A transaction model of household car ownership: the impact of life events and built environment factors

M. (Maarten) van de Kamp

Complex Systems Engineering and Management, Delft University of Technology
M.vandeKamp@student.tudelft.nl, 4291611

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Abstract

Governments all over the world are facing sustainability challenges. To provide for liveability and accessibility, especially in dense and growing cities, is not an easy assignment: pollution, CO2-emissions and congestion are common problems, among others induced by car ownership and use. Traditionally, car ownership is mainly explained by looking at socio-demographic characteristics, like age, income and having a driving license. More recent research showed that life events related to work, family and residential location, and built environment factors are promising explanatory factors of changes in car ownership. Theoretically, it is better to assess the impact of these factors on *changes* in car ownership (with a transaction choice model), instead of on the absolute *number* of cars (with a holding model). Therefore, transaction choice models are used to quantify the effects on car ownership. Their outcomes showed first of all that a transaction model has a significantly higher explanatory power than a holding model ($p<0.001$), and secondly, that adding life events and built environment factors significantly improves it even more ($p<0.001$). Especially the life events of residential relocation, job transitions, and gaining a licence – including multiple anticipated and delayed effects – were found to affect car transactions, while the absence of free nearby parking was found to decrease car acquisitions and increase car disposals. Therefore, reduced free parking at the street – especially near new business and residential areas – and campaigns aimed at people experiencing the habit-breaking effect of life events, are policy measures with the potential to reduce car ownership. Furthermore, the outcomes of the transaction model can be applied in a dynamic car ownership forecasting model, which can inform policymakers even more and enable them to work towards a more sustainable and accessible future.

Keywords: car ownership, car transactions, transaction model, life events, built environment, parking

1. Introduction

All over the world, governments are facing the challenge to provide for liveability and accessibility. This is not an easy assignment, especially in dense and growing cities: pollution, CO2-emissions and congestion are common problems, among others induced by the use of cars. Therefore, one of the policy aims in the Netherlands is to make mobility increasingly more sustainable, which includes stimulating the use of electric cars, public transport and bike, and limiting parking (Ministry of Infrastructure and Water Management, 2017).

Car *ownership* is an important intermediate factor affecting car *use*. This relates for example to the time and distance travelled as well as the negative externalities related to that (Van Acker, Mokhtarian,

& Witlox, 2014), so one way to reduce car use is to reduce car ownership. Therefore, knowing the underlying causes for changing car ownership levels is crucial to influence travel behaviour and to work towards a more sustainable future.

Traditionally, car ownership research is mainly explained by looking at socio-demographic characteristics, like age, income and having a driving license. However, there is uncertainty about how car ownership will develop in the future, which transcend these factors. First of all, it is unknown what the impact is of upcoming transport services (i.e. shared mobility, mobility as a service, and autonomous vehicles) and ongoing climate policies (e.g. banning cars from inner cities, or taxes for polluting cars) on car ownership and use (Fatmi & Habib, 2018; Van Paassen, 2018).

The second question that brings uncertainty is whether socio-demographic characteristics are able to fully explain changes in car ownership, for example in case of the trend that is visible in developed countries (Van Wee, 2015). Here, especially for young people, the growth of car ownership and use seems to decrease, flatten out, or is even reversed (Goodwin & Van Dender, 2013), also in the Netherlands (CBS, 2017). Although some point at a changing attitude towards the car, several papers argue that, in the Dutch context, situational factors are a more realistic explanation for this trend (KiM, 2014; Oakil, Manting, & Nijland, 2016; Ruijs, Kouwenhoven, & Kroes, 2013; Van der Waard, Jorritsma, & Immers, 2013): young adults increasingly study and live in urban areas, resulting in decreased car ownership and use until they are settled down. Demographic transitions like this are often visible in the occurrence of 'life events' (Chatterjee & Scheiner, 2015), for example related to changes in household composition (like getting a child) and residential choices (like moving to another town). Part of the uncertainty related to the future of car ownership can be reduced by examining the effects of these situational factors (both life events and built environment factors).

Next to that, it is theoretically better to assess the effect of these factors on *changes* in car ownership – with a transaction choice model – instead of on the *absolute* number of cars, with a holding model (Anowar, Eluru, & Miranda-Moreno, 2014; De Jong, Fox, Daly, Pieters, & Smit, 2004; De Jong & Kitamura, 2009). This is because the number of vehicles owned by a household results from several time-dependent transaction decisions instead of from repeated decisions about the optimal absolute size of the vehicle fleet.

Therefore, this paper examines to what extent a transaction model for household car ownership in the Netherlands, including life events and built environment factors, can improve the representation of choice behaviour compared to a holding model. After giving an overview of the literature (section 2), the method and data are discussed in more detail (section 3). The impact of going from a holding to a transaction model, and that of subsequently adding life events and built environment factors, is assessed in section 4, while section 5 provides a conclusion, various recommendations, and policy implications.

2. Car ownership literature

The literature regarding car ownership covers multiple fields. Therefore, we will give attention to the relation of car ownership and life events, and to the impact of built environment factors.

