ANALYZING THE TRANSITION TOWARDS ALTERNATIVE VEHICLES IN ADVANCED AND EMERGING ECONOMIES

By Edmundo Molina Pérez (4039432)

Policy Analysis Section

M.Sc. in Engineering and Policy Analysis

Thesis Committee:

Wil Thissen-Policy Analysis
Els van Daalen-Policy Analysis
Claudia Werker-Economics of Innovation
Gönenç Yücel-Policy Analysis

To my parents,

to my brothers,

to Hilda; my family:

inspiration and strength.
SUMMARY

This research analyzes the effect of market differences between advanced and emerging economies on the diffusion of alternative vehicle platforms (AVPs). A system dynamics simulation model was built and used to explore this transition case. This model considers two generic regions resembling advanced and emerging economies, and three generic vehicle platforms: incumbent platform (gasoline vehicles), hybrid platform (hybrid-gasoline vehicles) and radical platform (electrical vehicles). In addition, the model considers the interaction of several feedback mechanisms (Social Learning, R&D, Learning by Doing, Network Externalities and Scale Economies); as well as technical factors of the vehicle platforms, consumers’ preferences and car manufacturers’ behaviour. The analysis of several simulation experiments shows that market differences between advanced and emerging economies can influence diffusion patterns of AVPs in three main ways:

First, the difference between the income level of consumers of advanced and emerging economies creates a systematic delay in the diffusion of AVPs in emerging economies. As a result, hybrid-gasoline vehicles diffuse earlier in advanced economies than in emerging economies. The diffusion of hybrid-gasoline vehicles in the advanced economies enhances its diffusion in the emerging region due to a global reduction in their purchasing prices and due to their technical improvement.

Second, the difference in speed of growth of each region’s vehicle market has the potential of creating a strong market niche for electrical vehicles in the emerging region. In advanced economies, electrical vehicles find strong barriers. On the one hand, consumers driving gasoline or hybrid-gasoline vehicles are more reluctant to adopt the unknown developing electrical vehicles. On the other hand, the growth of the vehicle market is expected to hardly grow. Thus, in advanced economies most vehicle sales are replacement sales. In the emerging region, the opposite occurs, the vehicle market grows steadily and high number of vehicle sales are from consumers that for the first time purchase a vehicle. First time vehicle buyers do not favour any particular vehicle, thus there are greater chances that they adopt AVPs if these meet their economic and proficiency criteria. As a result, electrical vehicles find a strong market niche in emerging economies, which can compensate for the stagnation of the vehicle market in advanced economies. However, how this market niche is exploited depends significantly on consumers’ preferences and consumers’ familiarity with AVPs. In this regard, if consumers only consider the vehicle’s purchasing price in their adoption decisions, the transition towards AVPs becomes less likely, especially in emerging economies. On the contrary, if consumers consider in a more balanced way all the attributes of a vehicle (e.g. purchasing price, cost of fuel, fuel efficiency and driving range), the transition towards
electrical vehicles becomes more likely in both regions. In this case, emerging economies can inject a strong impulse to the global diffusion of electrical vehicles.

Third, differences in consumers’ preferences between both regions can significantly influence diffusion patterns. On the one hand, if consumers in advanced economies are interested in vehicles’ proficiency and consumers in emerging economies are only interested in vehicles’ purchasing price. Then, in advanced economies, hybrid-gasoline vehicles penetrate this market at high levels, but electrical vehicles stagnate. In emerging economies, the hybrid-gasoline vehicles penetrate at modest levels due to the impulse received by its diffusion in advanced economies, but electrical vehicles fail. In this case, conventional gasoline vehicles benefit from the growing vehicle market in emerging economies. On the other hand, if consumers in emerging economies are proficiency oriented and consumers in advanced economies have a purchasing price orientation. Then, advanced economies lag behind in the diffusion of AVPs. In emerging economies, the diffusion of AVPs is also delayed due to the lack of the initial impulse of advanced economies. However, in this case, electrical vehicles find a strong market niche in emerging economies and penetrate this market at high levels.

It also has been found that if R&D resources are early allocated to AVPs, both the car manufacturers and the consumers discover earlier the potential of the each vehicle platform. This reduces the initial systematic disadvantages of AVPs against gasoline vehicles, increasing the possibilities of their global diffusion.

It has also been found that if the development potential of the three vehicle platforms is comparable, then market differences have a strong influence in the diffusion of AVPs. However, the more unbalanced the development potential of the three vehicle platforms is, the less determinant market differences become.

This research shows that the process of diffusion of AVPs can be enriched and strengthened if it is seen as a complementary process between advanced and emerging economies. Policy areas of concern are the support to the R&D of AVPs, the development of fuelling infrastructure for electrical vehicles and the encouragement of consumers to consider in a more balanced way all vehicle’s attributes in their adoption decisions.
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1. INTRODUCTION

1.1 SUSTAINABLE TECHNOLOGY TRANSITIONS IN THE TRANSPORTATION SECTOR

Climate change is expected to considerably alter the existing relations between humans and the environment, by causing a rise in sea levels and changing rainfall and solar radiation patterns all over the globe. These changes can potentially force human migration out of coastal areas and hamper humans’ food production capacity (IPCC, 2007). Therefore, without doubt, climate change is one of the most pressing issues in our civilisation; our failure to attenuate its impacts in our society may lead us to a chaotic future.

While climate change is driven by natural mechanisms and has always been a constant phenomenon in the history of our planet, there is plenty of scientific evidence demonstrating that the planet’s climate system is undergoing an accelerated change due to human activity. Since the industrial revolution of the 19th century, societies have become more reliant on energy to sustain their demographic and economic growth. Historically, energy production has been mainly based on the utilization of fossil fuels, which has increased the rate of greenhouse gas (GHG) emissions to the atmosphere. This has accelerated the process of climate change (IPCC, 2007).

The prospects for the future are extremely challenging. On the one hand, world population is expected to drastically increase in the coming decades, mainly in the developing world. On the other hand, energy demand per capita in emerging economies is also rising due to their economic development (Figure 1). Thus, GHG emissions and energy demand are expected to continue rising over the coming decades. This growth in energy demand also makes energy resources scarcer, increasing concerns over security of supply. Therefore, the energy sector faces today remarkable challenges in energy sustainability and energy security (IEA, 2009).

This complex context is fostering several changes in the energy sector. Some of the strategies used to tackle these problems in the energy sector include: increasing energy efficiency, enhancing consumer’s environmental awareness and supporting the diffusion of sustainable energy technologies. The objective of these actions is to diversify the supply of energy and reduce global GHG emissions (OECD, 2010). Moreover, these of actions are needed across several sectors (e.g. industry, transportation, energy production), and they also need to be implemented worldwide in advanced and emerging economies.
It seems that the energy sector has entered into phase of a revolutionary transition, in which our energy technologies and our energy habits are expected to considerably change.

In this context of energy transitions, the transportation sector has attracted immense attention due to its contribution to GHG emissions and global energy demand. The transportation sector uses primarily fossil fuels as an energy source. It is estimated that worldwide, the transportation sector accounts for more than half of the oil used and nearly 25% of energy-related CO2 emissions (IEA, 2008). Therefore an effective energy transition also requires a transition of our current mobility system.

There are several ways in which this could be attained; for example: by replacing personal vehicles with more environmentally friendly vehicles, by increasing the use of public transport, by switching to other means of transport as walking and cycling, by car pooling, by using current telecommunication systems to reduce travel demand (e.g. home office, internet shopping) and by travelling shorter distances (OECD, 2008).
While all these actions are important and progress has been made in all of them. The development and commercial introduction of more environmentally friendly vehicles (e.g. hybrid vehicles, plug-in hybrids, electrical vehicles and fuel cell vehicles) has become a central topic in energy transitions. If the energy demand of future vehicles is supplied by renewable energy, then a strong structural change towards energy sustainability will have been taken. However, the task of successfully introducing alternative vehicle platforms (AVPs) in the transportation sector has proven to be quite complex, involving the interaction of several actors; such as: car manufacturers, drivers, policy makers and technology developers (Struben & Sterman, 2006).

Over the last decades, investments have been made in the research and development (R&D) of AVPs and several policies have been implemented to support the development and diffusion of these technologies in the transportation sector. Yet, these technologies are still in the early process of diffusion and still important technological improvements are required to enhance their position in the industry. This is a clear proof for policy makers that strong changes are still needed, and that decisive support to the transition of the transportation sector is deem necessary (UNEP; EPO; ICTSD, 2010).

As discussed by Arthur (1988), in new markets, initially several technological regimes compete against each other to become the established technological paradigm. Once this paradigm has been defined, institutions, firms’ routines and complementary infrastructures are designed to comply with the dominant technological paradigm; thus, deterring the entrance of other technological alternatives. In this regard, the transportation sector is in a very mature market phase, in which, long ago, dominant technological paradigms were defined by firms and consumers, and in which multi-national companies dominate the market (From now on, in this thesis, transportation sector refers to the share of the transportation sector that deals exclusively with private mobility. This only includes the use of individual vehicle platforms to satisfy travel demand. Therefore, public transportation, car pooling, walking and cycling are excluded of this term). Therefore, the transportation sector can be considered to be locked-in with the internal combustion engine and efforts to introduce alternative technologies that are not far superior in terms of cost and efficiency will be naturally opposed by incumbent firms and current consumer preferences.

Several studies have been conducted to find ways in which it might be possible to induce technological change towards AVPs in the transportation sector. It is commonly agreed that it in order to do this, at least three actions need to be taken: 1) support the R&D of AVPs, 2) enhance the development of market niches for AVPs and 3) create institutional incentives for the adoption of AVPs among automobile firms
and consumers. The aim of this actions to create an environment in which these technologies can be nurtured through more intensive learning and innovative activity, without being negatively affected by competing with the incumbent vehicle platform (Jacobsson J. A., 2000). Struben et al. (2006) has exhaustively analyzed the transition towards AVPs, he concludes that for this transition to take place, it is necessary to implement policies aimed at: a) influencing consumers’ preferences, b) developing complementary infrastructure to support the diffusion of AVPs, c) fostering innovation activity and d) enhancing energy efficiency (Struben & Sterman, 2006). It appears that this kind of transition will require of strong structural changes that will impact not only on the evolution of the technology itself, but also the evolution of the transportation sector.

The environment of this transition case has become rather uncertain due two major factors 1) the wide variety of technology alternatives under development and 2) the development potential of each one of those alternatives. First, among the AVPs being proposed for this transition, there are: hybrid-gasoline vehicles, plug-in hybrids, electrical vehicles and fuel cell vehicles. In each one of these categories several designs are being proposed; for example: solar-electric vehicles, light and efficient internal combustion engine vehicles, individual units of transportation (e.g. Segway), etc. If all these technologies become commercial; then, the available options for personal transportation will increase substantially. Second, each one of these technological alternatives can yield different advantages in terms of fuel efficiency, GHG emissions and reduction of travel demand. However, it is quite uncertain how long the development of each vehicle platform will take and how feasible their development is. These factors complicate the task of estimating the potential contribution of each alternative to the reduction of GHG emissions and the enhancement of energy security. For example, the International Energy Agency (IEA) (2008) has developed several scenarios about the potential contribution towards GHG emissions abatement of the diffusion of different AVPs (Figure 2). These scenarios show that the range of possible futures in quite ample, ranging from cases in which GHG emissions are doubled to cases in which they are reduced. Taking on account, the uncertainty trumpet of Rosenhead (1989), this transition case can be framed as a clear example of deep uncertainty about the future. In fact, the IEA (2008) considers that AVPs in the transportation sector will probably not penetrate the market before 2030, due to the need of technical improvements, non competitive costs of technologies and the infrastructure requirements for their deployment. If significant changes do not occur, world transport energy use and emissions are expected to increase by more than 50% by 2030 (IEA, 2008).
In sustainable energy transitions there are two main strategies that can be followed to induce technological change in mature industries, these are: niche accumulation and hybridisation. The first approach, niche accumulation, refers to a process in which radical innovations are developed in specific markets niches that are protected against competition with the incumbent technology. The characteristics of these markets niches allow for experimentation and learning. These advantages are used to develop commercially the radical innovation. The second approach, hybridisation, refers to a process in which the design of the radical innovation starts close to the incumbent technology. This gives the hybrid design the possibility of gaining a market niche more rapidly than in the case of the radical platform. This hampers the dominant position of the incumbent technology and provides important learning for further development of the hybrid design. The new knowledge and experience acquired through the hybrid design allow for a second step in the transition, this is from the hybrid design towards a radical innovation (Raven, 2007). There is a wide consensus in the transportation sector that a hybridisation strategy is the most effective way of inducing a technological transition towards more environmentally friendly vehicles. It is argued that the introduction of a hybrid vehicle platform can accelerate the transition towards electrical vehicles or fuel cell vehicles, because the introduction of hybrid vehicles will create economic and knowledge spillovers that can be used by the radical platforms. In addition, it is also argued that the introduction of hybrid vehicles will also induce the development of the fuelling infrastructure needed for the radical platforms, as in the case of the plug-in hybrid vehicles (Hill, Hazeldine, Pridmore, Einem, & Wynn, 2009).

The logic behind a hybridisation strategy for the transportation sector is quite convincing. However, the automobile industry has changed significantly due to globalisation. Today, the automobile industry could be better picture as an industry in which a global supply chain serves several different markets (Sturgeon, 2008).
& Van Biesebroeck, 2010). Therefore, it would be important to know how important market differences of advanced and emerging economies are in determining the success of hybridisation strategies.

1.2 TRANSITION TOWARDS AVPS IN ADVANCED AND EMERGING ECONOMIES

In order to achieve a significant reduction in the demand of fossil fuels and in the emission of GHG, it is essential that both advanced and emerging economies transit to a more sustainable transportation system. However, the successful implementation of hybridisation strategies may be affected by the market differences of these two regions. First, innovation and infrastructure systems (e.g. institutional linkages of firms, government and knowledge institutions, technology creation, entrepreneurship activity, roads, public transport infrastructures, etc) of advanced economies are more developed than those of emerging economies. Second, there are also important differences in the way the economies of these two regions work, which can have an important influence in the way their vehicle markets evolve. For example, due to current levels of GDP per capita in advanced economies, the size of the vehicle market in this region is considerably higher than that of the emerging region (Figure 3). However, the GDP growth of emerging economies is higher than that of advanced economies (Figure 3). Also, as discussed before, the demographic growth of emerging economies is also higher than that of advanced economies (Figure 1). These two factors in the emerging economies are accelerating the growth of their vehicle markets. Thus, global car manufacturers also need to serve markets that grow at a notable different speed. Third, the preferences of consumers in both markets might be also different. For example, in advanced economies, due to a stricter implementation of environmental policies and better environmental education, consumers may be more inclined to purchase more environmentally friendly vehicles. While in emerging economies, due to a more precarious economic and institutional environment, consumers may be less inclined to purchase alternative vehicle platforms.

