the 1994 extension of the ALS. The 600 car trips that, after the ALS was enforced, may have been postponed are within the reliability margin of the total traffic during this half hour. The possible rescheduling of these trips to the restricted period is therefore disregarded here.

G.2.6 Car trips by commuters who worked in the Restricted Zone

The estimated numbers of car drivers who passed the ALS cordon during the restricted period included commuters who travelled to work beyond the Restricted Zone. In 1976 they accounted for almost 20% of the inbound traffic. As mentioned before, toll-free expressways that circumvented the Restricted Zone came into operation in the 1980s. It is therefore very unlikely that car owners who worked beyond the zone would stick to a route through the zone, for which they had to pay the license fee and which would also take time. Presumably most carpool drivers who were used to crossing the zone will also have changed to the speedier expressways. It is therefore assumed that car traffic by commuters through the restricted Zone came to an end in the 1980s.

G.2.7 Development of the actual travel mode and schedules of car owning commuters with a destination in the Restricted Zone

The assessments in the previous sections are assembled in Table G.1. The figures are rounded off to multiples of 1,000 car trips to underline the order-of-magnitude character of the estimates. One should consider that, compared to the 1976-1990 period, the data for 1994, 1998 and 2005 are less reliable as they are not based on car traffic counts but inferred from developments on more aggregate levels.

In the considered period the average car ownership per worker in the Restricted Zone increased from 16% to 20%. Even in 2005 few households owned more than one car. Of course, between 1976 the number of households increased as the younger generations grew up and formed their own family units and households which comprised several families of more than one generation split up. This means that as from 1976 about 16,000 workers in the Restricted Zone who stemmed from households that had never owned a car came into a position where they had one at their disposal. As members of non-car owning households almost exclusively used transit for their commute, over the years an increasing number of transit passengers became car owner. This leaves an increase of 31,000 car owners who stemmed from car owning households and were presumably acquainted with daily commuting by car.

Table G.1: Car deployment by commuters who work in the Restricted Zone

Year	Commuters who worked in the Restricted Zone and entered it daily in the indicated period:			
	Car owners	Car (incl. carpool) drivers		Carpool drivers
	<10:45	<7:30; >10:15	7:30-10:15	7:30-10:15
1976	33,000	9,000	9,000	4,000
1980, before change in ALS fare [1]	39,000	9,000	12,000	6,000
1980, after change in ALS fare	39,000	9,000	12,000	6,000
1989, before ALS adjustments [2]	53,000	7,500	16,000	5,000
1989, after ALS adjustments	53,000	7,000	19,000	?
1994, after ALS extension [3]	65,000	7,000	26,000	?
1998, before ERP introduction [4]	77,000	7,000	30,000	?
1998, after ERP introduction	77,000	7,000	30,000	?
2005	80,000	7,000	35,000	?

[1] As of 1 March: Private cars from S$4/day to S$5/day, company cars from S$8/day to S$10/day, taxi remains S$2/day. [2] As of 1 June: Restricted hours extended to include the 4:30pm-7:00pm period. Private cars, hire cars, taxis and goods vehicles S$3/day, company cars S$6/day. From 1 July onward motorcycles and scooters S$1/day. [3] As of 3 January: Restricted hours extended with the 10:15am-4:30pm period. Reduced fare of S$ 2, 4 and 0.7 for entrance during the 10:15am-4:30pm period only. [4] As of 1 September: Replacement of the ALS by Electronic Road Pricing (ERP) with time-variable rates. Fare for entrance of private cars to the Restricted Zone from S$1/entry after 9:30am to S$2.5/entry between 8:30 and 9:00am. Travellers may also pay up to S$3 at expressway gantries.

If car ownership and deployment by non-resident commuters is disregarded the 2005 modal share of cars in the commutes to the Restricted Zone was about 20%, about the same as in 1976 and a few percent below the national average. Apparently the increase in car ownership only affected the transit-car modal shares moderately. It may more often have given rise to the

discontinuation of the gearing of individual trip schedules to rideshares, which makes sense in an increasingly individualistic society. This development is reflected by the relative decrease of 4^+ carpools in the late 1980s. It will also have caused an increasing share of solo car drivers, which in 1976 already made up two thirds of all non-carpool drivers. These developments in the modal shares support the suggested origin of the 47,000 new car owners and a subdivision of them in 16,000 commuters with an alleged transit background and 31,000 more with a history as a car or carpool passenger.

G.3 Development of length, time and costs of trips to the Restricted Zone

Annex D offers an extensive overview of the time and money expenses in 1975 for the different alternatives that car owners might consider for their daily commute to the Restricted Zone. As the 1976 Consumer Price Index remained almost the same the post-ALS trip costs are also adopted as representative for the 1976 travel conditions. In the following subsections the time and money cost developments are retrieved. These apply to the average trip lengths for commuters who worked in the Restricted Zone. For the price levels the averages for the country are followed. All costs are expressed in the nominal S$ values that apply to the corresponding year.

G.3.1 Trip length

For 1975 the average distance that had to be covered twice a day by the commuters who worked in the Restricted Zone was assessed as 10 km for car drivers and 8 km for bus passengers (see Annex D). In that year 70% of the population lived within a radius of 8 km from the city centre. Since then the population has spread over the whole island (see Figure 13 on page 190). The weighted average distance over the trunk road system from residence to city centre accrued to over 16 km in 2005. Taking some correlation between residence location choice and job location into account might reduce the actual distance covered by the commuters but this effect will have been moderate because of the nature and concentration of the jobs in the Central Business District. As the sprawl of the population over the island had already started before 1975 an approximately linear increase in the average one-way commute distance of car drivers, from 10 km in 1976 to 15 km in 2005, is considered here as a realistic estimate of this development.

Buses will have required a slightly longer distance than private cars to serve the relevant stations and neighbourhoods. And for the majority of the residential areas the nearest Mass Rapid Transit station was in 2005 more than 12 km away from the stations in the Restricted Zone. Not surprisingly, the average Mass Rapid Transit trip distance was 11.5 km in 2005 while for trips with public buses this was only 5.2 km. One should realise that to these distances the access and egress trips should be added to find the total average commute distance.

G.3.2 Travel time

The average duration of a 10 km car trip to the Restricted Zone was, after ALS enforcement, estimated to take about 28 minutes, of which about seven minutes were required for walking to and from the parking place, embarking and parking, and manoeuvring in the residential and business areas, leaving 21 minutes driving at a cruising speed of almost 30 km/h. From the early 1980s onwards an expressway network came into operation that connected the newly developed residential areas to the Restricted Zone. Since then the largest share of the distances travelled by the car-driving commuters consisted of expressways. In 2005 this share was about 70%, on which the average speed during the peak hours was 63 km/h compared to

27 km/h on the arterial roads (ALS 2007). This reduces the average cruising time for a 15 km car trip to twenty minutes, one minute less than in late 1975. Additional support for this assumption comes from the national household surveys and population censuses. For 1982, when the first expressways had just come into operation, these show a national average travel time of 27 minutes for commuters who travelled by car (Willoughby 2000), which remained virtually the same until 2005. For all practical purposes the average travel time of car driving commuters to their work inside the Restricted Zone might thus be considered to have remained stable at 28 minutes over the years.

The average travel time of a bus trip in 1975 was about 41 minutes. The process of improving bus transport started in the early 1970s and was effectively continued until the late eighties. Naturally, the opening of the expressway network also had a positive impact on the travel times. Notwithstanding the increased travel distances due to the spread of residential areas, the national average travel time for commutes by public bus was only 39 minutes in 1982. When the Mass Rapid Transit system came into operation in the late 1980s several trunk bus lines that ran parallel to the railways were changed into feeder lines. The average travel time of the remaining commuters who travelled by bus only decreased to 38 minutes in 2005, due to the on-average decrease in trip length for this group. The group of commuters who travelled by Mass Rapid Transit was half as large and needed on average 41 minutes, yielding the same average 39 minutes. However, a sizeable number of Mass Rapid Transit travellers needed a bus trip as access and/or egress mode and required a travel time of 51 minutes for their commute. On balance, the travel time by public transport was thus 42 minutes in 2005, clearly worse than before the Mass Rapid Transit was introduced. The changes in average travel time over the years are only about 5%. For the order-of-magnitude assessments in this annex it seems sound to adopt a constant 41 minute trip duration for commutes by transit to the Restricted Zone.