2.1 Car ownership and life events

Traditionally, car ownership is mainly explained by looking at socio-demographic characteristics, which can have both positive (+) as negative (-) effects. Examples of that are income (+), education level (+), being male (+), age (+ & -), and the number of driving licenses (+) in a household (De Jong et al., 2004). However, car ownership is increasingly seen as a longer term decision shaping daily travel behaviour (Scheiner, 2018; Van Acker et al., 2014), just like other social, economic or spatial factors (like work and housing). Research with this long-term perspective can be described with different names like 'mobility biographies' (Scheiner & Holz-Rau, 2013), 'life course' (Beige & Axhausen, 2008) or 'life trajectory' (Verhoeven, 2010) approach.

In this approach, life events have a central position, which can break habitual travel behaviour. Often a change in social role or status plays a role here, for example by becoming a parent: having a child might strengthen the need for a new car and/or a new house. Changes in household composition, education, employment, and residential location – which are often interrelated – were found to affect travel behaviour in the review of Chatterjee & Scheiner (2015).

According to Zhang, Yu, & Chikaraishi (2014), *residential relocation* is more important for changes in car ownership than other life events. Most authors find it is mainly related to higher car ownership levels (Beige & Axhausen, 2012, 2017; Chatterjee & Scheiner, 2015; Gu, Feng, Yang, & Timmermans, 2020; Oakil, Ettema, Arentze, & Timmermans, 2014; Van de Kamp, 2019; Zhang et al., 2014), although positive effects on car disposal have been found as well (Cao, Naess, & Wolday, 2019; Clark, Chatterjee, et al., 2016).

Higher car ownership levels are often related to work related life events: previous research found positive effects of (anticipated) job transitions (Chatterjee & Scheiner, 2015; Gu et al., 2020; Van de Kamp, 2019), an increasing distance to work (Beige & Axhausen, 2012; Van de Kamp, 2019). However, Oakil, Ettema, et al. (2014b) found a positive effect of employment changes and a similar (but delayed) effect of retirement on car *disposals*. Chatterjee & Scheiner (2015) mention three papers that did not find any effect of retirement though.

Changes in household composition are found to affect car transactions as well, for example due to childbirth or other increases in household size, while lower car ownership was found to be related to a child leaving, and losing a partner (Chatterjee & Scheiner, 2015; Klein & Smart, 2019; Müggenburg et al., 2015; Oakil, Ettema, et al., 2014). However, not all of these effects are always found: Müggenburg, Busch-Geertsema, & Lanzendorf (2015) mention for example some authors that did not find an effect of childbirth on car transactions.

Finally, Clark, Chatterjee, et al. (2016) found that obtaining a driving licence positively affects car acquisitions. All in all, this and other life events are important variables to examine when researching car ownership.

2.2 Car ownership and the built environment

One of the life events with an impact on car ownership we discussed is residential relocation. This can be explained with two mechanisms: besides having a ‘habit-breaking’ effect, a residential relocation is accompanied by a changing residential environment, which affects car ownership as well.

The impact of several built environment factors on car ownership has been studied extensively in the past decades (second mechanism). The reviews of Ewing & Cervero (2010) & Stevens (2017) give a good overview of such research. These studies indicate that compact development, a specific form of urban planning, is related to reduced driving. This has been specified with several categories of factors, the 5Ds: *Density*, *Diversity* (of land use), *Design* (of street network), *Destination accessibility* (e.g. jobs and amenities), and *Distance to transit* (e.g. train station). An overview of them, including description and mechanism, is provided in Table 1.

Table 1. *Overview of the 5Ds of the built environment affecting travel behaviour (TB), based on Stevens (2017, p. 8)*

5Ds	Example	Mechanism affecting TB
Density	Population, households, or jobs per unit area	Placing destinations closer together
Diversity	Mixture of different land uses in a given area	Different amenities close to homes
Design	Network characteristics (like intersections)	Walking and biking more attractive
Destination access.	Distance to destinations (like downtown)	Destinations close to homes
Distance to transit	Distance to the nearest transit stop	Transit more attractive

Clark, Chatterjee, et al. (2016), for example, used a quite comprehensive approach related to car ownership, residential relocation and some built environment factors as well. However, they mainly looked at public transport factors. Among others they found that poorer access to public transport predicts higher car ownership levels. The impact of *residential parking* on car ownership is often lacking here (Ewing & Cervero, 2010; Stevens, 2017), despite its relevance for car ownership in denser cities and recent findings that it is a significant factor affecting car ownership (Albalate & Gragera, 2020; Christiansen et al., 2017; De Groote, Van Ommeren, & Koster, 2016; Guo, 2013; Ostermeijer, Koster, & Van Ommeren, 2019; Van De Coevering, 2008). Relevant parking aspects that are found to reduce car ownership are for example a lower number of places, a higher distance to them, and a higher parking tariff (and/or the need for a permit). The effect of parking aspects, together with other BE factors, is therefore important to take into account when examining car ownership (Van Wee, 2015).