Some studies suggest that the development of hybrid and electrical vehicles is quite likely for 2020, but only the most technologically advanced countries (US, Germany and Japan) will be able to implement these technologies successfully (Silberglitt, Antón, Howell, & Wong, 2005). This has serious implications for the sustainability objectives of the energy sector, because if significant emerging economies like China, India and Brazil are not capable of implementing these technologies successfully, the targets on global CO2 emissions reduction and energy diversification will not be met. Therefore, it is quite relevant to understand how the diffusion of AVPs can be enhanced or threatened by the market heterogeneity of advanced and emerging economies.
Introduction

The role of car manufacturers is also a key element in this transition case. On the one hand, most of the manufacturing operations of car manufacturers are dispersed globally, with a growing tendency to shift manufacturing capacity towards emerging economies (Table 1). This has encouraged firms in these emerging economies to be highly specialized in logistical systems around the internal combustion engine (Sturgeon & Van Biesebroeck, 2010). Therefore, there might be capacity constraints in emerging economies to successfully implement hybridisation strategies. On the other hand, the behaviour of the car manufacturer in terms of allocating resources for R&D of the alternative platforms is also a key factor in this transition context. First, most of the R&D of car manufacturers is done in advanced economies, and the majority of R&D public budget allocated to AVPs is spent by governments of advanced economies (US, Germany, Japan) (OECD, 2008). Therefore, there is little participation of emerging economies in the process of developing the AVPs, which could also become a capacity constraint for technology transfer from advanced economies to emerging economies.
However, the investment choices of the global car manufacturers are far more significant in this transition context. In this regard, car manufacturers need to choose which type of alternative vehicle platform to support with resources for R&D. Moreover, they also need to continue investing in the internal combustion engine to remain competitive in the market. The R&D strategies of car manufacturers are key elements in this transition context because R&D resources are essential for making AVPs commercial technologies that can compete with the internal combustion engine.

In this regard, according to Frenkena et al. (2004), the patenting activity in AVPs increased constantly in the period from 1980 to 2002. Considering patenting rates as a proxy of R&D investments, this could be interpreted as a sign that there has been a constant interest of car manufacturers in developing alternative vehicle platforms. The level of interest of car manufacturers across the different alternative vehicle platforms (hybrid vehicle, electrical vehicle and fuel cell vehicle) has been the same. Frenkena et al. (2004) argues that given the existence of knowledge spillovers across all AVPs and the premature stage of knowledge and technological development in AVPs, it is preferable a parallel development of all AVPs than a strong convergence towards a single technology, which, given all the unknowns, could turn out to be suboptimal. Therefore, it seems that following a balanced investing strategy on R&D could yield the highest benefits for all AVPs. In fact, among the main car manufacturers there has been a proportional effort in patenting activity of AVPs. These firms include: Honda, Toyota, General Motors, Mitsubishi, Daimler Chrysler, Nissan, Ford, Ballard, APC, IFC and Nippon. Interestingly, the study of Frenkena et al. (2004) shows that even though some car manufacturers began developing AVPs earlier than the rest, by 2002, almost all car manufacturers showed a similar level of interest in AVPs. This shows that in the automobile industry, innovative activity across all AVPs has tended to increase, and that all firms involved in R&D of AVPs are working evenly across all of them. However, when the level of
The interest of car manufacturers (patenting activity) on AVPs is compared against their level of interest on improving the internal combustion engine, it is possible to see that still the internal combustion engine remains as central part of their R&D strategies (Figure 4).

![Cumulative world total patents counts EPO for FC, EHV and ICE pollution control technologies. Source: (OECD, 2008).](image)

In addition to the structural differences between advanced and emerging economies, and the role of the car manufacturers, the technological characteristics of each alternative vehicle platform are also important. For example, relevant technical aspects of AVPs could include: the level of maturity of each platform, their technical potential in terms of fuel efficiency, environmental impact, driving range and cost. These attributes are important because these technological characteristics may influence their process of diffusion, calling for specific policies to support their development. For example, according to Johnstone et al. (2010), policy measures that are priced-based (e.g. subsidies, fuel taxation) are more efficient in enhancing the diffusion of sustainable energy technologies that are almost cost competitive (mature), while investments on R&D are more effective for less mature technologies. Moreover, will all AVPs coexist in the future?, or is it possible that one technology platform will become the dominant one in the sector? Following the Schumpeterian view of technological change, the automobile industry would need to go through a process of “creative destruction” through which the industry will define which AVPs to keep, based on the successful adaptation of existing firms and the creation of new ones, but there is no clear indication of which direction of change will be followed (Himmelweit, Simonetti, & Trigg, 2001).

It can be expected that, if advanced economies succeed in the diffusion of AVPs though a hybridisation strategy, then the generation of new technical knowledge, learning by doing and economies of scale in
this region will induce the diffusion of AVPs in less developed countries, due to the technical improvement and international commercialization of AVPs (Vernon, 1996). This type of diffusion pattern can be considered as an *expected diffusion pattern of AVPs* (Figure 5-a). However, the preceding discussing shows that there are enough contextual factors and market differences between advanced and emerging economies in this transition context to consider feasible that: 1) hybridisation strategies can fail given the uncertainties in this transition context and 2) advanced and emerging economies can follow different patterns of diffusion of AVPs, showing *an alternative diffusion pattern of AVPs* (Figure 5-b).

![Figure 5](image)

*Figure 5. Examples of expected and alternative diffusion patterns of AVPs.*

The transition of the transportation sector is also remarkably rich in terms of the mechanisms of interaction of consumers, manufacturers and fuel suppliers. Struben *et al.* (2006) shows that relevant mechanisms involved in this technological transition are the effect of learning-by doing of firms and consumers, the effect of economies of scale for technological improvement, technology spillovers across the incumbent and the new technologies, the interaction of consumers through word-of-mouth and social exposure, and the existence of infrastructure network externalities. The dynamic interaction of these mechanisms across different market niches represents the real complexity of this problem, which
is impossible to handle without a systematic method of study. Without doubt, improving our understanding of the dynamics of technological change in the automobile industry is a key asset for the correct implementation of climate change policy in the transportation sector.

The arguments presented in this chapter characterize this transition context by describing its relevant elements. These are: a) consumers, b) suppliers, c) alternative vehicle platforms, d) interaction mechanisms and e) market heterogeneity of advanced and emerging economies. This can be better picture using a system’s diagram. As shown in Figure 6, it is possible to see that each region influences independently the composition of its own vehicle market through processes of social learning and the formation of the fuel infrastructure. In addition, sales of vehicles in both markets determined possible technological trajectories for each vehicle platform through R&D of each platform, through the accumulation of experience and through scale economies in the production of each platform.

However, it is essential to frame these system elements to the relevant aspects of interest in this research. The following section deals explicitly with this issue by presenting the structure and design of the research.

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**Figure 6. System’s diagram of transition towards AVPs in Advanced and Emerging Economies**

- Social perception of AVPs in AEs
- Fuel Infrastructure Formation in AEs
- Structure of Vehicle Market in AEs
- Preferences of consumers in Advanced Economies
- Economic and demographic differences between advanced and emerging economies
- Technological evolution of vehicle platforms
- Learning by doing
- R&D
- Scale economies
- Network externalities
- Social learning
- Behaviour of car manufacturer
- Technology potentials
- Emerging economies (EEs)
- Social perception of AVPs in EEs
- Fuel Infrastructure Formation in EEs
- Structure of Vehicle Market in EEs
- Preferences of consumers in Emerging Economies
- Economic and demographic differences between advanced and emerging economies
- Technological evolution of vehicle platforms
- Learning by doing
- R&D
- Scale economies
- Network externalities
- Social learning
- Diffusion Patterns in AEs
- Diffusion Patterns in EEs

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**Figure 6. System’s diagram of transition towards AVPs in Advanced and Emerging Economies**

- Market differences
- Contextual variables
- Outcomes of interests
- System’s boundary
1.3 RESEARCH STRUCTURE

1.3.1 KEY ASSUMPTIONS

In reality, the system elements shown in Figure 6 (consumers, car manufactures, fuel suppliers, alternative vehicle platforms and interaction mechanisms) are multifaceted. For example, the vehicle preferences of consumers could be thought to be a function of their gender, age, socio-economic status and nationality. Also, when considering market heterogeneity of advanced and emerging economies, it would be possible to consider several sources of market heterogeneity; ranging from the socio-economic differences of these countries to their institutional and geographical differences. This research focuses on understanding the role of global market heterogeneity in this transition case. As a result, considering all the possible facets of the system elements will only make the study as complicated as reality itself. This would difficult enormously the task of gaining relevant knowledge that can be used to understand the role of market heterogeneity in this transition context. In order to avoid this, this research frames this transition context by making specific assumptions about the aggregation level and complexity of the system elements described in Figure 6. These are key assumptions that need to be considered thoroughly during the rest of this research. Next, these assumptions are described:

A. Key assumptions about market heterogeneity

Market heterogeneity refers to the differences between the vehicle markets of advanced and emerging economies. There are many differences between these vehicle markets (e.g. socio-economic, geographical, institutional and cultural). However, in this research attention is only paid to two specific market differences. Therefore, all other possible market differences are not considered in this research.

The first market difference of concern refers to the economic and demographic differences of advanced and emerging economies. In this regard, it has been widely reported that there is a significant difference in the economic and demographic growth between advanced and emerging economies. As a result, the vehicle market of emerging economies grows at a faster pace than the vehicle market of advanced economies. This type of market difference is defined in this research as the observed market difference.

The second market difference of concern refers to the possible differences between the vehicle preferences of consumers in advanced and emerging economies. In this regard, the cultural and institutional environment of each region may create differences in the way their consumers weigh the importance of the different attributes of a vehicle platform (Hård & Knie, 2001). For example, in one region consumers may be more environmentally conscious than in the other, or it might be possible that
consumers in both regions have the same preferences. It is highly unknown how the preferences of consumers are and it is possible to think of several plausible differences. This aspect of the analysis will be discussed in more detail in subsequent chapters. However, for now, this sort of market difference is defined in this research as the difference in consumers' preferences.

B. Key assumptions about the consumers

In this research the term consumers refers to inhabitants of advanced and emerging economies that use vehicles to fulfil their personal mobility needs. These actors may be consumers who already drive one of the vehicle platforms and who are faced with vehicle replacement decisions (e.g. switching towards an AVP, keep on using an internal combustion engine vehicle). These actors may also be consumers who have never driven a vehicle platform, and therefore are faced with a vehicle purchase decision for the first time in their lives. Attention is only paid to the level of income and vehicle preferences of consumers. Other factors describing consumers, such as gender and the age are not considered in this research.

C. Key assumptions about the car manufacturers

In reality there are many diverse car manufacturers serving vehicle markets in advanced and emerging economies. Moreover, for the development of AVPs it is also likely that new car manufacturers or technology developers will appear in the market to compete with incumbent firms. These actors are quite diverse in terms of their business strategies and available resources for the development of AVPs. This detail and diversity in car manufacturers and entrepreneurs’ behaviour has been let out of this research. Instead, the role of these actors is considered in a highly aggregated way, by considering only the general tendencies of the car industry. It is not of interest in this research which firms succeed or fail in developing AVPs. On the contrary, it is of interest the tendency of the industry towards the R&D of AVPs. Therefore, it is assumed that all car manufacturers can be considered as a single actor who represents the average tendencies in R&D of AVPs of the industry.

D. Key assumptions about the fuel suppliers

The characteristics of fuel suppliers in advanced and emerging economies can also be different. In some countries, the oil industry is liberalized and thus many competitors exist in the fuel market. While in others, the oil industry is state owned and therefore there is only one fuel supplier. There might also be differences in the regulation of fuelling stations. In some countries the income of fuelling stations is defined by regulators, while in other, it can be different across all competitors depending on their
success in the fuel market. In this research, it is assumed that the fuel market in advanced and emerging economies works in the same way. It is considered that fuel suppliers react only on the demand on fuel and the profitability of the fuel market, and that there are no regulators that control the supply of fuel or the profitability of fuel stations. In addition, it is also assumed that the price of electricity and fossil fuels is the same in both regions.

E. Key assumptions about the alternative vehicle platforms

In this research it is assumed that there are only three generic vehicle platforms available in the market. There is an incumbent vehicle platform. This platform is considered to be a mature vehicle technology which uses an internal combustion engine. This vehicle platform can use any type of fossil fuels as a source of power (e.g. gasoline, diesel). There is also a hybrid platform. This platform is considered to be an immature technology that uses primarily an internal combustion engine as a source of power, and an internal electrical mechanism for supplementary power. This platform uses only one type of fuel, which is the same fuel as the incumbent vehicle platform. There is also a radical vehicle platform. This platform is considered to be an immature technology that uses an electrical battery to storage electricity. This electricity is used as a source of power for the vehicle. Initially, this radical platform can also used an internal combustion engine as a complementary source of power. So initially the radical platform is considered to be a hybrid platform as well. In this research no other attributes are used to describe these vehicle platforms and no other type of vehicle platforms are considered in the analysis (For a more detail technical description of these vehicle platforms see section 2.6).