G.3.3 Fuel prices

Wilson (1989) published engineering estimates for the running costs of cars in Singapore. By far the most important component is fuel, for which he assessed S$8.05/km in nominal currency for the 1975 fleet. Across the years the majority of the cars remained in the 1,001 to 1,600 cc class. The share of this class in the total car population increased from 60% in 1975 to 66% in 1982 (Spencer and Sien 1985) but had fallen back to 59% in the years 1996-2005 (LTA 2007). The share of cars with 1,601 cc and more increased from 20% in the 1970s and early 1980s to 37% in 1996 and 39% in 2005. In 2005 99.99% of the private cars ran on premium petrol that in 2005 cost S$1.51 per litre at the pumps in Singapore (Singapore Statistics 2007). The fuel consumption of modern cars with a 1,600 cc engine that runs on petrol is about 0.07 litres per kilometre which sets the average fuel price in 2005 currency at S$0.106/km. For the intervening years the corresponding average fuel costs per commute were retrieved by assuming that they developed proportionately to the international prices on the oil market, taking changes in the petrol taxes (Spencer and Sien, Willoughby), fuel consumption of cars and average commute distance into account.

G.3.4 Road pricing

By 1976 the nominal ALS fee for entrance to the Restricted Zone was S$4.00 for a private car. The changes in ALS fees are listed in Table G.1. In the intermediate years the fees remained at a constant level in nominal dollar values. As the Electronic Road prices vary over the commuting period, a S$3.00 to S$5.00 per day range is given, both for 1998 and 2005. These consider combinations of an entrance of the Restricted Zone at different times between 8:00 and 9:30 a.m., preceded by the passage of an expressway gantry.

G.3.5 Parking fees

In 1975 parking in the Central Business District was one of the major running costs for car driving commuters. After the ALS enforcement the average fee for whole-day parking was S$70 per month or about S$3.50 per day. A recent overview of the running costs in 2005 for a car used for 220 commutes to the Central Business District reveals an average parking fare of S$5.70 per day (Enter Singapore 2007), a 65% increase since 1975. The hourly parking fares were S$0.50 for the first, S$1.00 for the second and S$2.00 for each consecutive hour (Watson and Holland), amounting to about S$14.50 for a whole day parking at the hourly rate. In 2007 the average fares in the Central Business District were S$2.00/h (LTA 2006) which would amount to S$18 per day, a 24% increase in nominal currency. The development of the whole day as well as the hourly prices lagged behind the concurrent increase in the consumer price index. The parking fares in the intervening years are estimated here by interpolation, assuming an increase proportionate to 80% of the concurrent increase of the consumer price index since 1975.

G.3.6 Other running costs

Cost components of car ownership like depreciation, insurances and road taxes are only to a very limited extent dependent on actual use. In agreement with common use these cost components are disregarded here. Oil, maintenance and the replacement of tyres, batteries and so on are commonly taken into account. Wilson (1989) estimated these at S$0.019/km in 1975 but, due to the improved quality of engines, paints and so on, car maintenance costs per km show a declining trend across the world. Data in Enter Singapore (2007) estimate maintenance at about 25% of the fuel costs which would yield S$0.027/km. This implies an increase of 55% of the concurrent increase in the consumer price index since 1975. Applying this percentage of the consumer price index growth to Wilson's data would enable assessment of the running costs for the intervening years. In view of their small share in the total running costs, however, and the fact that few car drivers perceive them as costs, they are not further utilised here (see Wilson 1989).

G.3.7 Public transport fares and costs

In 1975 the average fare for an eight-kilometre bus trip to the Restricted Zone was about S$0.40. The fare development between 1990 and 2004 is extensively described in the report of a committee that evaluated the fare review mechanism (LTA 2007). For 2004 it reports an average fare of 0.65 for bus trips and 0.94 for trips with Mass Rapid Transit. In 2005 the average Mass Rapid Transit trip length was 11.5 km, the average bus trip 5.4 km and the average public transport journey distance, which included about 30% bus-trip chains, was 9.6 km. The average distances for the commutes to the Restricted Zone will have been longer, particularly for all-bus journeys. Taking the relevant distances, the modal shares of bus, Mass Rapid Transit and bus-Mass Rapid Transit journeys and the fares as indicated by the fare review mechanism into account enables the average transit costs for commutes to the Restricted Zone for 1989, 1994 and 1998 to be estimated. The bus costs for 1980 were assessed by interpolation between 1976 and 1989.

G.3.8 Overview of the development of operational expenses for commuting

The nominal monetary values of the considered cost components are listed in Table G.2. They apply to the 'average' traveller and take into account the increase in commute distance over the years. Comparison with the general development of consumer prices, which in 2005 amounted to 1.85 times the 1976 level, shows that the increase of the total running costs for commuting by car lagged behind while the transit costs developed at a faster pace.

Particularly during the 1980s the operational cost components for car travel hardly increased at all. Due to the strong increase in fuel prices from the early 1990s onwards the development in the total running costs surpassed the growth of the consumer price index. The increase in transit ticket expenses also exceeded the consumer price index growth for the whole 1975-2005 period.

Table G.2: Travel costs for daily commutes to the Restricted Zone

Year [1]	Daily expenses for an 'average' commute to the Restricted Zone and back home (in nominal S$)					
	Running costs for private car journeys					Transit
	Fuel	Parking	Road pricing	Other [2]	Total [3]	tickets
1976	1.4	3.3	4.0	0.4	9.1	0.8
1980, before change in ALS fare	1.7	4.0	4.0	0.5	10.2	1.2
1980, after change in ALS fare	1.7	4.0	5.0	0.5	11.2	1.2
1989, before ALS adjustments	1.7	4.7	5.0	0.6	12.0	1.7
1989, after ALS adjustments	1.7	4.7	3.0	0.6	10.0	1.7
1994, before ALS extension	2.2	5.3	3.0	0.7	11.2	1.9
1994, after ALS extension	2.2	5.3	3.0	0.7	11.2	1.9
1998, before ERP introduction	2.6	5.5	3.0	0.7	11.8	2.2
1998, after ERP introduction	2.6	5.5	3.0 to 5.0	0.7	11.8 to 13.8	2.2
2005	3.2	5.7	3.0 to 5.0	0.8	12.7 to 14.7	2.4

[1] For an explanation of the changes in road pricing see Table G.1. [2] Oil, maintenance, tyres etcetera. [3] For trips during the restricted hours.

G.4 Development of prices and nominal income of car owners

G.4.1 Price indices

Singapore Statistics (2007) published Singapore's annual consumer price indices from 1961 onwards. They are re-indexed with 1976 as the base year with an index of 100. The development of the travel expenses for commuting by transit and by car during the restricted hours or outside the restricted period, as listed in table G2 is in the same way indexed taking 1976 as the base year.

G.4.2 Car owners' household incomes

The nominal income of all households in Singapore almost quadrupled between 1975 and 1990, from S$820 to S$3,080 per month, and doubled to S$6,000 in the next fifteen years. Based on survey findings reported by Watson and Holland the average monthly household income of car owners in 1975 was S$2,000. For 1990 and 2000 corresponding averages of S$5,100 and S$8,400 per month were calculated, based on the income distributions of car owners in the report of the 2000 census (Singapore Statistics 2007). Taking the average nominal income growth from 2000 to 2005 into account the car-owners' average household income in 2005 was 2.0 times the 1990 level, a slightly higher rise than for the country as a

whole. The average household income of car owners in the 1990 census was 2.5 times that in 1975, compared to 3.8 for the population as a whole. This lower growth could be explained by the increasing share of car-owning households, from 30% in 1975 to over 35% in 1990 (see Section G1): as car ownership in Singapore increases with household income, an increase in the share of all households implies that many households with an 'average' income join the relatively more wealthy car-owning families, thus decreasing the average income. The somewhat decreasing share of car-owning households in the total population can explain the post-1990 slightly higher income growth of car owners. These explanations are supported by the development of shape parameters. For the national average household income this grew from 0.70 in the 1970s to 0.75 in 1990 and 0.90 in 2000, reflecting the strong increase in income inequality in the 1990s. For car-owning families it increased from 0.6 in 1975 to 0.75 in 1990 and 2000, reflecting the increasing share of car-owning households between 1975 and 1990 and the decreasing share since then. Taking all the evidence together it seems most appropriate to assume that the nominal household income of travellers who owned a car in the early 21th Century developed at the same pace as for all households.