Finally, the presence of amenities (like grocery stores, parks, hospitals, schools, and restaurants) can explain car ownership, since it facilitates daily activities that induce travel. Therefore, amenities at closer distance are used more to minimize the cost of time or money, although not always: quality plays a role as well (Naess, Peters, Stefansdottir, & Strand, 2018). Although research with this perspective is theoretically rigorous, not many quantitative results are found. However, Elldér (2018) concludes that an increasing number of amenities near the residential location reduces driving and instead increases walking and cycling.

All in all, next to traditional explanations, life events and built environment factors are important variables to consider when developing a car ownership model.

3. Research method and data

To quantify the effects of various explanatory factors on car ownership behaviour, multinomial logit (MNL) choice models are constructed in statistical software Biogeme (Bierlaire, 2018). Choice modelling is often based in Random Utility Maximization (RUM) theory (McFadden, 2000): people will choose for an alternative with the highest expected utility, which depends on the various attributes of alternatives (for example price and quality). Utility functions are specified for each choice alternative, which are used to calculate the probabilities of choosing them: a higher utility (relative to the utility of other alternatives) results in a higher probability of being chosen.

To examine whether or not a transaction model is better able to represent household car ownership decisions than a holding model, these two models are developed. The holding model is similar to the one that is used in Carmod (Significance, 2017).

Next to that, two versions of the transaction model were estimated: one with the effects of life events and the built environment and one without them. For the transaction model, one by one additional variables were added to the model in order to find the model that is significantly better than other models. Whether adding a variable resulted in a better model fit is evaluating with the Likelihood Ratio Statistic (LRS).

Adding parameters was done per category of variables, starting with those that were also included in the holding model. Subsequently other groups of variables were added and assessed: first some car related aspects (i.e. number of cars, car age), followed by life events and built environment factors.

The limited version was created with the same parameters included as the complete model, although life events and built environment factors were excluded. It was not chosen to add or change variables in order to improve model fit, since the results would probably not outweigh the effort for doing that. Only the spatial characteristics that are part of Carmod were added again here. Table 2 shows the variables included in the holding model and both transaction models.

Since the estimation dataset contains information of car transaction choices over multiple years, there are also multiple cases per respondent, which could be correlated. Therefore, to account for this dependency, the ‘sandwich estimator’ is used, resulting in more robust outcomes. However, using this method does not affect the estimated utility parameters, but only increases their standard error (Daly & Hess, 2010). Using the 'jack-knife' method would account for a bias in the estimated coefficients as well as in the accuracy of these estimates. However, for practical reasons it is chosen to use the sandwich estimator for all estimated choice models.

Table 2. *Overview of variable categories used in the holding model and the transaction model for household car ownership.*

Category	Holding model	Limited transaction model	Complete transaction model
Car ownership	0, 1, 2+ cars	-1, 0, +0, +1	-1, 0, +0, +1
Car characteristics	-	Car age Initial number of cars	Car age Initial number of cars
Household characteristics	Socio-demographics Licence possession	Socio-demographics Licence possession	Socio-demographics Licence possession
Built Environment	Urbanisation Pop./empl. density Zonal parking tariff	Urbanisation Population density Zonal parking tariff	Urbanisation Population density Zonal parking tariff Free parking availability Public transport accessibility Distance to supermarket
Life events	-	-	Life events related to family, work, home, licence possession

Since the holding model and both transaction models use the same data to estimate the effects on car ownership, their outcomes can be compared. Consequently, differences related to both structure (transaction versus holding) and substance (with or without the effect of the built environment and life events) can be examined.

3.1 Estimation data

The retrospective data was collected between January and June 2019, with participants in the survey were found through an online panel. They answered questions related to car ownership, residential location, household composition, occupation and various other individual or household characteristics from the period 2000 to 2019. Except for employment, questions about all these topics were asked at the household level, considering that decisions related to residential location and car ownership are not individual concerns. In the end, this initial dataset includes information of 1,487 respondents, which can be distinguished by urbanisation (Table 3) and age (Table 4). Although there are some deviations from the Dutch population, this does not hinder model estimation. A more detailed description of the survey design and data collection is given by Van de Kamp (2019).

Table 3*. Distribution urbanisation* (CBS, 2019c)**.**

Urbanisation level	Population	Sample
Selection G4 (extr. urbanised)	14%	11%
Other extremely urbanised	13%	26%
Strongly urbanised	23%	22%
Moderately urbanised	16%	14%
Hardly urbanised	17%	14%
Not urbanised	17%	13%

Table 4. *Distribution age (CBS, 2019a).*

Age	Population	Sample
18 to 35 years	24%	14%
35 to 50 years	25%	23%
50 to 65 years	27%	31%
65+ year	24%	32%

The retrospective dataset was coupled to secondary data sources from CBS (2019c, 2019b), Significance (2017) and KiM (2017), to enrich the model estimation process with additional zonal information. Among others this relates to accessibility, urbanisation levels, and the proximity of local destinations, which are mainly used to estimate parameters of the transaction model.

The initial dataset contained 1,487 cases: one for every respondent. This has been transformed into an estimation dataset with 24,920 cases, where for every respondent each year from 2001 to 2018 is taken into account separately. Each case is therefore a snapshot of a variety of individual, household and spatial characteristics in that year. A great advantage of this data compared to other data is that it contains information on changes in these characteristics compared to the previous year as well (life events).