F. Key assumptions about the interaction of consumers, car manufacturers and regions

This research focuses on a number of specific interactions in this transition context. These are: R&D of AVPs by the car manufacturers, word of mouth of consumers, marketing campaigns about the different vehicle platforms, car manufacturers’ learning by doing, scale economies and fuel infrastructure externalities. The role and influence of these interactions in vehicle transitions has been described and studied in detail by Struben et al. (2006) and by Struben (2008) in several different regions (e.g. United Sates, California, Brazil and Argentina). There might also be other relevant interactions in transition context or other processes of social learning about the AVPs. For example, it might be possible that the preferences of consumers can be influenced by external sources of information such as opinion groups, or by their individual learning about AVPs (Yücel, 2010). However, these other interactions are not considered in this research. The research focuses only in the interactions described in the work of Struben.
1.3.2 RESEARCH QUESTIONS

The assumptions described in the previous section frame this transition context to the specific dimensions of interest in this research. Then, it is now opportune to specify the inquiries of interest in this analysis. In this regard, the objective of this research is to understand in which ways market differences between advanced and emerging economies can influence the transition towards AVPs, and to analyze the policy relevance of this phenomenon.

Therefore, the research questions of this study are the following:

1. How can market differences of advanced and emerging economies influence global diffusion patterns of alternative vehicle platforms (Hybrid Vehicle Platform and Radical Platform)?
2. What is the policy relevance of these market differences in the transition towards alternative vehicle platforms?

1.3.3 RESEARCH METHOD

The research questions of this project are primary relevant for the first stage of policy making. In this phase it is necessary to explore policy problems exhaustively to formalize and understand the main elements involved in the analysis. According to Van Daalen et al. (2002) a computer simulation model is a suitable tool of analysis during this stage of policy analysis because it can be used as an eye-opener to bring new issues into policy discussion. Simulation models can also be used in later phases of the policy cycle. It is important to consider the phase of the policy cycle in which simulation models are intended to be used because the nature, usefulness and level of aggregation of simulation models varies in function of the needs of each phase of policy analysis. For example, if a simulation model is required for deciding upon the number of lanes needed for a highway. Then, most likely, a detail geographic information system is needed for this design.

In the transition context of AVPs, computer simulation models could be used as eye-openers to understand this socio-technical system, and to perform several experiments without compromising huge amounts of economic and human resources (Yücel, 2010). This can undoubtedly benefit the process of policy making by pointing at new areas in which it is necessary to focus. This study attempts to use computer simulation to analyze the relevance of market differences in this transition case.

The chosen modelling paradigm is System Dynamics. According to Enserink et al. (2010), while selecting a system’s modelling paradigm is important to consider if the model delineation, the time horizon, the
aggregation level and the nature of the desired insights are adequate features of a modelling paradigm to answer the research questions. Following these considerations, the author considers that System Dynamics is a suitable modelling paradigm for this research because: 1) the aim of this research is on analyzing possible diffusion patterns of AVPs in light of generic differences of advanced and emerging economies (high level of aggregation), 2) during a long time horizon (at least 30 years) and 3) to be able to explain possible dynamic behaviour based on the causal structure of the system. However, because Systems Dynamics uses the concept of feedback process as a building block for understanding the dynamic behaviour of a system, and because in this case there are several feedbacks mechanisms interacting (see section 2.7 for several examples), then System Dynamics is also an appropriate method of analysis for this research. Moreover, the interaction of these mechanisms creates complex dynamics that cannot be fully understood using only common sense and logic. This is to say that without the assistance of a computer simulation model, it would be very difficult to fully understand the forces of change in this particular problem (Enserink, Hermans, Kwankkel, Thissen, Koppenjan, & Bots, 2010).

Pruyt (2006) emphasizes the diversity of the scientific nature of System Dynamics. He points at the fact that it is possible to find applications of System Dynamics following different philosophical paradigm frameworks (e.g. Post-Positivism, Critical-pluralism, Constructivism, etc). In light of this consideration, it is important to clarify that the main objectives of using a System Dynamics in this research, are the following:

- To interpret quantitative modelling results in a qualitative way, keeping a close eye on the nature of the socio-technical system under study, the boundaries of analysis and the level of aggregation of the model;
- To learn, gain insight and understand the causal structure of the behaviour of the socio-technical system under study;
- Therefore, the purpose of this research is not to provide a quantitative description of reality, which can be used for prediction, or for the formulation of natural or social laws.

In addition to specifying a modelling paradigm, it is also important to mention which previous work on the field is used as the basis for the analysis. In this regard, there are two basic research works that are used for conceptualizing the socio-technical system under study. First, the work of Struben et al. (2006) and Struben (2008) is without doubt an important landmark in the field. This research work already studies and describes in detail some of the causal structures of the automobile industry by which consumers and automobile manufacturers interact. Among these relevant structures are: the network
effects of fuelling infrastructure, the decision processes for allocating resources to product and process development of firms, the process of learning by doing of users and firms in the industry, the effect of spillovers between different technology platforms and the co-evolution of automobile technologies with other infrastructures (e.g. roads, fuelling infrastructure). While, not all of these mechanisms are explicitly considered in the conceptualization of this research, it is wise to critically reflect upon the work of Struben to contrast and to enrich the analysis of diffusion patterns of AVPs. Second, the Actor-Option framework of Yücel (2010) provides a good theoretical foundation that can be used for developing a computer model in a systematic and comprehensive way, but more importantly, it provides an adequate theoretical framework by which it is possible to explain the phenomena observed in socio-technical transitions. In contrast to the work of Struben, which level of detail for the case of diffusion patterns of AVPs is quite high, and therefore it can be better seen as a specific case study of technological change, Yücel’s framework condensates many ideas in the field of technological transitions and provides a clear set of building blocks (attributes of technological options, characteristics of users and mechanisms of interaction), by which it is possible to explain diffusion patterns in socio-technical systems. To sum up, in this research, the Actor-Option framework is used as the theoretical foundation of analysis, the work of Struben et al. (2006) and Struben (2008) is used as a point of departure to define the causal structure of the system, and additional research is executed to define the causal relations of advanced and emerging economies relevant for the diffusion of AVPs.

Finally, because of the subject of the model is to understand how market differences of advanced and emerging economies influence diffusion patterns of AVPs, it is not necessary to develop a model that resembles a specific real context. Rather, as the model is intended to be used as an eye-opener, then it is more appropriate to develop the model following a generic structure. In this regard, three generic technological options are considered: an incumbent vehicle platform (proxy: internal combustion engine), a hybrid vehicle platform (proxy: hybrid-gasoline vehicle) and a radical vehicle platform (proxy: electrical vehicle); and two generic regions are studied: an advanced region (proxy: advanced economies) and an emerging region (proxy: emerging economies). These terms are used from now on in the remaining of this work.
2. SYSTEM CONCEPTUALIZATION

In this chapter all the aspects previously discussed regarding the diffusion of AVPs in advanced and emerging regions are formalized using mathematical descriptions. These mathematical descriptions are used to create a conceptual model of the interactions and characteristics of the consumers, suppliers and different vehicle platforms involved in this transition context. In this sense, a conceptual model of a system dynamics model is an abstraction of reality in which it is possible to picture feedback structures existing in the system which can offer an endogenous explanation of its behaviour.

The modelling framework used in this study corresponds to the Actor-Option framework of Yücel (2010). This framework provides a set of building blocks that are used to develop models for analyzing transition cases. In general terms, this framework provides a set of concepts and interactions mechanisms that can be used to frame a transition case. Actors in this framework represent the social element of socio-technical systems. The behaviour of actors is characterized by their preferences, perceptions, commitments and their roles in the socio-technical system (e.g. regulators, suppliers, consumers). Options in this framework refer to the technologies or artefacts. Options are characterized by their physical and contextual properties. Finally, this framework describes a set of mechanisms through which actors interact and through which their behaviour influences the properties of options. Each one of the following sections uses this framework to formalize the analysis.

2.1 SOCIETAL FUNCTION OF CONCERN

The societal function that characterizes the transition case under study is private car passenger mobility. This encompasses all activities, for which current private passenger vehicles are used today, mainly urban/rural and inter-urban/rural travelling. While the analysis is not focussed on a particular set of countries, there are two generic areas of concern for this research: an advanced region and an emerging region. Several experiments will be conducted in order to analyze plausible transitions paths in these regions. The time scope of analysis will be the first half of the 21st century.

These regions differentiate themselves based on two aspects: 1) the growth of rate of their potential vehicle market, which is driven by the demographic and economic growth of each region, and 2) the

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1 A feedback structure consists of two or more causal influences between elements in such a way that a change in variable A causes a change in variable B. There can be positive/reinforcing feedback loops in which an initial increase in variable A leads after sometime to an increase in variable A or negative/balancing feedback loops in which an initial increase/decrease in variable A leads after sometime to a decrease/increase of variable B” (Pruyt & Van Daalen, 2009).
preference structure of vehicle users in both regions. These differences are explained in more detail in
the following sections, and exemplified in chapter 3.

2.2 ASPECTS OF THE SOCIETAL FUNCTION THAT CHARACTERIZE THE TRANSITION

Chapter 1 describes comprehensively the relevance of the transition towards AVPs. It has been shown
that global transportation energy demand represents a considerable share of global energy demand and
global GHG emissions. Moreover, in future decades this demand is expected to grow, in great part, due
to the economic and demographic growth of emerging economies. Therefore, environmental and energy
security aspects are relevant for this transitional change. The transition towards AVPs is commonly
perceived as an essential step towards de-carbonizing our global mobility system (IEA, 2009).

2.3 ALTERNATIVE MEANS OF FULFILLING THE SOCIETAL FUNCTION

In this transition study the alternative means of fulfilling private car mobility encompasses the
alternative vehicle technologies that can be used for satisfying people’s demand for private mobility. In
our current mobility system there are other options and/ or practices by which mobility needs can be
satisfied; for example, air and rail public transportation, or car pooling, but these alternative means are
public and not private, or focus on the way people travel and not in the technology used for private
mobility. Therefore they fall outside of the scope of this research. In addition, in our current mobility
system there is a wide portfolio of fuels used to power our private vehicles (e.g. gasoline, diesel, natural
gas, bio-fuels). However, these fuel options are all supported by the same technological platform, which
is the internal combustion engine. There are also several alternative vehicle platforms proposed to
substitute the internal combustion engine that use electricity as a source of power. For example, fuel cell
vehicles and electrical vehicles (OECD, 2008). In this research, the focus will be on two alternative vehicle
platforms: a hybrid platform that uses the same fuel as the incumbent vehicle platform, but which fuel
efficiency is much higher due to the use of a complementary electric powering system, and a radical
platform that uses electricity and an electrical battery as its source of power.

2.4 MAJOR ACTORS IN THE SYSTEM

Automobiles serve as intermediaries between fuel providers and vehicle drivers. As a result, car
manufacturers, fuel suppliers and vehicle drivers are co-dependent on each other to sustain the
functioning of our current private mobility system (Struben & Sterman, 2006). While other actors such as
policy makers and opinion groups are involved in this socio-technical system, in this research the analysis
has been constrained to three main and relevant actors, these are: the car manufacturers, the fuel suppliers and the consumers (vehicle drives and potential vehicle drivers). They can be grouped in two generic groups which are the consumers and the suppliers (car manufacturer and fuel suppliers). Next a discussion of their functions and their roles in this transition case is presented.

2.4.1 CONSUMERS

Consumers are the users and demanders of the technical options (incumbent vehicle platform, hybrid platform and radical platform). These actors influence the system in two main ways. First, they decide which type of vehicle platform to purchase. This has several impacts in the system. To mention a few; for example, their purchase decisions can increase or decrease the fleet of vehicles of each vehicle platform, this influences the social exposure of each platform, and also it influences the size of the fuel market for each vehicle platform. Second, through the accumulation of individual wealth, consumers increase the average kilometres they drive in their vehicles. This increases the size of the fuel market for each platform, which incentivises fuel suppliers to install new fuelling stations.

Consumers in this research are treated in a highly aggregated way. The main characteristics of consumers in this research are: their preferences, their economic wealth and their driving habits. Moreover, two different groups of consumers are included in this analysis. One group represents consumers of the emerging region, and another group represents consumers of the advanced region. These groups differ in their specified characteristics. For example, consumers of the advanced region have a higher GDP per capita, and drive more kilometres per year than consumers in the emerging region. It is important to notice that these attributes are not fixed and that they change through time. For example, the driven kilometres by consumers change as their individual wealth increases (GDP per capita).

2.4.2 SUPPLIERS

Two groups of suppliers are considered in this system: a car manufacturer serving both regions (advanced and emerging) and the fuel suppliers of both regions. The car manufacturer has a vital role in the system. On the one hand, through sales of the different vehicle platforms in both regions, the car manufacturer accumulates resources, which it allocates to the technological development of the three vehicle platforms. This increases the performance of the different platforms by increasing their fuel efficiency, making them more environmentally friendly and more commercially viable. This induced change in the properties of the vehicle platform can increase or decrease consumers’ attractiveness
towards these options, which ultimately influences their sales. Similarly to the case of users, the car manufacturer has specific preferences for deciding how to allocated R&D resources to the different vehicle platforms.

The fuel suppliers are in charge of installing and decommissioning fuelling stations for each vehicle platform. They do this by reacting on the profitability of the fuel market. For example, once they realized the profitability of the fuelling industry of one platform in one of the regions diminishes, they are inclined to exit the market. This dynamics affects the driving range of the vehicle platforms because the more number of stations in one region for one vehicle platform, the higher its driving range, which ultimately makes the vehicle platform more attractive for consumers, increasing its sales. Therefore, the provision of the fuelling infrastructure is also an important element in the process of adoption of a vehicle platform (Struben & Sterman, 2006).

2.5 DECISION MAKING PROCESS OF ACTORS

Formalizing the decision making process of consumers, car manufacturers and fuel suppliers is the core element of the model built for this research. This section describes this process for each one of the actors included in the analysis.