The national average household income was retrieved for 1975, 1990 and 2005 (see also Table 9 on page 191), and for several years in the 1990s. For all the intervening years the total nominal Gross National Income was available. After dividing by the number of households this measure was used as a base against which the average household incomes were interpolated. The results are indexed relative to the base year 1976.

G.4.3 Car owners' hourly wage rates

Following the same reasoning as for household income the development of the wages of workers who possessed a car at any time between 1975 and 2005 is assumed to be equal to the development of the national wage rate development. The development in the average hourly wage rate will deviate from the development of the average monthly household income if the number of workers per household and/or the average duration of the working week changes over the years. Using the same sources as above the average working week and average monthly income of all workers was retrieved for 1975, 1990, 2000 and 2005. These were interpolated in the same way as the average household incomes.

G.4.4 Overview of the development of prices and incomes

The indices for the years in which changes in the road-pricing regime occurred are assembled in Table G.3. Exxmining the price indices reveals that until 1998 the price index for commuting by private car during the tolled period lagged far behind the general increase in consumer prices whilst the costs of transit increased much faster. It is only in the last decade that the worldwide fuel price increase caused a steeper rise in the running costs for commuters by cars than for transit and for general consumer expenses. One should keep in mind, however, that the costs of transit never attained 20% of the costs of commuting by car during the restricted hours or 25% of those costs in the hours when road pricing did not apply.

The income indices, in comparison to the price indices, show the large increase in the spending power of Singapore's residents. Between 1975 and 1990 the development of the monthly household income and wages occurred at the same pace. Since then the wage rate has developed faster, which can be explained by a concurrent decline in the average number of employed persons per household combined with a small increase in the average working week.

The price, income and wage indices could be applied to estimate the hypothetical development of an individual's Value of Travel Time Savings (VTTS) as discussed in Subsection 7.4.7. The median VTTS of a population segment might also be used as the scale parameter for the transformation of a lognormal income or VTTS distribution from one year to another, but obviously only if the considered population segments are similar. It is, for example, not appropriate to derive a 2005 VTTS distribution for the workers in the Restricted Zone who owned a car then by applying the considered index to a corresponding 1976 distribution, as car owners made up 20% of these workers in 1994 and only 16% in 1976. Of course, when 4% non-car owning commuters are added to the 1976 population segment before its VTTS distribution is established the index might be used as scale parameter.

Table G.3: Price and income indices in Singapore for base year 1976

Year[1]	**Price and income development** in nominal S$ values (1976 = 100)					
	CPI [2]	Car RP [3]	Car other [4]	Transit [5]	Income [6]	Wage [7]
1976	100	100	100	100	100	100
1980, before change in ALS fare	120	110	120	150	160	160
1980, after change in ALS fare	120	120	120	150	160	160
1989, before ALS adjustments	150	130	130	210	320	320
1989, after ALS adjustments	150	110	130	210	320	320
1994, before ALS extension	170	120	150	240	450	510
1994, after ALS extension	170	120	150	240	450	510
1998, before ERP introduction	180	130	170	280	550	690
1998, after ERP introduction	180	150	170	280	550	690
2005	190	160	190	300	690	790

[1] For an explanation of the changes in road pricing see Table G.1. [2] National Consumer Price Index. [3] Total running costs for commutes by private car to the Restricted Zone and back home, during the restricted hours; in 1998 and 2005 during the most expensive half hour. [4] Same running costs but outside the tolled period. [5] Tickets for commutes by bus and/or Mass Rapid Transit to the Restricted Zone and back home. [6] Average monthly household income of Singapore's employed residents. [6] Average hourly wage rate of employed residents.

Samenvatting

Een Uitbreiding van Prospect Theorie
Inzichten over keuzegedrag uit de economie en de gedragswetenschappen en de relevantie daarvan voor verplaatsingsgedrag

Probleemstelling (Hoofdstuk 1)

Sinds lange tijd worden in de transportwetenschappen, de economie en veel andere sociale wetenschappen verschillende vormen van Nutstheorie (Utility Theory, hierna afgekort tot UT) beschouwd als het meest geschikte model voor de beschrijving en voorspelling van menselijk keuzegedrag. Een belangrijk basisprincipe van die theorie is dat iemand in verschillende situaties dezelfde voorkeursvolgorde heeft voor dezelfde set keuzealternatieven. Maar sinds het midden van de vorige eeuw staat de geldigheid van die theorie steeds meer ter discussie. Veel onderzoek in verschillende gedragswetenschappen heeft aangetoond dat mensen vaak niet die keuzen maken die je volgens UT zou verwachten. Daarmee rekening houdend hebben twee psychologen, Kahneman en Tversky (1979, 1991), in de jaren 1970 Prospect Theory (PT) ontwikkeld als een alternatief gedragseconomisch model voor menselijk keuzegedrag. Anders dan UT gaat PT er van uit dat iemands voorkeursvolgorde afhangt van de omstandigheden waarin hij een keuze maakt, en of die keuze als verlies of winst wordt ervaren. Hoewel de meeste wetenschappers zich er goed van bewust zijn dat mensen vaak in strijd met de principes van UT handelen sloegen deze en andere alternatieve theorieën in de wetenschap niet echt aan. Misschien komt dat omdat ze iemands gedrag in een bepaalde omgeving wel goed kunnen verklaren maar niet duidelijk aangeven hoe je dat gedrag dan naar andere omstandigheden kunt ‘vertalen’. Verbetering van de structuur en de mathematische formulering van op UT gebaseerde discrete keuzemodellen, vooral door verfijning van stochastische parameters, zijn in de economische en transportwetenschappen de overheersende aanpak om rekening te houden met waargenomen “inconsistent” keuzegedrag.

Het doel van dit boek is om na te gaan of PT, aangevuld met inzichten uit andere sociale wetenschappen, uitgebreid kan worden tot een theorie die het keuzegedrag van mensen beter verklaart dan UT. En als dat lukt is een volgend doel om te onderzoeken of van die uitgebreide theorie een operationeel model kan worden gemaakt dat in staat is iemands gedrag te voorspellen onder andere omstandigheden dan waarin de parameters van dat model geschat zijn. Beide doelen zijn bereikt. Het onderzoek dat daarvoor nodig was bestond uit vier fasen

die in dit boek uitgebreid worden beschreven. Deze samenvatting behandelt eerst die fasen van het onderzoek op hoofdlijnen, gevolgd door de belangrijkste conclusies en aanbevelingen.

Fase 1 Basisprincipes van menselijk keuzegedrag (Hoofdstuk 2)

Eerst is een onderzoek gestart naar de ontwikkeling van de opvattingen over menselijk keuzegedrag die in de verschillende sociale en geesteswetenschappen heersten. Die opvattingen zijn geanalyseerd vanuit een systeemtheoretische invalshoek. Kort gezegd: keuzegedrag wordt beschouwd als een mentaal proces dat een "input" in de vorm van informatie uit de omgeving omzet in een "output" in de vorm van een keuze of beslissing. Een uitgebreide beschrijving van de historische ontwikkeling vanaf ongeveer 1500 is in Annex A opgenomen. Het leverde drie disciplineoverstijgende paradigma's op. Het 'Paradigma van de Rationalisten' heerste tot het begin van de twintigste eeuw en wordt gedomineerd door de tweedeling in geest en lichaam zoals indringend gesteld door Descartes (1642). In systeemtheoretische zin kan het worden gekarakteriseerd als een zogenaamde "open-loop controller", waarin een letterlijk "redelijke", uniek menselijke geest de "machine" van het lichaam bestuurt met het doel om gelukkig te worden. In de eerste helft van de twintigste eeuw werd dit vervangen door het "Paradigma van de Behavioristen". Het gedrag van mensen en dieren werd toen beschouwd als de output van een "black box" die na "conditionering" in een leerproces een automatische en voorspelbare reactie vertoont op prikkels uit de omgeving. De contextonafhankelijke preferentievolgorde van de hedendaagse versies van Nutstheorie kunnen als een overblijfsel van dit paradigma worden beschouwd.