Table 5. *Sample description: car transactions since 2000.*

Observation years (average)	16.8	
Number of cases	24,920	100%
Additional cars	646	2.6%
Replaced cars	2,211	8.9%
Disposed cars	175	0.7%
No change	17,005	68.2%
Missing	4,883	19.6%

From almost 20% of these cases car transaction information is lacking (see Table 5), since respondents did not always provide a complete and consistent overview of their car ownership state since the year 2000 (or the year they turned 18). However, it can be concluded that these missing cases do not heavily affect the distribution of specific car transaction types: although the share of acquisitions and replacements slightly increases over the 18 years in the estimation dataset, it is not considered to affect the suitability of these data to use it for choice model estimation.

4. Model estimation

Based on the retrospective estimation data, the impact of going from a holding to a transaction model, and subsequently adding life events and built environment factors, is assessed.

4.1 Holding model

Not all of the promising factors that can explain car ownership decisions are part of the holding model: mainly socio-demographic characteristics are included here, although some aggregated zonal characteristics are part of this choice model as well. After specifying utility equations in Biogeme, the models were run. The resulting parameter outcomes are shown in Table 6. Although a direct comparison between the parameter estimates used in the holding model in Carmod and the holding model discussed here would not be a valid, comparing them to each other can still build some trust in the ability of the estimation dataset to capture car ownership choices. Therefore, the estimates used in the current models are displayed as well.

We can observe that the utility parameters of income, licence possession, and age display effects similar to that used in Carmod: the utility for having multiple cars is higher for people with a higher income, more licenses in the household, and the utility for having no car is lower for older people.

Comparisons regarding occupational factors can be made in a more indirectly way. As shown in Table 6, bigger households – regardless of the occupational status of the respondent – have a higher utility to own a car. When the respondent in the estimation dataset does not work, this is true as well, although with a lower utility to own a car compared to a worker. In Carmod, the utility for owning one or multiple cars is higher when there are more workers in the household (which also means a bigger household). Based on each of the choice models separately, it can be concluded that both household size and occupation affect the number of cars. The utility parameters for all socio-demographic factors show therefore no unexpected outcomes.

Table 6. *Estimation results of the holding model.*

Variable	**Utility having car(s) for …**	**Estimates per alternative** *0 cars*	*1 car*	*2+ cars*	**Carmod[##]** *0 cars*	*1 car*	*2 cars*	*2+ cars*
ASC	Constant utility for having one/multiple cars		0.931	-2.27		0.8465	-4.207	-7.007
Income 1 & 2[###]	...hh in income class 1 or 2 (below 20k)		-.938	-.791		i*0.6947	i*1.574	i*1.920
Income class 3	...hh in income class 3 (between 20 and 30k) *[ref.]*		0	0		i*0.6947	i*1.574	i*1.920
Income class 4	...hh in income class 4 (between 30 and 40k)		0	.496		i*0.6947	i*1.574	i*1.920
Income class 5	...hh in income class 5 (more than 50k)		.204*	.905		i*0.6947	i*1.574	i*1.920
License2	...hh with two driving licenses		0.166*	1.89		1.496	4.403	3.032
License3	...hh with three driving licenses		0	2.77		1.458	4.786	5.572
NoLic	...number of hh members without driving license		-0.834	-0.506		0.1152	0.1480	
Lic x Female	...female respondent with licence	-0.761	-0.327		0.7498	0.4423		
< 35 years	...age of respondent below 35 *[reference]*	0			0			
≥ 35 years	...age of respondent of 35 and higher	-0.493			-0.1900[#]			
≥ 50 years	...age of respondent of 50 and higher	-0.389			-0.2217[#]			
≥ 65 years	...age of respondent of 65 and higher	-0.658			-0.7953			
Student	...respondent that is student		0	0	1.294			
Working x HH1	...respondent with fulltime/parttime job *[reference]*		0	0				
Retired x HH1	...respondent that is retired *[reference]*		0	0				
No occup. x HH1	...respondent without occupation		-0.949	-1.94				
Fulltime x HH2	...respondent with fulltime job in bigger household		1.16	0.292*				
Parttime x HH2	...respondent with parttime job in bigger household		1.01	0.261*				
Retired x HH2	...respondent that is retired in bigger household		1.01	0				
No occup. x HH2	...respondent without occupation in bigger HH		0.298*	-0.704				
Pop. Density /100	...increasing population density (1km range)		0	-0.653*		-0.598	-1.095	-1.639
Rural	...rural areas (urbanisation level = 1)	-.737*	-.282*		-0.5809	-0.2328		
Very strong urban.	...very strongly urbanised areas (urbanisation = 5)	.583			0.2012			
Empl. density 1km	...increasing employment density (1km range) /100		0	.836*		-0.310	-0.684	-1.32
Empl. density 5km	...increasing employment density (5km range) /100		1.55*	2.12*		-1.37	-2.05	-2.33
Agricult. share	...increasing share of agricultural jobs in a zone	-.0436*			-2.965			
Parking tariff /100	...increasing parking tariff in a zone	.360*	.143*		0.2648	0.1109		