Consumers are faced with the decision of acquiring one of the three platforms offered to them (incumbent vehicle platform, hybrid vehicle platform, and radical vehicle platform). They decide upon this when they purchase a vehicle platform for the first time, or when they replace their current vehicle platform once its operational life has elapsed. In deciding upon which vehicle platform to purchase, consumers are assumed to make a multi-criteria decision, which is based on three aspects: the purchasing price of the vehicle platform, its operational costs and its driving range. The operational cost of a vehicle platform is defined as the price of the fuel used for powering the vehicle ($/litre of fuel), divided by the fuel efficiency of the vehicle (km driven/litre of fuel, or km driven/kWh of electricity). Thus, it represents the cost per driven kilometre of each vehicle platform ($/km driven). The driving range of each vehicle platform depends on the average expected driven kilometres of consumers and the coverage of the fuel market with fuelling stations for each vehicle platform. Consumers are assumed to increase their expected driven kilometres when their GDP per capita increases. However, for each vehicle platform, the effective driven kilometres that consumers can realized depends on the existing number of fuelling stations. For example, lack of fuelling stations for the radical vehicle platform reduces

---

2 Empirical studies suggest that consumers consider at least three attributes of a vehicle platform for their purchasing decisions, these are: purchasing price, operational cost, driving range. See Dagsvik et al. (2002) for a detail study on this topic.
its driving range. It is assumed that consumers use a component value function to evaluate each vehicle platform. Using a similar formulation as Yücel (2010), Equation 1 shows the structure used to represent this decision process. Here, it is possible to see that the value that consumers give to each platform depends on the importance that they give to the different attributes ($\lambda_i$) of the vehicle platform (such as: $\sum_i \lambda_i (t) = 1$). This is defined as the consumers’ preference structure. For example, consumers could consider the importance of the purchasing price ($\lambda_{\text{purchasing price}}$) of vehicle platforms to be more important than the importance of their operational cost ($\lambda_{\text{operational cost}} > \lambda_{\text{purchasing price}}$). On the other hand, the attributes of the vehicle platforms ($x_{ji}$) are evaluated comparing each attribute to the best available option in the market.

Equation 1, $V_j(t) = \sum_i \lambda_i (t) v(x_{ji})$

For the case of the purchasing price of the vehicle platforms, consumers evaluate its cost as shown in Equation 2. There are two components that consumers use to evaluate the price of a vehicle platform. First, they compare the vehicle price to their personal income $f_{\text{GDP}} \left( \frac{x_{j\text{price}}}{\text{GDP PPP}} \right)$. The shape of the elasticity of value of price to this ratio is shown in Figure 7. It is possible to see that as this ratio reduces the value of price ($f_{\text{GDP}}$) increases. Second, they compare the price of the vehicle to the price of the cheapest available option in the market ($f_{\text{price}}$). As shown in Figure 8, in this case, when the price of the vehicle is the cheapest in the market, consumers assign the maximum value ($f_{\text{price}}$) of 1, as the price increases in comparison to the cheapest available option, the value consumers assign to price ($f_{\text{price}}$) is reduced till a minimum of 0.3.

Equation 2, $v(x_{j\text{price}}) = f_{\text{GDP}} \left( \frac{x_{j\text{price}}}{\text{GDP PPP}} \right) * f_{\text{price}} \left( \text{MIN} \left( x_{j\text{price}}, x_{j\text{price}}, x_{k\text{price}} \right) \right)$

![Figure 7. Evaluation of vehicle’s price as a function of consumers’ income](image-url)
For the value of operational cost of the vehicle platforms, consumers evaluate this attribute as shown in Equation 3. In this case, consumers compare the operational cost of each vehicle platform, assigning the maximum value to the cheapest option in the market, as shown in Figure 9.

\[
\text{Equation 3, } v(x_{j,\text{operational cost}}) = f_{\text{operational cost}} \left( \frac{x_{j,\text{operational cost}}}{\text{MIN}(x_{l,\text{op}}, x_{j,\text{op}}, x_{k,\text{op}})} \right)
\]

Finally, in a similar way, for the case of driving range, consumers evaluate the performance of a given platform comparing its performance in each of these attributes to the best performance offered in the market by a vehicle platform, as shown in equations 4. The shape of the elasticity function is shown in Figure 10.

\[
\text{Equation 4, } v(x_{j,\text{driving range}}) = f_{\text{driving range}} \left( \frac{x_{j,\text{driving range}}}{\text{MIN}(x_{l,\text{dr}}, x_{j,\text{dr}}, x_{k,\text{dr}})} \right)
\]
However, the information that consumers receive to evaluate each vehicle platform is distorted by the social exposure they have to each vehicle platform. This phenomenon is conceptualized by using the concept of familiarity (WtC), which captures the social and cognitive learning process by which consumers gain information, understanding and attachment for a vehicle platform (Struben & Sterman, 2006). Familiarity can increase or decrease through time and it is dependent on three components i) marketing of a platform (Mi), ii) word-of-mouth of drivers of a platform to non drivers of the platform (W1ijk) and iii) word-of-mouth solely from non drivers of a platform to other non drivers of that platform (W2ijk), as described in Equation 5.

\[
\text{Equation 5, } \frac{dWtC_i}{dt} = M_i + W1_{ijk}(t) + W2_{ijk}(t)
\]

Therefore the utility that the different groups of drivers (a) gain from a determined vehicle platform (j) is given by Equation 6. It can be seen that the utility of each platform is corrected by the social exposure to it, depicted by WtC.

\[
\text{Equation 6, } U_{aj}(t) = [e^{V_{aj}(t)} - 1]WtC_{aj}(t)
\]

Finally, consumers of a determined vehicle platform consist of two groups: 1) those acquiring a platform for the first time and 2) those switching from their current platform to another one. This decision process is represented by using a multi-logit decision model, as shown in Equation 7 (Yücel, 2010). It can be seen that in order to determined the share by which drivers of a determined group (a) acquire a determined platform (j), they compare the utility they can gain for a given platform, as a proportion of the total utility offered by all vehicle options.
The car manufacturer is faced with the decision of how to allocate its resources to the development of the three different platforms (Incumbent Vehicle Platform (i), Hybrid Vehicle Platform (j), Radical Vehicle Platform (k)). The car manufacturer gains resources for R&D through sales of each vehicle platform \((s_i, s_j, s_k)\) in both regions: \((A)\) advanced region and \((B)\) emerging region. This is shown in Equation 8.

\[
\text{Equation 8, } \frac{dR}{dt} = [s_{i,A} + s_{j,A} + s_{k,A}] + [s_{i,B} + s_{j,B} + s_{k,B}]
\]

Thus, in order to increase the technological performance and reduce the cost of the three vehicle platforms, the car manufacturer needs to decide which share of these resources to allocate to the different platforms. The accumulation of experience with each platform and possible economies of scale also improve the performance of the different vehicle platforms, but the car manufacturer does not make a decision in this process. Since there are already three possible technological paradigms for the car manufacturer, it is assumed that it is only focused on developing incremental innovations that will further improve each vehicle platform. Therefore in this analysis, the random occurrence of radical innovations is not considered.

As previously mentioned, the automobile industry can be considered to be in a mature market state. It is also generally viewed as a scale intensive and price sensitive industry (Pavitt, 1984). Therefore, it is plausible to assume that the decision on how to allocate resources to the different platforms will be naturally influenced by the dominance of each vehicle platform in the automobile market (measure by its market share). This provides an endogenous mechanism on how the car manufacturer allocates resources to the performance improvement of the different vehicle platforms, and also a direct mechanism by which consumers and producers interact to define a dominant technological paradigm (Werker, 2003). However, in the automobile industry already there is a dominant incumbent vehicle platform. Therefore how is it that the car manufacturer can allocate resources to the other alternative platforms? Similarly to the case of consumers, the car manufacturer is assumed to make its decisions using a multi-criteria decision making process. Namely that, in allocating resources, it will consider two factors: 1) the dominance of each vehicle platform and 2) the importance of each platform for its business strategy. This second criterion is assumed not to be endogenous in the system; rather it is thought to be uncertain as there might be many factors that can affect its behaviour. For example, several car manufacturers may follow a quite aggressive environmental strategy, and as a result, they naturally allocate significant resources to the development of the alternative platforms. This could
influence the trends in the industry. The greatest advantage of this formulation is that it allows for exploration of different strategic paths for the car manufacturer. Equation 9 shows this conceptualization; it is important to notice that the importance (λ) of market dominance (share of sales, \( \frac{s_i}{\sum s_j} \)) of each platform (i), as well as its strategic importance (E) is not static and changes through time.

\[
R_i(t) = \lambda_i(t) \frac{s_i}{\sum s_j} + (1 - \lambda_i(t))E_i(t)
\]

\[
\lambda_i \in [0,1]
\]

\[
\sum_i E_i = 1
\]

Fuel suppliers decide whether to enter or leave the fuel market. In doing this, fuel suppliers will take on account the profitability of the fuel industry for each platform and the demand for fuel for each platform. Equation 10 shows that the number of fuel stations is equal to the number of fuel stations entering in operation (e) minus the number of fuel stations leaving the market for each vehicle platform (x).

\[
\text{Equation 10, } \frac{dF_i}{dt} = e_i - x_i
\]

Entering stations in the fuel market is a function of the utilization of the capacity of the fuelling infrastructure and the natural rate of growth of the fuelling industry. As long as the demand of fuel \( (F_d) \) is greater than the supply \( (F_s) \), the industry will grow to the desired level of the demand. However, the natural rate of growth of the industry \( (g_n) \) can be higher, if the average profitability of fuelling stations \( (p) \) is such that motivates a higher number of entrants \( (f^g(p)) \); this situation is depicted in Equation 12 (Struben, 2006).

\[
\text{Equation 11, } e_i = \text{MAX}[\frac{F_d}{F_s}, g_n]
\]

\[
\text{Equation 12, } g_n = g_n^0f^g(p); f^g(< 0) = 0; f^g(0) = 1; f^g' \geq 0; f^g'(\gg 1) = 0
\]

Stations leaving the market depend on a natural hazard rate \( (h) \) by which stations exit the fuel market, and also on the effect that expected profitability of the fuel industry has on this hazard rate \( (f^h) \). When the expected profitability of the industry is high, the exit rate of stations diminishes, the contrary occurs when expected profitability of the industry diminishes, as shown in Equation 13. However, mature stations value differently recent profits compare to new to industry fuel stations. For example, mature
stations are more responsive to immediate changes in industry profitability, while young stations are more inclined to stick to their business models when they enter the market, even though profitability in the industry is not the desired one. Therefore, the expected profitability that fuelling stations calculate is affected by the effect of the average age of fuelling stations on industry profitability ($f^{pa}$). The coverage of the fuel market has also an effect on the perceived profitability of fuelling stations ($f^{pc}$). When there are few fuelling stations in the market, the expected profitability is greater than the current profitability of the industry ($p(t)$), and it diminishes as the fuel market is covert by new fuel stations, as shown in Equation 14 (Struben, 2006).

$$\text{Equation 13, } x_i = h_i f^h(\pi); f^h(0) = 1; f^{hi} \leq 0; f^{hi} > 0$$

$$\text{Equation 14, } \pi = \pi(t) f^{pa}(a) f^{pc}(c);$$

$$f^{pa}(0) = 0; f^{pa} \geq 0; f^{pa} > 0; f^{pc}(0) = 1; f^{pc} \leq 0; f^{pc} > 0$$

This concludes the description of the decision making processes of the actors involved in the analysis.  

### 2.6 Attributes of the Three Vehicle Platforms

In this study three vehicle platforms are considered: 1) Incumbent Vehicle Platform, 2) Hybrid Vehicle Platform and 3) Radical Vehicle Platform. These three vehicles platforms are characterized through several attributes. There are four attributes that are taken on account by consumers to make their purchasing decisions, these are: purchasing price, operational cost, driving range and carbon footprint. Each one each vehicle platform is defined by other attributes that are important in shaping its technology development path. For example, the maturity level of the technology, the learning coefficient for its development, etc. These attributes are presented in Table 2. 

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3 Several of the processes described in this section are based on the work of Struben (2006). Simplifications were made to fit the scope and level of aggregation of this research.

4 Several of these parameters are taken from IEA (2008), chart 15.6, p436, and from the US the Environmental Protection Agency at epa.gov/oms/climate

---

"A positive causal relation indicates that if the influencing variable increases/decreases, then the influenced variable
Table 2. Attributes of Vehicle Platforms

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Units</th>
<th>Incumbent Platform</th>
<th>Hybrid Platform</th>
<th>Radical Platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average lifetime of vehicle platform</td>
<td>Yr</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Initial purchasing price</td>
<td>$/vehicle</td>
<td>8,000.00</td>
<td>25,000.00</td>
<td>45,000.00</td>
</tr>
<tr>
<td>Initial fuel efficiency</td>
<td>lt/km;kwh/km</td>
<td>0.08</td>
<td>0.05</td>
<td>0.25</td>
</tr>
<tr>
<td>Initial fuel carbon emissions</td>
<td>kgCO2/lt</td>
<td>2.32</td>
<td>2.00</td>
<td>0.25</td>
</tr>
<tr>
<td>Technology maturity level</td>
<td>Dmnl</td>
<td>0.80</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Learning coefficient technology development</td>
<td>Dmnl</td>
<td>-0.40</td>
<td>-0.40</td>
<td>-0.40</td>
</tr>
<tr>
<td>Initial recharging time radical platform</td>
<td>hr/kwh/station</td>
<td></td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Initial battery storage capacity radical platform</td>
<td>Kwh</td>
<td></td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Development Spillovers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of knowledge spillovers pi-pk</td>
<td>Dmnl</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of knowledge spillovers pj-pi</td>
<td>Dmnl</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength of knowledge spillovers pj-pk</td>
<td>Dmnl</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following sections of this thesis will elaborate further on the relevance of all these attributes for this transition study.

2.7 ACTIVE INTERACTION MECHANISMS IN THE TRANSITION CONTEXT

There are two types of interaction mechanisms which are active in this study: 1) mechanisms related to the properties of the vehicle platforms and 2) mechanisms related to actors' perceptions. For explanatory purposes these mechanisms will be described using causal diagrams.

2.7.1 MECHANISMS RELATED TO THE PROPERTIES OF THE VEHICLE PLATFORMS

In the context of analysis, there are three interaction mechanisms that change the attributes of the vehicle platforms. These are: resource driven changes, experience driven changes and scale driven changes. Figure 11 shows the first resource driven mechanism, which refers to changes in the attributes of the vehicle platforms through R&D. It can be seen that sales of the different vehicles platforms help the car manufacturer accumulating resources for R&D. Then the car manufacturer decides in which

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4 Several of these parameters are taken from IEA (2008), chart 15.6, p436, and from the US the Environmental Protection Agency at epa.gov/oms/climate

5 “A positive causal relation indicates that if the influencing variable increases/decreases, then the influenced variable increases/decreases too above/under what would have been the case otherwise, a negative causal relation indicates that if the influencing variable increases/decreases, then the influenced variable decreases/increases too above/under what would have been the case otherwise” (Sterman, 2000).
proportion to allocate these resources to each vehicle platform. This investment in resources increases the body of knowledge of the vehicle platforms, which in turn improves the proficiency of each platform. There is also an accumulation of knowledge through R&D. Ultimately this proficiency improvement increases sales of the platforms because they become more attractive to consumers. It is important to notice that improvements in the three platforms do not increase sales of the three platforms, since they compete for the same vehicle market, and that the allocation of resources to the development of the platforms is not proportional, since they also compete for the allocation of resources (Struben & Sterman, 2006).