In de afgelopen halve eeuw ontwikkelde het inzicht in het menselijk gedrag zich snel. Tientallen nieuwe gedragstheorieën werden voorgesteld in de almaar toenemende reeks gespecialiseerde subdisciplines van de sociale wetenschappen. In tegenstelling tot het behaviorisme onderscheiden de meeste theorieën afzonderlijke componenten van de mentale functie ("wat doet het brein"), en nemen ze aan dat begrip/cognitie bestaat uit mentale voorstellingen die worden bewerkt volgens bepaalde regels/algoritmes. Ze vallen daarmee binnen wat hier het hedendaagse "Paradigma van de Cognitivisten" is genoemd. Keuzegedrag wordt daarin beschouwd als een mentaal proces dat een aantal mentale functies verzorgt. Die zetten mentale voorstellingen van alternatieve gedragslijnen in een bepaalde situatie om in het besluit om één van die gedragslijnen te volgen. Zodoende sturen ze de interactie tussen de betreffende persoon en haar omgeving aan. Het doel van keuzegedrag is het bevorderen van het eigenbelang van het individu, uiteraard allereerst door verbetering van de "fitness to survive" en vervolgens door vergroting van het individuele welzijn/geluk. In deze uitgebreide studie werden geen grootschalige afwijkingen van dit principe gevonden. In concrete keuzesituaties wordt dat doel "geoperationaliseerd" tot meer kortzichtige motieven, met name de gevoelens die verwacht worden als uitkomst van de keuze. De bijbehorende keuzeprocessen worden veroorzaakt door percepties van bestaande strategische en tactische gedragsvoornemens en van de actuele toestand van het individu, bezien vanuit een opportunistische instelling. Vanuit systeemtheoretisch perspectief is dit een teruggekoppeld complex stimulus-organisme-gedrag systeem dat ervoor zorgt dat het organisme opgewassen blijft tegen de invloeden vanuit de omgeving (zie figuur 1 op blz. 13). Verrassend is dat het mensbeeld in Spinoza's *Ethica* (1677), dat eeuwenlang nauwelijks navolging kreeg, vanuit systeemtheoretisch perspectief vrijwel geheel past binnen dit paradigma.

In hoofdstuk 2 is nagegaan hoe het keuzegedragsysteem, zoals gedefinieerd in het cognitivisten-paradigma, volgens de verschillende wetenschappen nader kan worden beschreven. Eerst is geconstateerd dat het een heterogene reeks concrete keuzesituaties bedient. Ruwweg kunnen strategische, tactische en operationele categorieën van keuzegedrag

worden onderscheiden. De afzonderlijke processen verschillen in doorlooptijd, complexiteit en draagwijdte, die vaak samen hangen. Ze kunnen worden gerangschikt op een schaal die loopt van langdurige, complexe strategische besluitvormingsprocessen die een ingrijpende en langdurige doorwerking hebben via tactische processen tot kortdurende, eenvoudige operationele keuzeprocessen die onmiddellijk omgezet worden in concreet gedrag. Binnen een bepaald domein, bijvoorbeeld iemands verkeersgedrag, kunnen ketens worden onderscheiden die in zekere mate een "strategisch-operationele keuzegedrag hiërarchie" vormen. Vervolgens is geanalyseerd in hoeverre de werking van het keuzegedragsysteem in algemene termen kan worden gespecificeerd. De belangrijkste invalshoeken zijn daarvoor de procesbeschrijving, die aangeeft *hoe* het systeem doet wat het moet doen, en de functiebeschrijving, die aangeeft *wat* het systeem doet om zijn doel te bereiken.

Het mentale proces dat keuzegedrag verzorgt is denken. De huidige sociale wetenschappen onderkennen daarbinnen twee verschillende manieren of "systemen" (Stanovich and West 2000). Denken in Systeem 1 is onbewust, parallel en automatisch. In Systeem 2 verloopt het bewust, opeenvolgend en volgens regels, waarbij het behoorlijk wordt gehinderd door de beperkte capaciteit van het menselijke werkgeheugen. In verschillende disciplines binnen de gedragswetenschappen blijven de aanwijzingen zich ophopen dat menselijk keuzegedrag wordt gedomineerd door Systeem 1, zie b.v. het Nederlandstalige boek van Dijksterhuis (2007). Systeem 2 levert in veel gevallen niet meer dan een logische verklaring achteraf voor een keuze die al onbewust is gemaakt. Menselijk keuzegedrag is dus voor de betrokkenen een grotendeels verborgen mentaal proces. Daardoor kunnen mensen niet weten hoe hun gedachten tijdens dat proces veranderen. Omdat de veranderingen in de inhoudelijke betekenis van hun percepties niet fysiek gemeten kunnen worden is het niet mogelijk om voor welke procestheorie ook the claimen dat het een natuurgetrouwe beschrijving van keuzegedrag geeft.

De overkoepelende functie van keuzegedrag kan binnen het cognitivisten-paradigma worden gedefinieerd als het in iedere keuzesituatie kiezen van een haalbare gedragswijze uit een aantal alternatieven, waaronder niets doen, die in de betreffende context voldoet aan bepaalde actuele behoeften van het individu. Hij kan worden ontleed in vier functies die samen hetzelfde doen, en niet meer dan dat. Dat zijn: "Framing", het formuleren van de concrete omstandigheden in een referentiealternatief plus een aantal alternatieve handelingswijzen met hun verwachte uitkomsten enzovoort; "Judgment", oordeelsvorming over de grootte van de kenmerkende eigenschappen van de alternatieven en de waarde die daaraan wordt toegekend; "Evaluation-and-choice", het toekennen van een overall waardering aan de alternatieven en het vergelijken daarvan met een keuzecriterium, uitmondend in een keuzebesluit; en "Choice behaviour strategy", een coördinerende keuzegedragstrategie functie die nodig is om de gevolgen van het opdelen van de overall functie te niet te doen. Het verborgen karakter van keuzegedrag impliceert dat er geen aanleiding is om een specifieke volgorde aan te nemen of te verwerpen voor het doorlopen van deze functies (zie figuur 2 op blz. 21). De vele mogelijke interacties, volgordes en/of iteraties van deze functies en hun subfuncties kenmerken keuzegedrag als een complex systeem. Deze functionele visie op keuzegedrag is in dit boek de Meta Theorie voor Keuzegedrag genoemd, omdat die iedere mogelijke reeks concrete aannamen volgens iedere keuzegedragtheorie afdekt over hoe iemand tot een concrete keuze kan komen. Het is niet bedoeld om een waarheidsgetrouwe beschrijving van het mentale keuzeproces te bieden. Daarom kan het wel gebruikt worden om de volledigheid en consistentie van operationele keuzegedrag theorieën te toetsen maar niet om hun geloofwaardigheid als beschrijvend model voor werkelijk keuzegedrag te beoordelen.

Fase 2. Waargenomen keuzegedrag vergeleken met theoretische aannamen (Hoofdstuk 3 t/m 5)

In hoofdstuk 3 zijn twee verschillende, intern consistente en niet overcomplete pakketten van theoretische aannamen samengesteld uit de micro-economische literatuur die ieder in staat zijn de overkoepelende functie van keuzegedrag in concrete situaties vorm te geven. Ze zijn in tabel 1 (blz. 34) gerelateerd aan de verschillende functies volgens de Meta Theorie en opgesomd onder UT en PT. Beide theorieën beschouwen mensen als onverzadigbare "nuts-maximaliseerders". Behalve in enkele minder relevante opzichten verschilt PT van UT omdat het aanneemt dat mensen keuzealternatieven formuleren als veranderingen in hun "verworvenheden" en dreigende verliezen daarin zwaarder laten wegen dan winsten terwijl UT aanneemt dat ze de verwachte totaalomvang van die verworvenheden vergelijken. Het meest essentiële verschil lijkt te zijn dat PT een contextafhankelijke keuzegedragstrategie en daaraan gerelateerde voorkeursvolgorde voor alternatieven aanneemt terwijl volgens UT alle mensen een specifiek eigen, onveranderlijke voorkeursvolgorde hebben voor de verschillende alternatieven. Die volgens UT contextonafhankelijke voorkeursvolgorde maakt het mogelijk om iemands keuzen in een willekeurige situatie te voorspellen als de voorkeursvolgorde van de daar relevante alternatieven in een andere situatie is bepaald. Het is daardoor zowel een beschrijvend-verklarende gedragstheorie als een voorspellende. Omdat in PT geen aannamen zijn geformuleerd over hoe iemands keuzegedrag van de ene context kan worden "vertaald" naar een andere is het alleen een beschrijvend-verklarende gedragstheorie.