*[#]Carmod uses age group 55+ instead of 50+; [##]Parameter estimates from Carmod that cannot easily be compared have been omitted (e.g. number of workers); *P>0.05*

[###]In Carmod income is accounted for by means of a continuous measure, so the parameter estimates have to be multiplied with a scaled income factor (i)

Lastly, the group of zonal characteristics is examined. As we can observe in Table 6, the model resulted in various insignificant estimates, including those for population density, a low urbanisation (rural) and the parking tariff. This can explain that the signs of the utility parameters for employment density and the share of agricultural jobs in a zone are different from that in Carmod, since these are insignificant as well. Only the positive parameter estimate for owning no cars in very strongly urbanised areas is statistically significant ($p<0.05$), which is also the case in Carmod.

All in all, it is concluded that the retrospective estimation data leads to parameter estimates for the holding model that are similar to those used in Carmod, which increases confidence in its ability to capture car ownership choices.

4.2 From Holding to Transaction model

The added value of using a transaction model instead of a holding model can be evaluated by using the Ben-Akiva & Swait test (1986). This test gives an upper bound for the probability that a model A is the best representation of the actual data-generating process, despite having a lower log-likelihood than another (non-nested) model B.

The transaction model used to assess its added value compared to a holding model, is different from the transaction model discussed in the rest of this paper. Since model fit comparisons only hold when the same choice is modelled, this adjusted transaction model only implicitly models the choice between no transaction (0), car acquisition (+1), replacement (+0), and disposal (-1). Instead, similar to the holding model, the choice to have 0, 1, or 2 or more cars is modelled.

At the same time, the distinguishing nature of a transaction model is maintained by making the choice for the number of cars conditional on the initial car ownership state: for households with no cars, only the choice between no transaction and acquisition was modelled; for one-car households the choice between no cars (disposal), one car (replacement of no transaction), and two cars (acquisition); and for households with two or more cars the choice between two or more cars (acquisition, replacement or no transaction) and one car (disposal). The latter, though, is only possible for households initially owning two cars.

Using the adjusted transaction model instead of a holding model results in a significantly better model fit ($p<0.001$), as seen in Table 7. We can observe a great effect on the log-likelihood compared to the holding model, specifically related to inclusion of interaction variables with the initial number of cars.

Table 7. *Model fit assessment of the limited transaction model compared the holding model.*

Model	**Null-LL**	**Final LL**	**#observations**	**#parameters**	**P**
A. Holding model	-21,627	-11,883	19,686	37	
B. Transaction model (adj.)	-21,627	-5,518	19,686	20	<0.001

Although the adjusted transaction model displayed in Table 7 has a significantly better model fit than the holding model, it did not allow for a distinction between a choice to do nothing and replacing a car. Therefore, the model estimates discussed below are stemming from a different transaction model, which is able to make this distinction (see Table 8).

Assessing the sign and size of the estimated parameters of the limited transaction model (left half of Table 8) shows that more or less the same patterns are obtained as in the holding models. We can make a couple of observations. First, as expected, socio-demographic factors like income, education level and age, are important explanatory variables of changing car ownership, just like licence ownership and parameters more directly related to car transactions (i.e. initial car ownership and car age).

When examining the limited built environment parameters, we can see that both ‘traditional’ parameters (urbanisation and population density) affect car transactions, although the latter only affects the utility to replace a car. Living in less urbanised areas increases the utility of car acquisition.

Table 8. *Estimation results of the transaction choice model used in the transaction model.*