Figure 11. R&D driven Change.

The formation of fuelling infrastructure around a vehicle platform is an essential element to foster its development and for increasing its attractiveness for consumers. The fuelling infrastructure is indeed a resource by which the attributes of the vehicle platform can be modified. Figure 12 describes this additional resource driven change. It can be seen that the sales of the three vehicle platforms in regions A (advanced region) and B (emerging region) increase the vehicle fleet of each platform in each region. This promotes the growth of fuel demand for the specific fuel market of each platform, which is an incentive for fuel suppliers to enter the fuel market of the different platforms. As the number of fuel stations increase, the driving range of the different platforms expands. This increases the proficiency of the vehicle platforms, which ultimately increases their sales. There are two other processes in the formation of fuelling infrastructure that are important. First, both an increase in GDP per capita and in
the driving range of vehicles increase the demand for fuel, this reinforces the process of formation of fuelling infrastructure. Second, the growth of the fuelling market, reduces the profitability of the fuelling industry, this balances the process of formation of fuelling infrastructure. There are two fuel markets: a gasoline market for the incumbent vehicle platform and a hybrid vehicle platform, and an electricity market of the radical platform.

Figure 12. Fuel infrastructure driven change.

Another source of change in the attributes of the vehicle platforms is the experience driven change. Figure 13 shows how this process of change occurs in the context of the automobile industry. The experience of the car manufacturer in manufacturing the different vehicle platforms increases and accumulates in time through the sales of the vehicle platforms. This implies that the car manufacturer learns to produce more efficiently the vehicle platforms the longer it has been doing so, which ultimately reduces the cost of the vehicle platforms. For example, through the accumulation of experience the car manufacturer learns which routines are more effective for manufacturing and also it optimizes the allocation of resources. Figure 13 shows how this occurs in this transition context. In this case, sales of the different platforms in both regions increases the experience of the car manufacturer with each platform, which reduces their costs, making them more attractive for consumers, which ultimately yields
an increase in sales. Once again this does not occur in the same proportion for each platform, since the three platforms compete in the same market (Struben, 2006).

Scale driven changes also influence the attributes of the three vehicle platforms. On the contrary to the case of the experience driven changes, this mechanism of change in the platform properties occurs instantaneously for the car manufacturer. As Figure 14 shows, the sales of each platform in both regions help the car manufacturer achieve scale economies in each platform. This scale economies occur when the car manufacturer is capable of manufacturing large volumes of vehicles, which help him to purchase at better prices the raw materials needed for manufacturing the different platforms. It also allows the car manufacturer to exploit to a larger extend its production capacity. This scale economies reduce the cost of the vehicle platforms, which in turn affects their sales in both regions.
2.7.2 MECHANISMS RELATED TO ACTORS’ PERCEPTION

In this transition context only one mechanism that affects the perception of actors is considered. As shown in Figure 15, when the fleet of vehicles of a particular platform increases in one of the regions, it also increases its social exposure. This occurs through word-of-mouth of current drivers of a vehicle platform to other non drivers of that platform, through word-of-mouth of non drivers of a vehicle platform to other non drivers, and through marketing of each platform (Struben & Sterman, 2006). This mechanism of interaction is very important for this transition context. Without social learning consumers have no way of finding out the real proficiency of each platform, only through this process, consumers gain enough information to assess more accurately the performance of each vehicle platform, this in turn can increase or decrease sales for a particular platform depending on the preference structure of consumers (Struben & Sterman, 2006).
3. Behavioral Analysis

3.1 Method of Analysis

The objective of this research is to analyze the influence of market differences of the advanced and the emerging region on diffusion patterns of AVPs. The previous chapter described the conceptualization of the socio-technical system in which the transition towards AVPs is embedded. This conceptualization has been used to build a systems dynamics simulation model for supporting the analysis of this research. It is important to reiterate that the model is of a generic nature\(^6\). Therefore, the purpose is not on predicting or forecasting diffusion patterns of alternative vehicles in any particular region; but, on the contrary, to learn and gain insights into the possible ways in which diffusion patterns of alternative vehicles could be influenced by these market differences. For example, is commonly accepted that if alternative vehicles are diffused in advanced economies, emerging economies will follow afterwards a similar pattern of diffusion (e.g. IEA (2009) and Vernon (1996)). The purpose of this chapter is to challenge this view and explore whether alternative patterns of diffusion can emerge in heterogeneous markets, and explain such patterns based on the transition mechanisms describe in chapter 2 and on nature of the market differences. In the following paragraphs a brief discussion of the types of market differences is presented. In addition, the role of the relevant contextual factors which need to be included in the behavioural analysis is also discussed. Then, the methodology to conduct the behavioural analysis is presented.

The basic market difference in this transition context corresponds to the demographic and economic differences between advanced and emerging economies. On the one hand, GDP per capita of inhabitants of the advanced region is considerably higher than that of inhabitants of the emerging region. On the other hand, the demographic and economic rate of growth of the emerging region is higher than that of advanced economies. These differences have been widely observed through empirical studies, and it is widely agreed that this differences between the advance and the emerging region exist (OECD, 2009). This has been defined as the observed market difference.

The preference structure of consumers in these two regions is also an important factor which can influence transition dynamics. As described in section 2.5, consumers give a specific weight to each one of the three decision attributes of a vehicle platform (purchasing price, operational cost and driving

\(^6\) As in the case of Arthur (1988), generic models are built to demonstrate general theoretic principles or for exploring different abstract/generic circumstances of a problem.
For example, it might be possible that among all attributes of the vehicle platforms, consumers consider purchasing price as the most important one, partially neglecting the remaining three. On the contrary, it might be possible that consumers consider all three attributes to be important. Consumers in both regions do not need to have the same preference structure. For example, in one of the regions, consumers could be more price oriented; while in the other region, consumers could consider the three attributes of vehicle platforms to be important. The preference structure of consumers in both regions is uncertain, and it is possible to think of many combinations that could be plausible, as in the previous example. In fact, experimental research show that in some regions of China, a key emerging economy, when surveying the environmental friendliness of consumers, it has resulted that inhabitants of some rural regions in China have a very strong inclination towards protecting the environment and consider that is rightful to do so (Huang, 2006). This sort of market difference is defined as the difference in consumers’ preferences.

Moreover, the analysis of the transition towards AVPs is inherently embedded in various plausible contextual scenarios. Therefore, in order to study this problem seriously, it is necessary to explore extensively the effects of market differences on diffusion patterns under different contextual scenarios. According to Enserink et al. (2010) contextual scenarios depict plausible developments of a system. These scenarios are built using the external/contextual factors of a system. In the socio-technical system under study (Figure 6, chapter 1) there are two relevant contextual factors that need to be taken on account. These are: the investing role of the car manufacturer, and the technological development potential of the three vehicle platforms. Next, these contextual factors are described in more detail.

The investing role of the car manufacturer is important in this transition context because it decides how to allocate resources to the development of the different platforms (Figure 11, chapter 2). The car manufacturer has been conceptualized in a rather aggregated way; its preference structure, as described in section 2.5, depicts the average tendencies of the R&D efforts of the different car manufacturers producing cars in the advanced and emerging regions. The preference structure of the car manufacturer can be inclined towards market dominance, meaning that resources for R&D are divided according to each vehicle platform’s share of sales in the global market (sum of advanced and emerging region markets), or it can be balanced towards the three vehicle platforms, investing equal resources in the development of the three vehicle platforms (e.g. as shown by Frenkena et al. (2004)).

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7 In reality, the car industry is composed of several manufacturers; each one with a particular preference structure in line with their business strategy, but such individual strategic behaviour is out of the boundaries of this study.
Technology itself plays another important role in shaping diffusion patterns of AVPs. Today it is quite known which are the purchasing cost, the operational cost and the driving range (IEA, 2008) of AVPs. However, it is not known the development potential of each vehicle platform, nor which type of probability distribution can describe their potential in an appropriate way. For example, it is not entirely known how much further internal combustion engine vehicles could be improved in terms of efficiency and pollution control; or for example, how rapid, hybrid and electrical vehicles could be developed commercially.

The technology potential of each vehicle platform is described by their maturity level and their development potential. The technology maturity of the different vehicle platforms indicates the position of each platform in the learning curve. As shown in Figure 16, in a reference case, it can be thought that the incumbent vehicle platform (gasoline vehicles) is quite ahead its technology learning curve. As a result, further accumulation of knowledge will not improve significantly the proficiency of the incumbent vehicle platform. On the contrary, the hybrid and the radical vehicle platforms can be considered to be at early stages of development, progressing more noticeably as new knowledge is acquired. However, this intuitive conceptualization is not certain; it might be that, as shown in the dotted lines in Figure 16, the incumbent vehicle platform is in an early stage of development with still ample room for development. In contrast, the radical vehicle platform could have a much greater development potential than expected, represented by a higher learning coefficient. To understand in a more comprehensive way the influence of market differences in shaping diffusion patterns, it is important to analyze its effects under different development potential scenarios, which is a substantial part of technology transitions.

The aforementioned contextual variables are continuous. Therefore, the number of plausible contextual scenarios to explore is enormous. Given the broad boundaries of this study, the challenge of this analysis is to set a point of departure. In order to provide a systematic method of exploration of these scenarios, first a specific number of contextual scenarios have been set as an initial point of analysis. Then, several simulation experiments in these contextual scenarios are performed to test the effect of market differences on diffusion patterns AVPs. Next a brief description on how these base scenarios have been built is presented.
The car manufacturer could decide how to allocate resources for R&D only taking on account the market share of each vehicle platform in the global market ($\lambda_{market\ dominance}=1$, $E_{incumbent}=0$, $E_{hybrid}=0$, $E_{radical}=0$, Equation 9). This behaviour is defined as a market driven investor. On the other hand, the car manufacturer can allocate equal resources to the development of each platform ($\lambda_{market\ dominance}=0$, $E_{incumbent}=1/3$, $E_{hybrid}=1/3$, $E_{radical}=1/3$, Equation 9). This behaviour is defined as a balanced investor. Thus, the lower and upper limits for the preference structure of the car manufacturer are defined as follows:

- B1: Market driven investor
- B2: Balanced investor

The maturity of the different platforms and their potential of development are important factors for the analysis. As previously discussed, from a conservative point of view, all three platforms may be conceptualized as having the same development potential (same learning coefficients = 40%), only differing in their maturity level (initial position in the learning curve). For example, the incumbent vehicle platform can be considered as a very mature technology way ahead the learning curve (initial position = 80% of total potential already realized), while the hybrid vehicle platform and the radical vehicle platform can be considered to be at the beginning of that learning curve, as immature technologies. This technology context is defined as “conservative technology development potentials”. However, it might be that the incumbent vehicle platform is at a much more favourable position for development (initial position=50%). In this case, further significant improvements can be made to the incumbent platform. This technology context is defined as “High potential incumbent platform”. Also, for the case of the hybrid and the radical vehicle platforms, it might be that their development potential is much greater than anticipated (learning coefficients=100%). These technology contexts are defined as
“High potential hybrid platform” and “High potential radical platform”, respectively. Thus, these four contextual cases are:

- T1: Conservative technology development potentials
- T2: High potential incumbent platform (*Low cost and fuel efficient incumbent vehicle platform*)
- T3: High potential hybrid platform (*Hybrid vehicle platform success*)
- T4: High potential radical platform (*Radical platform success*)

Therefore, if we combine the different instances previously defined, it is possible to create 8 different base scenarios to begin the behavioural analysis, as shown in Table 3.

### Table 3. Scenarios for behavioural analysis.

<table>
<thead>
<tr>
<th>Preference Car Manufacturer</th>
<th>Market Driven Investor (B1)</th>
<th>Balanced Investor (B2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative (T1)</td>
<td>Scenario 1 B1T1</td>
<td>Scenario 2 B2T1</td>
</tr>
<tr>
<td>High Potential Incumbent (T2)</td>
<td>Scenario 3 B1T2</td>
<td>Scenario 4 B2T2</td>
</tr>
<tr>
<td>High Potential Hybrid (T3)</td>
<td>Scenario 5 B1T3</td>
<td>Scenario 6 B2T3</td>
</tr>
<tr>
<td>High Potential Radical (T4)</td>
<td>Scenario 7 B1T4</td>
<td>Scenario 8 B2T4</td>
</tr>
</tbody>
</table>

With the aid of simulation, these contextual scenarios can be explored to gain a richer understanding of the conditions in which, *market differences* play an important role in the diffusion of AVPs. For example, one scenario may consider a manufacturer that is a market driven investor and technologies that have a conservative development potential. In addition, consumers in both regions may be considered to be price oriented. If these conditions create different and counterintuitive diffusion patterns of AVPs (see section 1.2) in both or one of the regions, then important questions to ask will be: are these differences in diffusion patterns the result of *the observed market difference?*, will these diffusion patterns change if there is *a difference in consumers’ preferences?*, if so, what kind of changes occur? In order to answer these questions each contextual scenario is exhaustively explored. This is explained next.
Consumers in both regions (advanced and emerging) assign a specific weight to each of the three attributes of vehicle platforms (purchasing price, operational cost and driving range), according to their preference structure (Equation 1). In one of the cases, consumers may consider price as the only important criterion in their preference structure \( \lambda_{\text{purchasing price}} = 1, \lambda_{\text{operational cost}} = 0, \lambda_{\text{driving range}} = 0 \), Equation 1. This type of preference structure is defined as price oriented. On the opposite side, consumers may consider all attributes to be important for evaluating a vehicle platform \( \lambda_{\text{purchasing price}} = 1/3, \lambda_{\text{operational cost}} = 1/3, \lambda_{\text{driving range}} = 1/3 \), Equation 1. This type of preference structure is defined as proficiency oriented.