Hoofdstuk 4 onderwerpt waarnemingen en theoretische gevolgtrekkingen over menselijk keuzegedrag uit meer dan honderd gedragswetenschappelijke publicaties aan een nader onderzoek. Vele tientallen keuze-experimenten en een groot aantal praktijkwaarnemingen bieden de mogelijkheid om na te gaan hoe geschikt de theoretische aannamen van UT en PT zijn om het waargenomen keuzegedrag te beschrijven. Daaruit blijkt dat, vergeleken met de UT aannamen, de meeste aannamen van PT dat beter doen. Die laatste zijn uitgebreid met enkele theoretische aannamen die tot geen van beide theorieën behoren maar het waargenomen keuzegedrag volgens studies uit verschillende gedragswetenschappen goed kunnen verklaren. In hoofdstuk 5 zijn die gebruikt als basisaannamen van een "Extended Prospect Theory" (EPT). De aannamen zijn opgesomd in tabel 2 (blz. 96). Na wat herschikken levert dat vijf aannamen waarin EPT als beschrijvend model zich het meest onderscheidt van de vergelijkbare aannamen volgens UT en/of PT. Die zijn in de tabel op de volgende bladzijde naast elkaar gezet. De aannamen verschillen nogal voor wat betreft de range van omstandigheden waarin ze van belang zijn. Terwijl het formuleren van eigenschappen van alternatieven als veranderingen ten opzichte van een referentiealternatief als een algemeen geldend principe kan worden beschouwd is bijvoorbeeld het toekennen van niet-lineaire weegfactoren aan kansen een aanname die alleen relevant is voor keuzegedrag uit onzekere of probabilistische alternatieven.

De wijze waarop de bovenbedoelde aannamen van EPT zijn gekozen zorgt ervoor dat ieder daarvan geschikt is om specifieke elementen van keuzegedrag goed te beschrijven en verklaren. Maar om EPT ook te kunnen gebruiken voor beleidseffect analyses en prognoses zijn drie aanvullende aannamen geformuleerd. De eerste is gerelateerd aan het uit de sociale psychologie bekende "cognitieve consistentie" principe en stelt dat de meeste individuen dezelfde keuzegedragstrategie volgen in regelmatig terugkerende keuzesituaties die op elkaar

Tabel: Onderscheidende aannamen van EPT, UT and PT

Extended Prospect Theory	Utility Theory	Prospect Theory
Kaderen in de context en verliesaversie		
Mensen formuleren alternatieven en hun eigenschappen als context-afhankelijke veranderingen (winst of verlies) ten opzichte van een voortdurend aangepast referentie-alternatief, en de meeste van hen kennen aan een verlies een hogere waarde toe dan aan een winst van dezelfde omvang	Mensen formuleren alternatieven en hun eigenschappen als contextonafhankelijke toestanden die ze na hun keuze verwachten, onafhankelijk van de richting waarin die veranderen	Mensen formuleren alternatieven en hun eigenschappen als contextafhankelijke veranderingen (winst of verlies) ten opzichte van een referentiealternatief en kennen aan een verlies een hogere waarde toe dan aan een winst van dezelfde omvang
Waarderen van de eigenschappen van alternatieven		
De waarde die mensen toekennen aan een eigenschap van een alternatief is een concave functie van de grootte als het een winst betreft en een convexe functie voor verliezen	De waarde die mensen toekennen aan een alternatief is een concave functie van de grootte	De waarde die mensen toekennen aan een eigenschap van een alternatief is een concave functie als het een winst betreft en een convexe functie voor verliezen
Wegen van kansen op uitkomsten van alternatieven		
De meeste mensen wegen de verwachte kansen op onzekere gevolgen van hun keuzen met een niet-lineaire factor	Mensen waarderen de verwachte kansen op onzekere gevolgen met weegfactor 1.0	Mensen wegen de verwachte kansen op onzekere gevolgen van hun keuzen met een niet-lineaire factor
Combineren van de waarde van eigenschappen		
Mensen kunnen affectief saillante eigenschappen van een alternatief waarderen in een kwalitatieve "gevoelsdimensie" terwijl ze voor andere eigenschappen geld of een ander medium gebruiken	Mensen waarderen alle eigenschappen van alternatieven in een vergelijkbare dimensie	Mensen waarderen alle eigenschappen van alternatieven in een vergelijkbare dimensie
Interpersoonlijke verschillen in keuzegedragstrategieën		
Verschillende mensen gebruiken in dezelfde situatie verschillende keuzegedragstrategieën, zoals persoonsgebonden combinaties van formulering van alternatieven, ambitieniveau (acceptabel of het beste alternatief) en beslisregels	Iedereen kiest het alternatief dat na het "optellen" van de waarde van al zijn eigenschappen het hoogst scoort op zijn voorkeursvolgorde	In dezelfde situatie kunnen verschillende mensen alternatieven anders formuleren maar iedereen kiest het alternatief dat na het "optellen" van de waarde van al zijn eigenschappen het hoogst scoort op zijn voorkeursvolgorde

lijken. De tweede volgt uit het "instant endowment" verschijnsel uit de "Behavioural Decision Theory": mensen passen hun referentiealternatief vrijwel onmiddellijk aan wanneer ze relevante wijzigingen in hun omstandigheden ervaren. De derde is ontleend aan Kleins (1993) "recognition-primed model" uit de "Naturalistic Decision Theory". Dat houdt in dat mensen zich in een bepaalde keuzesituatie eerdere relevante keuzen op hetzelfde of hogere niveaus van de strategisch-operationele keuzegedraghiërarchie herinneren en die gebruiken als bouwstenen voor hun referentiealternatief, het selecteren van relevante alternatieven, vaststellen van maximaal acceptabele waarden van de eigenschappen daarvan enzovoorts.

EPT beschouwt het keuzegedrag van individuen met betrekking tot bijvoorbeeld het verkeer dus als een doorlopend proces, waarbij ze hun referentiealternatief steeds aanpassen aan veranderingen in de omstandigheden zoals ze die ervaren. Deze aannamen komen in de plaats van UT's contextonafhankelijke voorkeursvolgorde en maken het mogelijk om ook EPT te gebruiken als een zowel beschrijvend-verklarend als voorspellend model.

Fase 3 De geschiktheid van EPT als verklarend model voor reisgedrag (Hoofdstuk 6)

Om de geschiktheid van de aannamen van EPT voor het verklaren van keuzegedrag te kunnen nagaan en vergelijken met die van UT is in hoofdstuk 6 de literatuur over transport afgezocht naar publicaties die het gedrag van mensen in relatie tot hun dagelijkse verplaatsingen beschrijven. Dat leverde 85 studies op die voldoende informatie bevatten om tenminste een van de aannamen te evalueren. Ze werden uitgevoerd in 22 landen en bestrijken de hele range van verkeergerelateerd onderzoek, bijvoorbeeld van strategische woonlocatiekeuzen tot operationele rijstrookwisselingen en van laboratoriumexperimenten tot praktijkwaarnemingen van gereden routes.