		Limited						**Complete**					
Variable	**Utility car transaction for …**	*Acq*	*SE*	*Repl*	*SE*	*Disp*	*SE*	*Acq*	*SE*	*Repl*	*SE*	*Disp*	*SE*
ASC	Constant utility for car transaction	-6.94	(0.388)	-4.18	(0.266)	-5.09	(0.196)	-7.28	(0.383)	-4.79	(0.280)	-4.78	(0.267)
Inc12	...income class 1 or 2 (below 20k)	-	-	-0.314	(0.106)	0.681	(0.229)	-	-	-0.299	(0.105)	0.655	(0.226)
Inc4	...income class 4 (30 to 40k)	0.360	(0.112)	-	-	-	-	0.312	(0.109)	-	-	-	-
Inc56	...income class 5 or 6 (40k+)	0.457	(0.112)	0.198	(0.0715)	-	-	0.422	(0.107)	0.195	(0.0712)	-	-
Age35_50	...max. HH age of 35 to 50	-	-	0.408	(0.0915)	-	-	-	-	0.349	(0.0901)	-	-
Age51_65	...max. HH age of 50 to 65	-	-	0.582	(0.0964)	-	-	-	-	0.514	(0.0945)	-	-
Age65	...max. HH age of 65 and higher	-	-	0.433	(0.108)	-0.616	(0.264)	-	-	0.399	(0.108)	-0.508	(0.265) *
Occ_FT/PT	...fulltime or parttime job [ref]	-	-	-	-	-	-	-	-	-	-	-	-
Occ_HH1_No	...no occupation in 1p HH	-0.591	(0.217)	-0.668	(0.138)	-	-	-0.520	(0.206)	-0.611	(0.142)	-	-
Occ_HH2_No	...no occupation in 2p HH	-	-	-0.246	(0.0704)	-	-	-	-	-0.196	(0.0717)	-	-
Occ_Ret	...retired people	-0.517	(0.175)	-	-	-	-	-0.412	(0.176)	-	-	-	-
Educ_Higher	...higher education	0.202	(0.101)	-	-	-	-	0.164	(0.0972) *	-	-	-	-
Educ_Lower	...lower education	-0.375	(0.121)	-	-	-	-	-0.320	(0.121)	-	-	-	-
GDP	...change in GDP (%)	0.107	(0.0273)	-	-	-0.0824	(0.0417)	0.103	(0.0273)	-	-	-0.0958	(0.0418)
Cars0	...initially having no car	2.13	(0.119)	-	-	-	-	2.10	(0.118)	-	-	-	-
Cars2	...initially having two/more cars	-0.882	(0.253)	-	-	2.38	(0.189)	-0.953	(0.249)	-	-	2.50	(0.192)
Car_age1_2	...max. car age of 1 to 2 years	-	-	-1.13	(0.163)	-0.812	(0.409)	-	-	-1.13	(0.162)	-0.796	(0.416) *
Car_age6_10	...max. car age of 6 to 10 years	-	-	-0.151	(0.0715)	-	-	-	-	-0.165	(0.0716)	-	-
Car_age11pl	...max. car age of 11/more years	0.475	(0.127)	-	-	0.424	(0.190)	0.452	(0.130)	-	-	0.467	(0.190)
Lic	...having a license	1.87	(0.371)	1.94	(0.243)	-	-	1.75	(0.361)	1.89	(0.244)	-	-
FemLic	...women having a license	0.312	(0.0917)	-	-	-	-	0.269	(0.0890)	-	-	-	-
Lic2	...HHs with two licenses	0.685	(0.116)	-	-	-	-	0.732	(0.112)	-	-	-	-
Lic3pl	...HHs with three/more licenses	1.57	(0.209)	-	-	-	-	1.39	(0.192)	-	-	-	-

**P>0.05*

Table 8 *(continued).*

		Limited						Complete					
Variable	**Utility car transaction for ...**	*Acq*	*SE*	*Repl*	*SE*	*Disp*	*SE*	*Acq*	*SE*	*Repl*	*SE*	*Disp*	*SE*
Ln_urb	...natural logarithm urbanisation	0.309	(0.0811)	-	-	-	-	0.242	(0.0853)	-	-	-	-
PopuDens /100	...increasing popul. density/100	-	-	-0.170	(0.122)	-	-	-	-	-0.267	(0.0879)	-	-
ParkTar/100	...zonal parking tariff/100	-	-	-0.150	(0.0531)	-	-	-	-	-	-	-	-
FreePark	...free nearby parking available	-	-	-	-	-	-	0.358	(0.127)	0.625	(0.0948)	-0.581	(0.223)
BBI_100_110	...PT accessibility of 100 to 110	-	-	-	-	-	-	-	-	0.0944	(0.0549) *	-	-
BBI_110pl	...PT accessibility higher than 110	-	-	-	-	-	-	-	-	-	-	-0.436	(0.268) *
Dsuperm_750pl	...higher distance to supermarket	-	-	-	-	-	-	0.208	(0.107) *	-	-	-	-
ToWork	...a job transition	-	-	-	-	-	-	0.753	(0.152)	0.422	(0.106)	-	-
ToWork_pl1y	...a job transition (next year)	-	-	-	-	-	-	-	-	0.391	(0.108)	-	-
ToRetired	...transition to retirement	-	-	-	-	-	-	-	-	0.514	(0.147)	1.35	(0.329)
Reloc	...relocation (dummy)	-	-	-	-	-	-	0.643	(0.163)	0.516	(0.104)	0.786	(0.298)
Reloc_min1y	...relocation (last year)	-	-	-	-	-	-	-	-	-	-	0.729	(0.289)
Reloc_pl1y	...relocation (next year)	-	-	-	-	-	-	0.530	(0.168)	-	-	-	-
CHILDmin	...decrease in #children (dummy)	-	-	-	-	-	-	-	-	0.365	(0.140)	-	-
PARTNmin	...loss of a partner	-	-	-	-	-	-	-	-	-	-	2.33	(0.421)
LicPlus	...increase in driving licenses	-	-	-	-	-	-	1.11	(0.169)	-	-	-	-
LicPlus_min1y	...increase in licenses (last year)	-	-	-	-	-	-	0.569	(0.197)	-	-	-	-
LicPlus_pl1y	...increase in licenses (next year)	-	-	-	-	-	-	0.526	(0.240)	-	-	-	-

**P>0.05*

4.3 Adding life events and built environment factors

The estimated parameters of complete transaction model (including life events and additional built environment factors) are shown in Table 8 as well (right half). As we can see, the parameter estimates for socio-demographic factors in the complete transaction model are very similar to that of the limited model: often they very close to each other. Thus, the effect of life events and the built environment are not heavily correlated to that of many other variables. When that would have been the case, more substantial differences would be observed. In order to verify whether it increased model fit, the LRS was used.