With the aid of simulation in each contextual scenario it is possible to study several combinations of consumers’ preference structures in both regions. As shown in Figure 17, initially consumers are considered to be price oriented in both regions. This serves as a control experiment to study the effects of the observed market difference on diffusion patterns. Then, in each contextual scenario, different combinations of consumers’ preference structure are analyzed to understand the effects of a difference in consumers’ preferences on diffusion patterns. By following this method of analysis in each contextual scenario, it is possible to widely explore and understand the effects of market heterogeneity on diffusion patterns.

The time scope of the analysis has been set to 50 years. As discussed in chapter 1, this time scope is required for this analysis because the transition towards AVPs is a lengthy process that depends on the interaction of several long term oriented processes (R&D, social exposure and formation of fuelling infrastructure). Therefore, it is important to analyze the interactions of these processes during a period of time that can provide sufficient insights into the dynamic richness of this problem. For example, two different cases may exhibit the same initial dynamic behaviour, but may show completely diverging end stages. The author considers that 50 years is a convenient time for experimentation because in this time

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**Figure 17. Behavioural analysis in contextual scenarios.**
period, it is possible to appreciate full diffusion or failure of the alternative platforms in the simulation runs. Finally, much targets for the transition towards alternative vehicle platforms have been set to the time horizon of 2050, having a similar time horizon in this analysis can help the reader ground the observations made in the analysis to a more palpable horizon.

This finalizes the discussion about the methodology of the behavioural analysis. The following sections are divided in two parts. The first part presents a detail discussion of the behaviour of the system in Scenario 1. The purpose of this section is to present an example of the analysis carried out over all the eight scenarios. The rest of the scenarios are omitted from the main discussion of this thesis, but these can be found in the appendixes. The second part presents the results found in the behavioural analysis.

3.2 BEHAVIOURAL ANALYSIS OF CONTEXTUAL SCENARIOS: SCENARIO 1

This section presents the behavioural analysis of scenario 1 (Figure 18). The behaviour of this first scenario is discussed extensively to familiarize the reader with the different facets of the system. For the remaining scenarios, the discussion can be found in the appendixes.

![Figure 18. Scenario 1 Conservative development potentials and market driven investor.](image)

Scenario 1 indicates that the preference structure of the car manufacturer is of that of a market driven investor, which means that it allocates resources to the development of each vehicle platform based on their individual share of sales ($\lambda_{\text{market dominance}}=1$, $E_{\text{incumbent}}=0$, $E_{\text{hybrid}}=0$, $E_{\text{radical}}=0$, Equation 9). Also, this scenario considers conservative technology development potentials for the three platforms (learning coefficients=40%). The incumbent platform is considered to be way ahead its learning curve, and the hybrid vehicle platform and the radical vehicle platform are considered to be at the beginning of their respective learning curves (initial position 20% and 0% respectively). **As a starting point of analysis for**
this scenario, consumers’ preference structure in both regions is considered to be price oriented, which means that they only consider the purchasing price of vehicle platforms in their adoption decisions \( (\lambda_{\text{purchasing price}}=1, \lambda_{\text{operational cost}}=0, \lambda_{\text{driving range}}=0, \text{Equation 1}). \)

Before describing the diffusion patterns resulting of this first case in scenario 1, it is important to describe in more detail the observed market difference between the advanced and emerging region. Initially, as shown in Figure 19, consumers in the advanced region are considerably wealthier than consumers of the emerging region. As the rate of growth of GDP per capita in the emerging region is greater than in the advanced region, this economic gap tends close. In addition, as shown in Figure 3, chapter 1, empirical evidence shows that there is a curvilinear correlation between car ownership and inhabitants’ GDP per capita. Therefore, given the higher GDP per capita in the advanced region, the average number of vehicles per person is much greater than in the emerging region. Figure 20 shows the size of the vehicle market in both regions. As it can be seen, initially, because of average consumers’ wealth in the advanced region, the size of the vehicle market in the advanced region is greater than in the emerging region, regardless of the notable differences in their population (1 billion in the advanced region, 5 billion in the emerging region). However, as mentioned before, the population and the average wealth of consumers in the emerging region grow at rates that overtake the size of the vehicle market in the advanced region. It is important to consider this because in this scenario the car manufacturer allocates resources based on the global share of sales of the three vehicle platforms.

![GDP per capita in Advanced Region (A) and Emerging Region (B)](image)

**Figure 19. GDP per capita differences between the advanced and the emerging region.**
The diffusion patterns of scenario 1 are shown in Figure 21. Here, it is possible to see that in both regions diffusion of the alternative vehicle platforms is quite limited. In both regions, the market share of the hybrid platform only starts growing in the last years of the simulation. In the case of the radical platform, it is possible to see that it does not diffuse at any level in both regions.

This occurs due to the slow technological development of the hybrid platform. As shown in Figure 22, the commercialization of the alternative platforms is rather slow, during most of the time of the simulation, the purchasing price of the alternative platforms in considerably higher than the price of the incumbent platform. Therefore, price oriented consumers in both regions are not incentivize to purchase any of the alternative platforms. For example, consumers in the advanced region can afford the hybrid platform, but the majority of them do not purchase it because the incumbent platform is considerably cheaper than the hybrid, which does not incentivise sales of the hybrid platform (Equation 1). As the volume of sales of the alternative platforms does not grow, the mechanisms of change of R&D driven change (Figure 11), scale driven change (Figure 14) and experience driven change (Figure 13) are never activate in favour of the alternative platforms.
As shown in Figure 23, in this scenario, R&D resources are principally allocated to the development of the incumbent platform because it always has the greatest share in sales; this hinders the development of the alternative platforms because it delays the activation of R&D driven change.
What is the influence of market differences in these diffusion patterns? In Figure 21 it is possible to see that there is a delay between the diffusion of alternative platforms in the advanced region and the emerging region. This delay is caused by the observed market difference. As shown in Equation 1, consumers evaluate the purchasing price of the different vehicle platforms comparing its price to their individual income, if the purchasing price of a given platform is considerably higher than their individual income, consumers evaluate poorly the purchasing price attribute of that platform. However, there is a considerable important gap between the income of consumers of the advanced region and the income of consumers in the emerging region. Therefore, consumers in the advanced region evaluate the price of the three platforms higher than consumers in the emerging region. This means that consumers of the advanced region can consider the alternative platforms accessible in terms of price earlier than consumers in the emerging region. Since, in scenario 1, consumers only consider the purchasing price in their purchasing decisions, then consumers in the advanced region adopt earlier the hybrid vehicle platform than consumers of the emerging region.

Finally, as the number of consumers driving the hybrid or the radical platform in both regions is rather limited. Then familiarity of consumers with the alternative platforms never grows in the case of the radical platform, and only grows slowly in the case of the hybrid platform, as shown in Figure 24. This delays the process of social learning for the alternative platforms in both regions, which prevents consumers from fully appreciating the attributes of the alternative platforms (Equation 6).
This concludes the explanation of the basic behaviour of this scenario. It is clear that when consumers are completely price oriented in both regions and when the car manufacturer is a market driven investor, diffusion of AVPs fails to realize at a significant level. This is mainly because none of the transition mechanisms discussed in chapter 2 can reach a level of influence that can hinder the dominant position of the incumbent platform.

Another market difference concerns differences between the preference structure of consumers in the advanced region and consumers in the emerging region. This has been defined as the difference in consumers’ preferences. Initially, scenario 1 considers that the preference structure of consumers in both regions is identical. Evidently, the preference structure of consumers can be different. For example, it could be that consumers in the advanced region are proficiency oriented and that consumers in the emerging region are price oriented. However, how this market difference can influence diffusion patterns in both regions?

In order to search for this possibility, a new simulation experiment is performed. For this experiment, the preference structure of consumers in both regions changes. This is done by using a vector $\alpha = \{0, ..., 0.37; \Delta = 0.01\}$, such as, in each simulation experiment, the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1 - \alpha$, $\lambda_{\text{operational cost}} = 0 + \alpha/2$, $\lambda_{\text{driving range}} = 0 + \alpha/2$. And by using a vector $\beta = \{0, ..., 0.37; \Delta = 0.01\}$, such as, in each simulation experiment, the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}} = 1 - \beta$, $\lambda_{\text{operational cost}} = 0 + \beta/2$, $\lambda_{\text{driving range}} = 0 + \beta/2$. This is for all the combination of elements in $\alpha$ and $\beta$. For this experiment 200 instances are simulated.
this does not cover the full extent of the possible combinations of the two vectors $\alpha$ and $\beta$ (4870 instances), but in order to avoid the burden of having to run an immense number of cases, the sampling method of the Latin Hypercube is used in this experiment.

The results of this experiment show that there is a threshold of diffusion for the hybrid platform (around 60%, Figure 25). This threshold is the result of moving along the learning curve for the three vehicle platforms. At some point in time, the three vehicle platforms will be technologically mature, and consumers in both regions will be completely familiar with the three platforms. At this point, the market share of each vehicle platform will be a function of its relative position in terms of technological performance as compared with the other vehicle platforms (this threshold is different in each technological scenario). It is possible to see in the behaviour envelops that for the case of the hybrid platform; the difference in consumers’ preferences accelerates or slows down the process of diffusion of this platform, the speed of this transition varies greatly in function of the different combinations of the preference structure in both regions. When consumers are inclined towards price, the system shows the longest delay in the diffusion of AVPs. When consumers are inclined towards proficiency, the diffusion of AVPs can reach levels of sustain diffusion.

The analysis of scenario 1 shows that market differences generate alternative diffusion patterns. The results of the experiments reviewed in this section show that, when the preference structure of consumers in the emerging region is more inclined towards proficiency than the preference structure of consumers in the advanced region. Then, the diffusion of the hybrid platform occurs first in the emerging region. In addition, when the preference structure of consumers in emerging region is fully proficiency oriented, the rate of growth of the vehicle market of the emerging region enhances the diffusion of the radical platform. This alternative diffusion pattern is summarized in Table 4, and it is shown in Figure 26. It is important to notice that this alternative pattern does not represent a specific simulation case. Rather is should be understood as a family of cases in which this pattern of behaviour is found.

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>The emerging region leads the diffusion of the hybrid platform. In addition, early diffusion of the radical platform in the emerging region. Failure of the radical platform in the advanced region (Figure 26)</td>
<td>• Observed market difference: Growing vehicle market in the emerging region provides a market niche for the radical platform • Difference is consumers’ preferences: Proficiency oriented consumers in the emerging region. Price oriented consumers in the advanced region</td>
<td>• Market driven investor</td>
<td>• Conservative development potentials</td>
</tr>
</tbody>
</table>
Finally, the analysis of this section also shows that in the context of scenario 1, it is possible to find other alternative diffusion patterns that are not caused by market differences. These alternative diffusion patterns are not the focus of this research. However, these are listed in each contextual scenario to emphasize the influence of consumers’ preference structure in diffusion patterns of alternative vehicle platforms.
This finalizes the analysis of scenario 1.

3.3 ALTERNATIVE DIFFUSION PATTERNS FOUND IN BEHAVIOURAL ANALYSIS

The exploratory analysis of the eight contextual has shown that it is possible to find alternative diffusion patterns in this transition context. It has been found that, depending on the context of this transition, market differences can influence diffusion patterns in a way that the AVPs can succeed or fail in one region, or both regions. This section describes these diffusion patterns and discusses the reasons of their occurrence.

3.3.1 HYBRID VEHICLE PLATFORM’S ALTERNATIVE DIFFUSION PATTERNS

The simulation experiments show that, in many cases, if the hybrid platform is diffused first in the advanced region, then, this early diffusion helps reducing its purchasing price and improving its performance. This improvement of the hybrid platform encourages consumers in the emerging region to adopt this technology. This pattern of diffusion is frequently found in the simulation experiments. However, there are some cases in which an alternative diffusion pattern occurs. These cases are discussed next:

A. Regional sustained diffusion of the hybrid platform; sustained diffusion in the advanced region; failure in the emerging region;

This diffusion pattern is shown in Figure 27. In this case of diffusion, the hybrid platform fails in the emerging region, while it succeeds in the advanced region. This occurs in a context in which the car manufacturer supports equally the development of the three vehicle platforms, and in which the radical platform has an extraordinary development potential (Scenario 8). This pattern of diffusion is found when consumers are price oriented or proficiency oriented in both regions; and when consumers are more proficiency oriented in the emerging region than in the advanced region. This shows that the difference in consumers’ preferences is not determinat in this diffusion case, since preferences of consumers are not influencing this diffusion pattern. On the contrary, the observed market difference is
very important. In this contextual scenario, since the car manufacturer allocates sufficient R&D resources to the development of the high potential radical platform, the performance of the radical platform improves fast. This makes the radical platform more attractive to consumers in both regions. However, in the advanced region consumers have already started adopting the hybrid platform and the vehicle market in that region grows very little. Thus, consumers are more reluctant to consider the radical platform since the majority of them are driving the incumbent platform or the hybrid platform. In contrast, in the emerging region, the vehicle market grows at a very fast rate; therefore, a considerable share of these consumers are purchasing for the first time in their lives a vehicle platform, thus they are not locked-in with a particular vehicle; and therefore, they are more willing to consider the AVPs. In addition, the income of these consumers is also growing. As a result, when consumers in the emerging region compare the performance of hybrid platform to the performance of the radical platform, the hybrid is outperformed by the radical, which makes the hybrid fail in that region.

Figure 27. Regional sustained diffusion of the hybrid platform; sustained diffusion in the advanced region; failure in the emerging region.

B. Regional sustained diffusion of the hybrid platform; sustained diffusion in the emerging region; failure in the advanced region;

This diffusion pattern is shown in Figure 28. It shows that the hybrid platform succeeds in the emerging region and fails in the advanced region. This is a very unexpected and odd diffusion pattern. This pattern

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8 This occurs due to social exposure; new consumers compare more evenly the three vehicle platforms because the level of social exposure they have to the three platforms is the same as that of the market. Consumers that are driving one of the vehicle platforms are fully familiar with the performance of their platform. Thus, this increases the performance gap between their platform and the other platforms, equation 6 chapter 2.
of diffusion occurs in a context in which the car manufacturer behaves as a market driven investor and in which there is a high development potential incumbent platform (Scenario 3). This means that the car manufacturer allocates R&D resources to the development of the three platforms based on each platform’s market share. Thus, the larger the market share, the larger the resources destined to R&D. It also means that cheap and fuel efficient incumbent vehicles become quickly available in the global vehicle market.