Aanwijzingen dat de meeste mensen de eigenschappen van de alternatieven als verlies of winst ten opzichte van een referentiealternatief waardeerden en dat ze daarbij een hogere waarde toekenden aan een verlies dan aan een winst van dezelfde omvang werden gevonden in 70 studies. Voor de meeste daarvan is dat wetenschappelijk overtuigend aangetoond, voor de andere is het aannemelijk gemaakt. De 15 resterende studies bieden geen aanwijzingen dat deze aanname moet worden aanvaard of verworpen. Uit geen studie bleek dat de overeenkomende aanname van UT het gedrag beter verklaarde dan die van PT en/of EPT. Waar een "loss aversion factor", dat is de verhouding tussen de waardering voor verlies en winst, kon worden bepaald ligt die in de range van 1,4 tot 2,8, wat dezelfde gemiddelde waarde van 2,0 oplevert als werd gevonden voor een groot aantal experimenten in andere gedragswetenschappen. Dit levert een bruikbare eerste schatting voor toepassingen van dit principe in onderzoeken van verplaatsingsgedrag.

Twee studies tonen aan dat een machtsfunctie, zoals voorgesteld in PT, het verschil in verloop van de waarde tussen winst en verlies goed weergeeft. De conclusies die getrokken kunnen worden uit studies waarin UT's nutsfunctie werd beschreven met een tweede orde Taylorreeks[151] ontwikkeling waren niet eenduidig. De andere studies leverden geen aanwijzingen op dat het verloop van de waarde van een toenemend verlies en van een toenemende winst met een machtsfunctie met exponent beneden 1.0 kan worden weergegeven. Het overall beeld is dat de waarde van winst en verlies in de meeste gevallen goed kan worden benaderd door een lineaire functie van de omvang die is geknikt in de oorsprong. Dit sluit niet uit dat in uitzonderlijke gevallen een verminderde marginale waardering bij toenemende omvang ervan wel van belang kan zijn, bijvoorbeeld wanneer de winst en/of het verlies erg groot zijn ten opzichte van de referentiesituatie.

De meeste van de 85 studies gingen niet over situaties waarin de uitkomsten van keuzen een kanskarakter hebben en een paar studies waarin dat wel het geval was leverden geen aanwijzingen over de vraag of de betrokken mensen een niet-lineaire weegfactor toepasten op hun kansverwachtingen of dat ze die kansen ongewogen meenamen in hun beslissing. In de helft van de resterende 27 studies werd het niet-lineair wegen van kansen wetenschappelijk overtuigend aangetoond, de andere helft bevatte aanwijzigen die dit plausibel maken.

[151] Een in de wiskunde veelgebruikte benaderingswijze voor niet-lineaire fiuncties.

Opvallend is dat in geen enkel onderzoek naar strategisch keuzegedrag gerelateerd aan bereikbaarheid ingegaan werd op probabilistische eigenschappen van alternatieven.

Zeventien studies leverden aanwijzingen voor verschillen in waardering tussen affectief saillante en meer "utilitaire" eigenschappen van alternatieven. Dit verschijnsel kwam vrijwel alleen voor bij strategische keuzen die aan verplaatsingsgedrag gerelateerd waren en bij Stated Preference onderzoek waarbij de kans op dodelijke ongevallen een van die eigenschappen was. Voor deze toename van verschillen in affectieve en utilitaire waardering wanneer de keuzesituatie hoger scoort op de strategisch-operationele keuzegedraghiërarchie zijn ook in andere gedragswetenschappen aanwijzingen gevonden.

Aanwijzingen voor het gebruik van verschillende keuzegedragstrategieën door verschillende mensen in dezelfde context zijn gevonden in 43 studies. In de meeste gevallen betrof dat verschillen in het aantal eigenschappen van alternatieven die als verlies werden geformuleerd en gewaardeerd. Voor een aantal studies waarin de interpersoonlijke verschillen werden verklaard uit het toepassen van verschillende "decision rules" zouden die even goed veroorzaakt kunnen zijn door verschillen in "framing". Daarom zouden interpersoonlijke verschillen in het formuleren van de alternatieven in relatie tot het referentiealternatief wel eens de belangrijkste bron van interpersoonlijke verschillen in keuzegedrag kunnen zijn.

Fase 4 De geschiktheid van EPT voor beleidseffect analyse en predictie (Hoofdstuk 7)

In Singapore is veel ervaring opgedaan met rekeningrijden. Omdat de veranderingen in het woon-werkverkeer van autobezetters als reactie op de invoering en latere tariefwijzigingen goed zijn gedocumenteerd in een groot aantal publicaties biedt dat een interessante mogelijkheid om de geschiktheid van EPT als voorspellend model te vergelijken met UT.

Om zo'n vergelijking te kunnen maken is in hoofdstuk 7 een discreet keuzemodel afgeleid van de basisprincipes van EPT. In overeenstemming met het meer generieke karakter van EPT blijkt dat model ook geschikt om de overeenkomstige principes van UT te implementeren, door voor alle keuzesituaties van één individu hetzelfde referentiealternatief op te leggen en door alle coëfficiënten[152] die de mate van verliesaversie beschrijven op 1.0 te stellen. De tactische ritkeuze omstandigheden waarvoor het model is ontwikkeld zijn zodanig dat probabilistische eigenschappen van de keuzealternatieven buiten beschouwing kunnen blijven. Hoewel in de nutsfunctie[153] een stochastische parameter is gedefinieerd die rekening kan houden met de waardering van affectief saillante eigenschappen konden onvoldoende gegevens over de persoonlijke omstandigheden van de autobezitters achterhaald worden om die te kunnen kalibreren. Daarom zijn die bij het kalibreren en de predicties buiten beschouwing gelaten. De variatie in omvang van de eigenschappen van de relevante alternatieven ten opzichte van die van de referentietrip was beperkt, zodat de waardering daarvan met een lineaire functie kan worden benaderd. Daardoor verschilden de modelimplementaties van EPT en UT alleen in het referentieafhankelijk of onafhankelijk inkaderen van de context, het al dan niet aanpassen van de referentiesituatie aan veranderingen, het al dan niet toepassen van verliesaversie en het al dan niet onderkennen van

[152] Deze "verliesaversiefactor" is gedefinieerd als het quotient van de waarde van een verlies en de waarde van een winst van dezelfde omvang.

[153] "Waardefunctie" zou een betere vertaling zijn voor het begrip "value function" dat in dit boek wordt gebruikt om duidelijk te maken dat het algoritme niet noodzakelijkerwijs de principes van "Utility Theory" volgt, maar dat begrip is in het Nederlands niet zo ingeburgerd als "nutsfunctie".

verschillen in keuzegedragstrategieën tussen groepen autobezitters. Voor de relevante coëfficiënten en verdelingen zijn globale aannamen gedaan die uitgebreid worden toegelicht in sectie 7.3.

De uiteindelijk aangehouden nutsfunctie bevatte maar twee soorten eigenschappen: tijd en dollars. Daarom kunnen alle interpersoonlijke verschillen in de waardering van de eigenschappen van alternatieven en in het belang dat aan verschillende eigenschappen wordt toegekend worden beschreven met één stochastische coëfficiënt (VTTS = "Value of Travel Time Savings"). Deze is voor een individu gedefinieerd als het quotiënt van diens marginale psychologische waarden van vrij beschikbare tijd en geld. Voor het bepalen van de reactie op plotselinge veranderingen in iemands persoonlijke omstandigheden, zoals de invoering van rekeningrijden en latere tariefwijzigingen, kan de VTTS constant worden verondersteld. Voor geleidelijke lange termijn veranderingen in iemands persoonlijke omstandigheden zijn, uitgaande van verschillende persoonsgebonden budgetteringsstrategieën, drie mogelijke ontwikkelingen van diens VTTS als gevolg van hedonische adaptatie onderkend: evenredig aan de consumenten prijsindex, het maandelijks huishoudinkomen en het uurloon. Tussen 1976 en 2005 verdubbelde de consumenten prijsindex in Singapore, het nominale huishoudinkomen nam toe met een factor zeven en het nominale uurloon met een factor acht. Modelimplementaties van zowel EPT als UT, gekalibreerd voor het basisjaar 1976, laten zien dat, wanneer de VTTS evenredig aan de prijsindex wordt verondersteld, in de periode tot 2005 het berekende aantal autobezitters dat tijdens de "belaste" uren met de auto naar het werk ging ver achter blijft bij de waargenomen veranderingen in trip planning. Evenredigheid aan het uurloon leverde juist een royale overschatting op. Voor beide modelimplementaties benaderden de berekeningen waarin de VTTS geïndexeerd werd met het maandinkomen de waarnemingen veruit het beste. Alleen die benadering wordt hierna aangehouden.