The LRS was determined based on the log-likelihood of both transaction models and the difference in number of parameters (degrees of freedom, df). Chi square ($\chi 2$) values were used to assess model fit: the complete model is superior to the limited one since the LRS is substantially higher than the critical chi square value at a 0.1% significance level (see Table 9). Therefore, it is concluded that life events and built environment factors significantly improve the ability to explain car transaction choices compared to a holding model.

Table 9. *Model fit complete and limited model: with and without life events (LE) and built environment (BE) factors.*

Model	Null-LL	Final LL	#parameters	df	LRS	Crit. χ^2	P
Limited: without BE & LE	-27,805	-9,896	37				
Intermediate: only with BE	-27,805	-9,840	43	6	211	22.458	<0.001
Complete: with BE & LE	-27,805	-9,723	58	15	233	37.697	<0.001

From the additional built environment factors especially the presence of free nearby parking is an important explanatory variable, since it affects the utility for all three the transactions. Car disposals are less likely when there is free parking, and car replacements and acquisitions are more likely. The effects for public transport accessibility (BBI) and distance to supermarkets are less promising, since the related parameters values are not significant using a 5% significance level.

The effect of life events on car transaction seem to be even more substantial than the built environment effects. Acquisitions are more likely in case there is a job transition in the same year, an increase in licenses in the previous, current or next year, and a residential relocation in the current or coming year. Just like free parking, a relocation affects all three transaction types: moving to another home goes more often together with a car transaction. Another remarkable finding is that an anticipated relocation increases the chance of car acquisition, while relocating also has a lagged effect on car disposal the year afterwards. Anticipated and delayed effects are also found for the positive effect of gaining a licence on car acquisitions. Losing a partner also increases the utility for car disposal, while a decrease in number of children makes replacement more likely. A possible explanation for this is that smaller households need smaller cars.

5. Conclusion and recommendations

Based on the results discussed before, we can assess the extent to which a transaction model for household car ownership in the Netherlands, including life events and additional built environment factors, can improve the representation of choice behaviour compared to a holding model.

The use of a transaction choice model, instead of a holding model, significantly improved its model fit (p<0.001), with a substantial log-likelihood increase. Subsequently adding the effects of life events and built environment factors significantly improved its explanatory power as well, using a 99.9% significance level. Thus, using a transaction model to account for the effect of these additional variables greatly improves the capacity to explain (changes in) car ownership.

5.1 Research contribution

Altogether, the findings of this paper confirmed much recent work, but also provided new insight into the nature of car ownership decisions, especially regarding the effects of life events and built environment factors.

Especially life events with a spatial component were found to affect car transactions: both residential relocations and job transitions are important factors to consider. Relocating increases the chance of all types of car transactions (acquisition, replacement and disposal), while an anticipated relocation results in more acquisitions. The latter was not found by other authors before. The conclusion of Clark, Chatterjee, et al. (2016) that car ownership increases that coincide with residential relocations are predominantly driven by other factors, can therefore be questioned. A delayed positive effect of relocation on car disposals was found as well. Altogether, these findings confirm previous research on the impact of residential relocation on car ownership and transactions (Beige & Axhausen, 2012, 2017; Oakil, Ettema, et al., 2014; Van de Kamp, 2019; Zhang et al., 2014) (Gu et al., 2020), including much research in the review of Chatterjee & Scheiner (2015).

Work related life events affect car transaction choices as well. Job transitions (i.e. new employer and/or different status) mainly result in more car acquisitions, but also in more replacements. The latter is true as well for an anticipated work change. This confirms the findings of Van de Kamp (2019) that anticipated work change around residential relocation increases car ownership. Also (Gu et al., 2020) and four papers in the review of Chatterjee & Scheiner (2015) found a positive effect of a change in employer on the number of cars. Although not explicitly examined here, part of these effects can be due to a changing distance to work (Beige & Axhausen, 2012; Van de Kamp, 2019).

However, Oakil, Ettema, et al. (2014b) found a positive effect of employment changes on car *disposals*, just like a delayed positive effect of retirement on that. Both findings cannot be confirmed in our research, although we found that retirement substantially increases the chance of car disposal in the *same* year (instead of a delayed effect), and next to that the chance of replacement as well. This does not align with the findings of Chatterjee & Scheiner (2015), who mention three papers that did not find any effect of retirement.

Changes in household composition were found to affect car transactions, but not as substantially as other authors found. As an example, no effect of childbirth was found, despite previous findings (Chatterjee & Scheiner, 2015; Klein & Smart, 2019; Oakil, Ettema, et al., 2014). However, also Müggenburg, Busch-Geertsema, & Lanzendorf (2015) mention some authors that did not find an effect of childbirth on car transactions. In contrast, the positive effect of a child leaving on car disposal could not be confirmed, although we saw an increased chance of replacing a car, with a higher chance for smaller cars.