In this case, the difference in consumers’ preferences causes this alternative diffusion pattern to appear. Here, consumers in the advanced region are price oriented and consumers in the emerging region are proficiency oriented. In this case, when consumers in the advanced region are price oriented, the hybrid platform fails. In the advanced region, consumers are more inclined to purchase the incumbent platform because it has reduced its price significantly. Since the vehicle market in the advanced region is the biggest at the global level, then, the global sales of the incumbent platform keep on growing. This incentivises the car manufacturer to keep on allocating R&D resources to the incumbent platform, which delays the development of the AVPs and keeps on reducing the purchasing price of the incumbent platform. Therefore, in this context, price oriented consumers in the advanced region perpetuate the region’s locked-in with the incumbent platform.

In the emerging region, consumers are proficiency oriented; as a result, they consider the operational cost and the driving range of the vehicle platforms to be equally important for their purchase decisions. Therefore, even though the incumbent platform is cheap and fuel efficient, some consumers in the emerging region still consider to adopt the hybrid platform and the radical platform, which are more fuel efficient than the incumbent platform. The majority of these early adopters of AVPs in the emerging region are consumers who are purchasing a vehicle for the first time. Since in this region, the vehicle market grows at a very fast rate, these early adopters are enough to support the diffusion of the hybrid platform. However, the diffusion process of the hybrid platform occurs slowly because the hybrid platform receives little R&D resources, which delays its development process, and therefore, its diffusion in the emerging region. Globally the penetration levels of the hybrid platform remain very low.
C. Global sustained diffusion of the hybrid platform; parallel diffusion in both regions;

This diffusion pattern is shown in Figure 29. In this case, the emerging region catches up with the advanced region in the diffusion of the hybrid platform. Globally the hybrid platform reaches a significant penetration level, becoming the dominant vehicle platform. This pattern is found in Scenario 5. In this contextual scenario, the car manufacturer behaves as a market investor and the hybrid platform has a high development potential.

Preferences of consumers are very important in this case because this pattern occurs only when consumers in both regions are proficiency oriented. This diffusion pattern occurs due to the interdependence of both regions and to the observed market difference. The diffusion process starts in the advanced region; here consumers have an income level that makes the hybrid platform affordable to consumers earlier than in the emerging region. The growing sales of the hybrid platform in the advanced region are noticed by the car manufacturer, who raises the resources allocated to the R&D of the hybrid platform. Since this platform has a high development potential, this allocation of resources rapidly improves its performance and reduces its purchasing price. In addition, as more people begin driving the hybrid platform in the advanced region, its social exposure grows, which increases consumers’ knowledge about the attributes of the hybrid platform, incentivizing its sales. These changes in the advanced region have a significant impact in the emerging region. The improvement of the hybrid platform due to its early adoption in the advanced region incentivizes consumers in the emerging region.
to also purchase this platform. However, in this diffusion case, this effect is very strong in the emerging region because consumers are also proficiency oriented and because the vehicle market in the emerging region grows rapidly. First, consumers are more willing to purchase the hybrid platform because this platform offers a very good trade off between purchasing price and performance (low operational cost at affordable purchasing prices). Second, the growing market in the emerging region becomes a great market niche for the high potential hybrid platform, since many first time buyers are willing to adopt this platform. In this case, the transition towards the hybrid platform occurs fast; proficiency oriented consumers start the diffusion process, then the car manufacturer supports this process by quickly increasing the R&D resources for this high potential platform. This outperforms the other two platforms, which become less attractive to proficiency oriented consumers in both regions.

![Figure 29. Global sustained diffusion of the hybrid platform; parallel diffusion in both regions.](image)

**D. Global sustained diffusion of the hybrid platform; leading diffusion in the emerging region.**

This diffusion pattern is shown in Figure 30. It shows that the hybrid platform is diffused globally. However, this platform is diffused earlier in the emerging region than in the advanced region. Interestingly, this diffusion pattern is found in several contextual scenarios; it can occur in scenarios in which the car manufacturer behaves as a market investor or in scenarios in which it behaves as a balanced investor (e.g. Scenarios 1 and 2). It can also occur in scenarios in which the three vehicle platforms have similar development potentials or in scenarios in which one of the platforms has a superior development potential (e.g. Scenarios 4 and 5). Therefore, the context is not so determinant in this diffusion case. Then, what is causing this diffusion pattern? The answer is given by the market
differences between the two regions. First, this diffusion pattern occurs only when the preferences of consumers are different across both regions. Specifically, when consumers in the emerging region are proficiency oriented and consumers in the advanced region are price oriented. If consumers are proficiency oriented in the emerging region; then, in this case, in contrast to case C, the early adopters of the hybrid platform are consumers of the emerging region. These consumers adopt the hybrid platform because it offers greater fuel efficiency than the incumbent platform and because it is less expensive than the radical platform. In this case, the process of diffusion in the emerging region is slow. However, it accelerates, as people in the emerging region increase their income level, which increases the share of consumers switching from the incumbent platform to the hybrid platform. More importantly, it increases the share of first time buyers that purchase the hybrid platform. In the advanced region, where consumers are price oriented, the process of diffusion of the hybrid platform takes longer because the process is not accelerated, until the penetration levels of the hybrid platform in the emerging region are large enough to induce a decline in the hybrid platform’s purchasing price. However, this takes considerable time, since the size of the vehicle market in the emerging region is initially smaller than that of the advanced region. Thus, consumers in the advanced region continue using the incumbent platform until the hybrid platform becomes price competitive. Globally, the penetration levels of the hybrid platform are high.

![Graphs showing market share over time for different regions.](image)

*Figure 30. Global sustained diffusion of the hybrid platform; leading diffusion in the emerging region.*
E. Global failure of the hybrid platform.

There are few cases in which the hybrid platform fails globally. Market differences between the advanced and the emerging region are not determinant in these cases. Nevertheless, it is important to briefly mention these special cases.

The preferences of consumers are evidently important. In this case, if consumers are price oriented in both regions, then the odds of success of the hybrid platform reduce significantly. In this case, the diffusion of the hybrid platform fails when the incumbent platform has a high development potential. Here, the hybrid platform cannot compete against the cheap and fuel efficient incumbent platform, especially because consumers feel more inclined to purchase these cheap vehicles. In other cases, the hybrid platform does reach an initial level of diffusion, but this only occurs in the last phase of the experiments. Thus, these cases can also be considered a failure for the hybrid platform. These cases occur when the radical platform has a high development potential or when the three platforms have a conservative development potential. In these cases the hybrid platform cannot find a significant market niche because consumers focus solely on the purchasing price of vehicles.

This diffusion pattern shows that the predominance of price oriented consumers can harm importantly the process of diffusion towards AVPs. Table 6 summarizes the alternative diffusion patterns discussed so far for the hybrid platform.
### Table 6. Alternative diffusion patterns of hybrid platform

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Contextual scenario: Behaviour car manufacturer, development potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Regional sustained diffusion of the hybrid platform. Sustained diffusion in the advanced region, failure in the emerging region</td>
<td>1. Observed market difference: Rate of growth vehicle market in the emerging region, coupled with rapid affordable radical platform (price or proficiency oriented practitioners in both regions, or more proficiency oriented in the emerging region)</td>
<td>Balanced investor, high potential radical platform</td>
</tr>
<tr>
<td>B. Regional sustained diffusion of the hybrid platform. Sustained diffusion in the emerging region; failure in the advanced region</td>
<td>1. Observed market difference: Growing vehicle market in the emerging region provides a market niche for the radical platform 2. Difference in consumers' preferences: Proficiency oriented practitioners in the emerging region. Price oriented practitioners in the advanced region</td>
<td>Market driven investor, high potential incumbent platform</td>
</tr>
<tr>
<td>C. Global sustained diffusion of the hybrid platform. Parallel diffusion in both regions</td>
<td>1. Observed market difference: Rate of growth of vehicle market in the emerging region (proficiency oriented practitioners in both regions)</td>
<td>Market driven investor, high potential hybrid platform</td>
</tr>
<tr>
<td>D. Global sustained diffusion of the hybrid platform. Leading diffusion in the emerging region</td>
<td>1. Observed market difference: Growing vehicle market in the emerging region provides a market niche for the radical platform 2. Difference in consumers' preferences: Proficiency oriented practitioners in the emerging region. Price oriented practitioners in the advanced region</td>
<td>Market driven investor, conservative development potentials  Balanced investor, conservative development potentials  Balanced investor, high potential incumbent platform  Market driven investor, high potential hybrid platform</td>
</tr>
<tr>
<td>E. Global sustained diffusion of the hybrid platform. Leading diffusion in the emerging region</td>
<td>Not significant</td>
<td>Market driven investor, conservative development potentials  Market driven investor, high potential incumbent platform  Market driven investor, high potential radical platform</td>
</tr>
</tbody>
</table>

### 3.3.2 RADICAL VEHICLE PLATFORM’S ALTERNATIVE DIFFUSION PATTERNS

In the case of the radical platform, most of the simulation experiments show that after the introduction of the hybrid platform, the diffusion of the radical platform starts first in the advanced region and then in the emerging region, showing that hybridisation strategies can indeed be successful. However, several alternative diffusion patterns of the radical platform are also found in the behavioural analysis. In this case, the simulation experiments show that market differences can noticeable influence the diffusion of the radical platform. Also, in general, this vehicle platform, finds more barriers and it is more responsive to changes in the context of the diffusion. These alternative patterns of diffusion are discussed:
A. Regional initial adoption of the radical platform. Initial adoption in the advanced region; failure in the emerging region;

This diffusion pattern is shown in Figure 31. It shows that in the advanced region the hybridisation strategy works as expected. The hybrid platform is diffused first, and later, the radical platform is initially diffused in this region. On the contrary, in the emerging region, the hybridisation strategy fails because the radical platform only achieves a very low level of penetration. At the global level, the radical vehicle platform only penetrates the vehicle market at a very low level. This diffusion pattern occurs in a context in which there is a balanced investor car manufacturer and in which the development potential of the three vehicle platforms is conservative (Scenario 2). It can also be found in cases in which the incumbent platform has a high development potential (Scenario 3). This alternative diffusion pattern occurs due to the difference in consumers’ preferences between the advanced and the emerging region. In the advanced region, consumers are proficiency oriented and in the emerging region consumers are price oriented.

In the advanced region consumers favour the development of the AVPs because they consider that vehicles’ purchasing price, fuel efficiency and driving range are equally important attributes. In this regard, initially the radical platform is a hybrid with the incumbent platform. Thus, this platform offers the same driving range as the incumbent and the hybrid platforms. The radical platform also offers superior fuel efficiency. However, its high initial purchasing price does not incentivise enough proficiency oriented consumers to adopt the radical platform over the hybrid platform, which is considerable cheaper. This creates a strong initial disadvantage for the radical platform in the advanced region because the initial adopters of AVPs choose the hybrid platform over the radical platform. This initial share of consumers adopting AVPs in the advanced region reinforce the diffusion of the hybrid platform through social learning, experience driven change and scale economies. Therefore, as the vehicle market in the advanced region grows at a very low rate, the radical platform cannot find a market niche large enough to reinforce its diffusion process through the same processes.

In this context, the car manufacturer allocates equal R&D resources to the development of the three platforms. As a result, the performance of the radical platform continues to improve, which makes it more attractive for consumers, who switch from the incumbent and the hybrid platform to the radical platform. However, this is a very lengthy process because of two factors: 1) the rate of growth of the vehicle market in the advanced region, which reduces the possibilities of the radical platform to find a strong market niche; and 2) because after 15 years of R&D, the radical platform becomes capable of
covering 100% of the consumers’ trips using battery power. Paradoxically, due to the lack of fuelling infrastructure, this technical improvement reduces the driving range of the radical platform, as compared to the other two platforms. Thus, the radical platform also needs to wait for the development of the fuelling infrastructure to compete with the other platforms. After 50 years, the radical platform only reaches penetration levels of around 10% in the advanced region.

In the emerging region, consumers are price oriented. Therefore, the only way in which the diffusion of the radical platform can be induced it is through a reduction of its purchasing price. In contrast to the case of hybrid platform, in which its diffusion in the advanced region causes a global reduction of its purchasing price, inducing also its diffusion in the emerging region. In the case of radical platform, the diffusion of the radical platform is so limited in the advanced region that it does not reduce its global price significantly. Thus, price oriented consumers in the emerging region cannot be incentivized through this induced interaction of both regions. As a result, price oriented consumers in the emerging region continue preferring the incumbent platform over the AVPs. Therefore, no fuel infrastructure is developed for the radical platform and there is little social learning about the AVPs. Price oriented consumers in the emerging region become even more reluctant to adopt the AVPs in a context in which there is a high potential incumbent platform. In this case, the incumbent platform reinforces its position globally; the diffusion of the radical platforms fails in the emerging region, and in the advanced region reaches a lower penetration level compare to the one shown in Figure 31.

Figure 31. Regional initial adoption of the radical platform. Initial adoption in the advanced region; failure in the emerging region.
B. Regional initial diffusion of the radical platform. Initial adoption in the emerging region; failure in the advanced region;

This diffusion pattern is shown in Figure 32. In contrast to the previous case, this diffusion pattern shows that the radical platform succeeds in the emerging region, penetrating the market at levels close to 25%, while it fails in the advanced region. This diffusion pattern is found in several contextual scenarios. It can be found in scenarios in which the three vehicle platforms have a conservative development potential (Scenario 1 and Scenario 2). It can also be found in cases in which there is a market driven investor car manufacturer and in which there is a high potential incumbent platform (Scenario 3). This rare and unexpected diffusion pattern occurs when there is a difference in consumers’ preferences. Specifically in the case in which consumers are price oriented in the advanced region and consumers are proficiency oriented in the emerging region.