Voor modelimplementaties van UT is de VTTS coëfficiënt gekalibreerd door, voor de periode voordat rekeningrijden werd ingevoerd, de berekende en waargenomen keuzen van autobezitters om al dan niet per auto naar het werk te gaan te vergelijken (Sectie 7.4). Berekeningen met dit UT model, van de reacties van autobezitters die geconfronteerd werden met de invoering van rekeningrijden in juli 1975, laten onder meer een veel grotere overstap naar het openbaar vervoer zien dan waargenomen, terwijl het aantal automobilisten dat de rekening betaalde om hetzelfde reisschema aan te kunnen houden juist sterk werd onderschat (Sectie 7.5). Gezien de grote afwijkingen tussen het waargenomen en berekende verkeersgedrag is een nieuwe kalibratie uitgevoerd waarbij de waargenomen reacties op de invoering van rekeningrijden zijn meegenomen, leidend tot een aanzienlijk hogere VTTS. De daarmee berekende reacties op de tariefverhogingen in 1976, 1980 en 1989 wijken op dezelfde wijze af van de waarnemingen als die op de invoering in 1975 (Sectie 7.6 en 7.7). Daarentegen wordt de toename in autogebruik na de stevige tariefverlaging in 1989 correct voorspeld. Wanneer in het model een verliesneutrale parameter wordt ingevoerd die het effect van transitiekosten en/of een status quo voorkeur simuleert, zodanig dat de reactie – of liever het uitblijven daarvan – op de tariefsverhogingen correct wordt voorspeld, verdwijnt ook de toename in autogebruik na de tariefsverlaging, die wel degelijk optrad. Dit levert dus geen consistente verklaring voor het keuzegedrag in het Singaporese woon-werkverkeer. Geïmplementeerd met een VTTS die de toename in huishoudinkomen volgt overschat het UT model de geleidelijke verschuiving naar autorijden tijdens de "beprijsde" uren tussen 1976 en 2005 (zie Figuur 20 op blz. 250). Dit komt overeen met de suggestie van Gunn (2001), gebaseerd op modelberekeningen in overeenstemming met UT, dat de ontwikkeling van de

VTTS achterblijft bij het toename in huishoudinkomen[154]. Uiteraard kan dat achterblijven ook verklaard worden doordat de weerstand tegen de verandering door de verliesneutrale UT modellen wordt onderschat.

De VTTS is in de modelimplementaties van EPT op dezelfde wijze en met gebruik van dezelfde waarnemingen gekalibreerd en geherkalibreerd als het UT model. De grootte bleef daarbij vrijwel gelijk. Dat viel te verwachten omdat de reacties van automobilisten op de invoering van rekeningrijden over de hele linie veel beter voorspeld dan met het UT model. Ook de veranderingen in vervoerwijze en tijdschema, of liever het grotendeels ontbreken daarvan, als gevolg van de kort daaropvolgende tariefverhoging van 1976 werden vrij nauwkeurig ingeschat. Nagegaan is of die reacties ook goed voorspeld kunnen worden als de ochtendrit zoals die voor de invoering van rekeningrijden werd gemaakt werd aangehouden als referentiesituatie, in plaats van de combinatie van vervoerwijze en tijdschema die tussen invoering en tariefverhoging gold. Dit leverde een grotere overschatting van de overstap naar openbaar vervoer en/of een ander tijdschema dan de berekeningen met het UT model. Voor de hele daaropvolgende periode tussen 1976 en 2005 werden de effecten op het autogebruik van zowel plotselinge tariefverhogingen en verlagingen als van geleidelijke veranderingen in prijzen en inkomen vrij nauwkeurig voorspeld met de EPT modelimplementatie, waarin uiteraard de referentiesituatie voortdurend aan die ontwikkelingen werd aangepast.

Conclusies (Hoofdstuk 8)

De resultaten van dit onderzoek zijn beschreven in hoofdstuk 8. Hieronder worden de overkoepelende conclusies opgesomd.

1. Menselijk keuzegedrag kan worden beschouwd als een mentaal proces dat zorgt voor vier functies die tot een keuze leiden: inkaderen van de context, beoordelen van de eigenschappen van de alternatieven, vergelijken van en kiezen uit de alternatieven, en keuzegedragstrategie uitvoeren. Redeneren, dat grotendeels onbewust plaatsvindt, kan die functies in iedere willekeurige volgorde uitvoeren.
2. De concrete aannamen over keuzegedrag zoals in de verschillende versies van UT en PT worden aangehouden kunnen in twee sets worden ondergebracht die ieder een complete en niet overtollige uitvoering van die vier functies mogelijk maken.
3. De meeste aannamen van PT beschrijven de aspecten van keuzegedrag waarop ze betrekking hebben beter dan de overeenkomende aannamen van UT, zowel onder experimentele omstandigheden als in de praktijk.
4. Enkele afwijkende aannamen gedaan in andere gedragswetenschappen verklaren het keuzegedrag in de situaties waarvoor ze zijn voorgesteld beter dan zowel UT als PT. Die zijn, samen met die waarin PT beter presteert, gebruikt om EPT te formuleren.
5. Een nadere analyse van 85 studies uit de transportliteratuur, die samen het hele terrein van verkeersgedrag gerelateerd onderzoek beslaan, toont aan dat de vijf aannamen in de tabel op blz. 397 die EPT als beschrijvende theorie het meest onderscheiden van UT een betere verklaring bieden voor de relevante waarnemingen uit die studies dan de overeenkomende aannamen van UT. Op een enkele uitzondering na toonden geen van de studies aanwijzingen voor het tegendeel.

[154] Zie ook de Aanvullingen op de leidraad OEI: “De beste inschatting van de reële groei van reistijdwaardering in de tijd is voor zowel zakelijk als niet-zakelijk personenvervoer gelijk aan de helft van de groei van de reële loonvoet. Op dit punt is aanvullend onderzoek noodzakelijk” (VenW 2004: 14).

6. PT biedt geen heldere aanwijzingen hoe met de contextafhankelijkheid van keuzegedrag moet worden omgegaan als men er beleidseffect analyses of prognoses mee wil doen. Door drie aanvullende aannamen te ontlenen aan verschillende sociale wetenschappen is EPT uitgebreid van een beschrijvend-verklarend model tot een dat ook voor predicties geschikt is.
7. Uitgaande van de aannamen van EPT kan een discrete keuzemodel worden ontwikkeld dat ook gebruikt kan worden om de aannamen van UT te simuleren, door beperkingen of "vaste waarden" op te leggen aan parameters in de nutsfunctie.
8. Voor de UT implementatie van zo'n model bleek het niet mogelijk een VTTS waarde te vinden die veranderingen in het autogebruik in Singapore als gevolg van abrupte verhogingen zowel als verlagingen van het tarief voor rekeningrijden kwalitatief goed voorspelde, ook nietals een verliesneutrale transitiekosten parameter werd toegevoegd. De EPT implementatie voorspelde beide typen veranderingen correct en was met dezelfde VTTS waarde ook in staat de effecten van de lange termijnontwikkeling in transportprijzen en inkomens op het autogebruik vrij goed te benaderen.

Aanbevelingen (Hoofdstuk 8)

In het belang van een succesvolle invoering van het EPT paradigma in gedragsonderzoek en beleidseffectmodellen wordt onderzoek aanbevolen waarmee de volgende vragen kunnen worden beantwoord:

- Zijn ook de waarderingen die mensen *achteraf* toekennen aan een als verlies ervaren uitkomst van hun keuze veel hoger dan die van een winst van gelijke of verschillen ze niet wezenlijk?
- Past een individu haar referentiealternatief sneller aan na een als verbetering ervaren verandering in omstandigheden dan na een verslechtering?
- In welke mate en volgens welke "regels" passen individuen hun referentiealternatief aan hun ervaringen aan tijdens opeenvolgende keuzen met probabilistische uitkomsten, en zijn er systematische verschillen daarin tussen groepen mensen?
- Zijn interpersoonlijke verschillen in de gevolgde keuzegedragstrategie gerelateerd aan relatief stabiele persoonlijkheidskenmerken?