The loss of a partner has a strong positive effect on car disposals, confirming previous findings (Chatterjee & Scheiner, 2015; Müggenburg et al., 2015; Oakil, Ettema, et al., 2014). However, effects of an increase in household size could not be confirmed.

The last important life event discussed here is obtaining a licence, with a major positive effect on car acquisitions. This was also found by Clark, Chatterjee, et al. (2016). In this research, though, we also found a positive effect for obtaining a licence in the years before and after car acquisition, which was not previously found.

All in all, this research provides a deeper insight into the effects of a variety of life events on car transaction behaviour, for example by identifying multiple lead-lag effects, but by highlighting life events with a spatial component as well. The effect of occupational transitions has been investigated less by mobility researchers according to Müggenburg et al. (2015), but here the importance of taking these into account is confirmed as well. The suggestion of Oakil, Arentze, Ettema, Hooimeijer, & Timmermans (2014) that very limited interdependencies exist among car ownership change, residential relocation and employment change, can therefore be rejected.

The main built environment factor with an effect on car transactions is the availability of free parking near the residential location: car acquisitions and replacements are more likely, while the chance of disposal is reduced when there is free parking. This is in line with the limited number of studies on the impact of residential parking, which found that is a significant factor affecting car ownership and use (Christiansen et al., 2017; Guo, 2013; Van De Coevering, 2008) (Albalate & Gragera, 2020) (Ostermeijer et al., 2019).

Other promising categories of built environment factors – like public transport availability, and the proximity of amenities – showed less clear effects on car ownership. The conclusion of Clark, Chatterjee, et al. (2016) that poorer access to public transport leads to lower car ownership levels can therefore not be confirmed.

On the other hand, decreasing population density was found to increase the chance of car acquisition and replacement, confirming part of the effect of the traditional 5Ds (Ewing & Cervero, 2010; Stevens, 2017). However, no effect for employment density and share of agricultural jobs was found, so the search for better mechanisms that explain changes in car ownership and use is still ongoing, in line with what Elldér (2018) and Naess (2015) argue for. It might be the case that these built environment factors only affect car use instead of car ownership, since that is the focus of the majority of research on the effect of built environment factors.

5.2 Recommendations

The empirical results discussed before can subsequently be used for dynamic modelling and simulation of household car ownership in the Netherlands, since transaction models can be incorporated in it (while a holding model cannot). In this way, not only the impact of life events and built environment factors on car ownership can be captured, but also other inherent advantages of dynamic modelling can be utilized. For future revisions of the Dutch car ownership models, using a dynamic model structure instead of a static one can therefore be of added value to inform policymakers. In order to get there, we will examine some recommendations to build upon this research and to address the limitations of it.

The first recommendation is related to the estimation dataset, that did not capture all relevant variables on a household level. For example, this related to occupation or licence possession, which limited the possibility of recognizing their effects on car ownership to a better extent. Still, we found multiple significant effect for parameters related to these variables. In case of future data collection, finding a way to measure these variables on the household level as well, could result in even more insight into car transaction choices.

Another recommendation is to extend the scope of the transaction model. Distinctions between vehicle types, for example, were not part of it. This could have given additional insight into car transaction decisions, since replacing a small four-person car by a large seven-person bus is a different choice than a replacement the other way around. Also considering the rise of electrically driven cars, being able to make these distinctions in a transaction model would have much added value. Next to that, using a different model structure might help to disentangle the effects on car transactions by using interaction variables with the initial number of cars. For example, the effect of household income on acquiring a first car is probably different than that on buying a second or third car.

5.3 Policy implications

Next to the potential of being used in a dynamic car ownership forecasting model, the empirical results of this research already have some implications for transportation and urban planning policies.

First of all, we found that the absence of free nearby parking reduces the probability of car acquisitions and makes car disposal more likely. Two potential policy measures are therefore implied: reducing the availability of free parking with permits and/or paid parking, and increasing the distance to parking spots, for example with centralised parking. This is something that for example the municipality Amsterdam (2020) is already doing: street parking is increasingly reduced, the use of (underground) parking garages is stimulated, and the number of parking places near new residential and business areas is decreased.

The latter aligns well to the opportunities opened up by residential relocations and occupational transitions. This research confirms that especially these life events can be seen as window of opportunity to change travel behaviour (Ministry of Infrastructure and Environment, 2016; Müggenburg et al., 2015). Municipal publicity campaigns targeted at those who change residential or job location can be launched to utilize the habit-breaking effects of these life event, thereby encouraging a deliberate evaluation of their daily and long-term travel choices. To change people's travel behaviour, it is crucial that alternatives are present and (made more) attractive.

Making car alternatives more attractive can for example by done with intensified commuting arrangements, by encouraging the use of public transport or bike (especially for new employees). In the Netherlands, this is currently visible in the stimulation of e-bikes, a travel allowance for kilometres by bike, and intensified pilots regarding Mobility as a Service (Ministry of Infrastructure and Water Management, 2018).

All in all, a window of opportunity is opened to break travel habits and reduce the negative externalities related to owning and using cars. By doing that, further steps towards a sustainable and accessible future can be taken.

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