Verder worden een aantal diepgaande onderzoeken aanbevolen naar welke subjectieve keuzeset mensen hanteren in een bepaalde context, omdat dit een van de meest wezenlijke elementen van de keuzegedragstrategie is waarvan relatief weinig bekend is. Ook andere interpersoonlijke verschillen in keuzegedragstrategieën in verschillende domeinen en omstandigheden verdienen de aandacht van gedragsonderzoekers, economen en transportwetenschappers.

Aanbevolen wordt het discrete keuzemodel uit sectie 7.4 verder te ontwikkelen tot verschillende eenvoudig toepasbare operationele mathematische modellen. Voor de hand liggend is het inbouwen van de daar geformuleerde waardefunctie in een state-of-the-art discreet keuzemodel van het logit type. Een interessant alternatief ontstaat als de nutsfunctie wordt ingebed in een microsimulatie model dat het mogelijk maakt de keuzecontext van individuen te benaderen, door zowel de VTTS coëfficiënt als bereikbaarheidskarakteristieken en andere relevante eigenschappen te trekken uit waargenomen, geschatte en/of verwachte frequentieverdelingen. Zo'n "agent based" model zou ook goed kunnen worden gebruikt om de geaggregeerde keuzedata van diverse grote studies nader te onderzoeken, wat aanvullend materiaal zou opleveren om de geschiktheid van de EPT en UT paradigma's te vergelijken.

Met betrekking tot beleidsontwikkeling wordt aanbevolen het EPT paradigma nu al in kwalitatieve zin te gebruiken en het tegelijkertijd stapsgewijs verder uit te bouwen door de ontwikkeling van operationele beleidseffectanalyse modellen. Daarbij geld dat, hoewel de geschiktheid van EPT hier vooral is getoetst aan gedrag in relatie tot personenverkeer, het een generiek keuzegedrag concept is dat evenzeer toepasbaar lijkt op andere beleidsterreinen die raken aan het gedrag van individuen. EPT is, ook zonder verder onderzoek, geschikt om vooraf kwalitatief het succes in te schatten van verschillende soorten maatregelen die ten doel hebben het gedrag van mensen te veranderen. Dat kan door voor relevante groepen van burgers de balans in te schatten van de veranderingen in positieve en negatieve zin die door de beleidsmaatregel worden veroorzaakt, waarbij de negatieve gevolgen weer ongeveer tweemaal zo zwaar tellen als de positieve. Natuurlijk is een meer kwantitatieve effectberekening te verkiezen. Met een model gebaseerd op EPT lijkt het haalbaar om de reacties van verschillende individuen te voorspellen, in samenhang met de verdeling daarvan over verschillende sociaal-economische groepen. Dat biedt uitzicht op een genuanceerde inschatting van zowel het draagvlak voor invoering van de betreffende maatregel als op de mate waarin de gewenste gedragsverandering wordt bereikt.

About the author

Evert Jan van de Kaa was born on January 24 1946 in Ede where he obtained his Gymnasium diploma in 1964. In the second half of the Sixties he enjoyed student life in Delft and studied Civil Engineering at the Technical University. His final-year subject was Irrigation and Hydropower and he received his masters degree in 1971.

In that same year he married, moved to Emmeloord in the northeast of the Netherlands and started, on Labour Day, his career in hydraulic research at the nearby Rivers and Navigation branch of Delft Hydraulics Laboratory, nowadays part of Deltares. He carried out research projects concerning the stability of bank protections subject to hydraulic phenomena like currents, waves, jets and wakes generated by sailing ships that in turn influence the movements of those ships in constrained waters. The applied research approaches were hydraulic scale models, prototype measurements and mathematical model simulations, often in combination, and of course supported by literature searches. This research experience aroused his persistent interest in the understanding of complex systems. It also resulted in many technical notes and research reports and several book sections, lecture notes and congress papers. Some examples are:

1977: Discussion of "Sinkage and Resistance for Ships in Channels". *Journal of the Waterway Port Coastal and Ocean Division*, **103** (3), 389-392.

1978 (co-author H.G. Blaauw): *Erosion of bottom and sloping banks caused by the screw race of manoeuvring ships*. Delft Hydraulics Laboratory Publ. 202, Delft.

In 1978 Evert Jan was asked to run the Fairways Department of what in 2007 became the Traffic and Navigation Directorate of Rijkswaterstaat. The office was located in the southwest of the Netherlands, which required a long-distance move of domicile to Prinsenbeek. The multi-disciplinary Fairways Department had ten staff members, mainly academics, engaged in research and development, policy advice and consultancy in the fields of navigation and fairway design. Human factors became an important research topic, which complicated the modelling of the considered ship-fairway interaction systems. In addition to running the department Evert Jan was in charge of some large-scale research and consultancy projects and participated in several national and international working groups, committees and panels. From 1976 to 1983 and from 1984 to 1986 he was also a part-time lecturer at Dutch Polytechnics and occasionally lectured at five university refresher courses. During this period

he regularly produced research and consultancy reports, lecture notes and congress papers on navigation and fairway design. Some examples are:

1984: Safety Criteria for Channel Depth Design. *Procs. 3rd US - Netherlands Meeting on Dredging and Related Technologies*. Vicksburg, MS, U.S. Army Engineer WES, pp. 213-233.

1985 (first author): Erosion Control of Navigation Embankments. *Procs. 26th International Navigation Congress,* S I - S 4, pp. 53-72. Brussels.

In 1986 Evert Jan became director of the Water Management and Navigation division of the Zuyder Zee Works Directorate of Rijkswaterstaat and moved with his family to Ermelo in the centre of the Netherlands. The division had about two hundred employees engaged in policy development, administration, project planning, maintenance and operation with respect to the waterways, dams, locks and sluices in the Zuyderzee district. His challenges were to put integral water management into operation in the area and to manage the division during a merger of the directorate with another public service. The implementation of integral water management was approached by considering the waterways, including their physical, chemical and biological compounds and processes as complex systems. In 1989, after the eventful merger process, Evert Jan was appointed as director of the Water Management and Navigation division of the new directorate that nowadays is called IJsselmeergebied, and a few months later he also became deputy general director. He kept these positions until 1996. During this period he chaired several working groups, committees and boards at regional and national level, and was a member of many others. He also published several reports, conference papers and journal articles. These include:

1990 (co-author): Some conflicts of interests in using natural water resources. *Procs. 27th International Navigation Congress*, S. I – S. 3, pp. 85-101. Osaka.

1991: Ecological aspects of waterway management in the Netherlands illustrated with examples from the IJsselmeer area. *PIANC Bulletin* **73**, 72-99.

From 1996 till 2002 Evert Jan was director of the Infrastructure and Intelligent Transport Systems division of the Transport Research Centre (now Centre for Traffic and Navigation) of Rijkswaterstaat in Rotterdam, which once more required a long-distance relocation of his family, to the small village of Hoeven in the southwest of the country. This division employed about 120 staff members, most of them university graduates, who were engaged in applied research, policy advice and development with respect to design, maintenance and dynamic traffic management, predominantly for the road network. As expected, an organization of many professionals behaved as a different 'system' compared to one that was predominantly engaged in operations. Again, Evert Jan chaired and attended several boards and committees at national level and published several articles. Some examples:

1998: A Managers' Approach to Architecture. *CD-ROM Procs. 5th ITS World Congress*. Seoul.

2001: Intelligent Operation of Motorway Networks, a Prerequisite for vital Urban Networks. *CD-ROM Procs. IRF World Congress*, IRF, Paris.

In 2002 Evert Jan made a career shift back to science, though in a field other to the one in which he started after his graduation from Delft. He is a senior research fellow at the TRAIL Research School in Delft, applying his experience with complex systems to the understanding of the impact of the behaviour of citizens and other actors on the development of the Transport system, which resulted in this book.

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