In the case in which the three platforms have conservative development potentials, the reasons of occurrence of this diffusion pattern follow a similar logic as described for case A. In this case, proficiency oriented consumers in the emerging region are more inclined towards adopting the radical platform. Initially the only technical disadvantage of this platform against the other two platforms is its purchasing price. However, this initial disadvantage is overcome due to two factors: 1) the increase in the income level of consumers in the emerging region and 2) the reduction in its purchasing price through R&D. First, in emerging region the income level of proficiency oriented consumers grows fast enough to encourage a significant share of consumers to adopt the radical platform. Second, through R&D, the car manufacturer finds new materials and/or processes that can reduce the production cost of the radical platform, and thus, its purchasing price. Moreover, there are knowledge spillovers across the R&D of the three platforms. As a result, even if the car manufacturer behaves as a market driven investor, the radical platform benefits of the R&D of the incumbent and the hybrid platforms. Of course, the larger the share of R&D resources destined to the radical platform, the faster its development. Once these initial disadvantages are overcome, the radical platform needs to reinforce its diffusion process through social learning, experience driven change and economies of scale. However, as in case A, in the emerging region, the lack of fuelling infrastructure slows down the diffusion process of the radical platform.

The observed market difference is also important. In this case, the growing vehicle market of the emerging region becomes a strong market niche for the radical platform because consumers are proficiency oriented. Especially important are first time vehicle buyers who are more prompt to adopt the AVPs. When the radical platform penetrates in this market niche, its diffusion is accelerated because
it can gain a market share large enough to accelerate the social learning of consumers, and give the car manufacturer the opportunity of increasing its experience with the radical platform. In fact, the diffusion of the radical platform is strong enough to start a second noticeable second phase of the hybridisation strategy, reducing the market share of the hybrid platform.

In the advanced region, the radical platform has little odds of success because: consumers are price oriented, the vehicle market size of both regions is different and its vehicle market does not grow significantly. First, price oriented consumers are reluctant to adopt the AVPs because of their higher prices. Second, the diffusion of AVPs in the emerging region is not strong enough to induce a reduction in the purchasing prices of AVPs because the size of the vehicle market in the emerging region is smaller than that of the advanced region. Third, the lack of first-time vehicle buyers in the advanced region, reduces the possibilities of the radical platform of finding an appropriate market niche because consumers are more reluctant to leave their current platform and switch to a more expensive and unknown platform. This reluctance to change in the advanced region is reinforced in a context in which the incumbent platform has a high development potential. In this context, in the global vehicle market, cheap and more fuel efficient incumbent vehicles become quickly available. As a result, price oriented consumers in the advanced region become even more reluctant to adopt the AVPs. In this particular context the radical platform fails in the advanced region, and reaches a lower penetration level in the emerging region compared to the one shown in Figure 32.

![Graphs showing market share over time for different regions and vehicle platforms.](image)

**Figure 32.** Regional initial diffusion of the radical platform. Initial adoption in the emerging region; failure in the advanced region.
C. Regional sustained diffusion of the radical platform. Sustained diffusion in the emerging region, initial diffusion in the advanced region;

This diffusion pattern is shown in Figure 33. This case shows that the radical vehicle platform penetrates in the emerging region at very high levels. In contrast, in the advanced region, the radical platform only reaches a initial level of diffusion. This diffusion pattern is found in a context in which the car manufacturer behaves as a market driven investor and in which there is a high potential radical platform (Scenario 7). This diffusion case shows that it is possible to find cases in which the radical platform does not succeed in the advanced region, regardless of its high development potential.

The market differences between the advanced and the emerging region are important to explain the occurrence of this diffusion pattern. In this case, the radical platform fails in the advanced region due to two factors. First, proficiency oriented consumers in the emerging region are more inclined to adopt the radical platform than price oriented consumers in the advanced region. Second, due to the observed market difference, the rate of growth of the vehicle market in the emerging region offers a better niche for the radical platform than the advanced region. In the emerging region a considerable share of adopters of the radical platform are first time vehicle buyers, while in the advanced region most of vehicle sales are replacement sales.

In addition, the interplay of these market differences with the development potential of the radical platform and the behavior of the car manufacturer is also important. In this context, the radical platform has a very high development potential. This means that if R&D resources are allocated to its development, it quickly improves its performance reducing its purchasing price, increasing its fuel efficiency and increasing the storage capacity of electrical batteries. Thus, making the radical platform more competitive against the other two platforms. However, the behaviour of the car manufacturer and consumers’ preferences in the advanced region delay the development of the radical platform. On the one hand, the market driven investor car manufacturer, allocates R&D resources to the three platforms based on each platform’s market share. Therefore, since the global vehicle market is dominated by the incumbent platform, R&D resources for the radical platform are scarce. On the other hand, the structure of the vehicle market in the advanced region is a key factor in the diffusion of AVPs. Initially the size of this vehicle market in the advanced region greater than that of the emerging region. Thus, changes in this vehicle market have strong impacts in the allocation of R&D resources by the car manufacturer. Since, in this case, consumers in the advanced region are price oriented, then the development of the
high potential radical platform is delayed until the vehicle market in the emerging region grows to a similar size of that of the advanced region.

In the emerging region, once the size of its vehicle market is as big as that of the advanced region, the transition towards the radical platform accelerates. Before this, the diffusion of the radical platform occurs at a similar speed as the diffusion of the hybrid platform. First, early adopters of AVPs in the emerging region divide among those adopting the hybrid platform and those adopting the radical platform. Some consumer prefer the cheaper hybrid platform, while other prefer the more fuel efficient radical platform. Second, initially the radical platform offers the same driving range as the hybrid and the incumbent platform, because it is a hybrid with the incumbent platform, thus it can use the same fueling infrastructure. Once the size of the vehicle market in the emerging region becomes as big as that of the advanced region, the development of the high potential radical platform accelerates. This occurs because the car manufacturer allocates more R&D resources to its development. This reduces its purchasing price and increases the storage capacity of batteries. Proficiency oriented consumers in the emerging region are very responsive to these improvements, preferring the radical platform over the hybrid platform. Moreover, the initial lengthy diffusion of the radical platform in the emerging region, incentivizes the development of an initial share of fueling infrastructure. Therefore, once the radical platform runs solely on electrical power, the driving range reduces, but not so dramatically that this can disincentivize sales. In fact, the growth of the vehicle market in the emerging region and the growing sales of the radical platform enhance the development of the fueling infrastructure.

Figure 33. Regional sustained diffusion of the radical platform. Sustained diffusion in the emerging region, initial diffusion in the advanced region.
D. Global sustained diffusion of the radical platform. Leading diffusion in the emerging region;

This diffusion pattern is shown in Figure 34. In this case the radical platform reaches high penetration levels in the vehicle market of the advanced and the emerging region. Moreover, the diffusion of the radical platform occurs first in the emerging region. This case of diffusion is found only in cases in which the radical platform has a high development potential (Scenario 7 and Scenario 8).

In this diffusion case, several factors are important. These are: the preferences of consumers, the behaviour of the car manufacturer and the observed market difference between the advanced and emerging region. First, this pattern of diffusion occurs when consumers in both regions are proficiency oriented, or when emerging region’s consumers are more proficiency oriented than consumers in the advanced region. Second, this pattern of diffusion can also occur when consumers are price oriented in both regions. However, if consumers are price oriented, this diffusion pattern only happens if the car manufacturer supports in a balanced way the development of the three vehicle platforms. If the car manufacturer behaves as a market driven investor, as explained in previous cases, the high potential of the radical platform remains unexploited. Third, as exemplified before, the observed market difference between the emerging and the advanced region creates a strong market niche for the radical platform in the emerging region. In this case, the growing vehicle market and the high number of first time vehicle buyers in the emerging region accelerate the diffusion of the radical platform.

The development potential of the radical platform is important in this case, but it is not significant without interacting with the other factors. In the technology field, the radical platform has strong initial disadvantages against the other two platforms. On the one hand, it is by far, the most expensive platform in the market. On the other hand, it is the youngest technology. Thus, it requires a longer process of development than the other two platforms. If the radical platform has a similar development potential as that of the other two platforms, it is impossible for the radical platform to overcome its initial disadvantages and become the dominant platform. Therefore in scenarios of conservative development potentials the radical platform always penetrates the market after the hybrid platform and at lower levels. However, in this case, in which the radical platform has a high development potential, it has the possibilities of diffusing in the market at higher levels than the hybrid platform. In fact, the radical platform does not need to have the highest possible development potential. Rather, its development potential only needs to be higher than the development potential of the other two platforms (at least 30% higher).
The high potential of the radical platform needs to be exploited to achieve a sustained and dominant level of diffusion. The exploitation of its potential can be incentivized by consumers or by the car manufacturer. First, consumers can enhance the diffusion of the radial platform if they are proficiency oriented. If consumers are proficiency oriented in both regions, then the diffusion of the radical platform occurs fast. In this case, consumers of the advanced region begin the diffusion process by switching from the incumbent platform towards the AVPs. This enhances the process of social learning, and experience driven change of the radical platform. In addition, the radical platform improves its performance fast due to the allocation of R&D resources and to knowledge spillovers from the other platforms. This rapid improvement of the radical platform incentivizes consumers in the emerging region to adopt the radical platform. The diffusion of the radical platform in the emerging region becomes the strongest factor supporting the diffusion of the radical platform at the global level. Here, the larger market niche in the emerging region supports the diffusion of the radical platform by enhancing the processes of social learning, experience driven change and economies of scale. Thus, in this case, proficiency oriented consumers in the advanced region start the transition process and proficiency oriented consumers in the emerging region support it to achieve a global rapid transition towards the radical platform. Second, the diffusion of the radical platform can be initiated by the car manufacturer. In this case, if the car manufacturer follows a balanced allocation of R&D resources, then the radical platform is diffused globally, even in cases in which consumers are price oriented in both regions. The resources that the car manufacturer allocates to the radical platform improve its performance rapidly, making this platform very attractive to consumers in both regions. Important attributes are its low operational cost and its declining purchasing price. In this case, the radical platform runs entirely on battery power and the fuelling of infrastructure in both regions develops fast. If the car manufacturer behaves as a market driven investor, then proficiency oriented consumers are essential for enhancing the development of the radical platform.

This diffusion pattern shows that the market differences between the advanced and the emerging region are quite significant in this transition case. Overall, it shows that the emerging region can become a key element in supporting the diffusion of the radical platform due to its growing vehicle market.
E. Global failure of the radical platform.

This final diffusion pattern shows that the radical platform fails in both regions (Figure 35). In this case, market differences between regions are not influential. Rather, other factors are more determinant in this case, and the radical platform fails regardless of market differences. Important factors in this case are: the preferences of consumers, the behaviour of the car manufacturer and the development potential of the vehicle platforms. First, in most of the cases in which consumers are price oriented the radical platform fails. As exemplified before, consumers need to be proficiency oriented to incentivize the development and diffusion of the radical platform; otherwise it cannot overcome its initial disadvantages against the other two platforms. Second, the radical platform fails in many cases in which the car manufacturer behaves as a market driven investor. Especially in cases in which consumers are also price oriented. Under this context, the radical platform has no change of success. However, it also fails in cases in which consumer are proficiency oriented. Here, the market driven strategy of the car manufacturer delays the development of the radical platform, and while this platform struggles to find a market niche among proficiency oriented consumers, time is wasted in the development of the platform, which hinders its competing position against the other platforms in the long run. Third, the development potential of the other two platforms can also influence the failure of the radical platform. In this case, if the other vehicle platforms have a higher development potential, the technical disadvantages of the radical platform are accentuated. Here, if the car manufacturer behaves as a market investor, the radical platform cannot compete with the other platforms to access R&D resources. If the car manufacturer behaves as a balanced investor, then the development potential of the other platforms outperforms the
radical platform. Therefore, it is possible to see that in scenario 1-7 is always possible to find cases in which the radical platform fails. However, contextual factors are far more determinant, than market differences.

Figure 35. Global failure of the radical platform.
3.4 DISCUSSION OF RESULTS

The behavioural analysis has shown that market differences between the advanced and the emerging region can influence diffusion patterns of AVPs. Important lessons learned in this transition context are discussed next:

Table 7. Alternative diffusion patterns of radical platform.

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Contextual scenario: Behaviour car manufacturer, development potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Regional initial adoption of the radical platform. Initial adoption in the advanced region; failure in the emerging region</td>
<td>1. Preference market difference: Proficiency oriented practitioners in the advanced region, price oriented practitioners in the emerging region.</td>
<td>Balanced investor, conservative development potentials Market driven investor, high potential incumbent platform</td>
</tr>
<tr>
<td>B. Regional initial diffusion of the radical platform. Initial adoption in the emerging region; failure in the advanced region</td>
<td>1. Observed market difference: Growing vehicle market in the emerging region provides a market niche for the radical platform 2. Difference in consumers' preferences: Proficiency oriented practitioners in the emerging region, price oriented practitioners in the advanced region</td>
<td>Market driven investor, conservative development potentials Balanced investor, conservative development potentials Market driven investor, high potential incumbent platform</td>
</tr>
<tr>
<td>C. Regional sustained diffusion of the radical platform. Sustained diffusion in the emerging region, initial diffusion in the advanced region</td>
<td>1. Observed market difference: Growing vehicle market in the emerging region provides a market niche for the radical platform 2. Difference in consumers' preferences: Proficiency oriented practitioners in the emerging region, price oriented practitioners in the advanced region</td>
<td>Market driven investor, high potential radical platform</td>
</tr>
<tr>
<td>D. Global sustained diffusion of the radical platform. Leading diffusion in the emerging region</td>
<td>1. Observed market difference: early adoption of the radical platform in the emerging region strengthens its position in the advanced region (Proficiency oriented practitioners in both regions) 2. Difference in consumers' preferences: Rate of growth vehicle market in the emerging region, coupled with rapid affordable radical platform (price or proficiency oriented practitioners in both regions, or more proficiency oriented in the emerging region)</td>
<td>Market driven investor, high potential radical platform Balanced investor, high potential radical platform</td>
</tr>
<tr>
<td>E. Global failure of the radical platform</td>
<td>Not significant</td>
<td>Market driven investor, high potential incumbent platform Market driven investor, high potential hybrid platform Market driven investor, high potential radical platform Balanced investor, high potential incumbent platform</td>
</tr>
</tbody>
</table>
The influence of the observed market difference is important for the diffusion patterns of the two alternative platforms. First, the income level of consumers in the advanced region is higher than the income level of consumers in the emerging region. Therefore, AVPs become affordable sooner for consumers in the advanced region, than for consumers in the emerging region. This is an important factor that stimulates the diffusion of AVPs earlier in the advanced region than in the emerging region, especially in the case of the hybrid platform. The initial diffusion of the hybrid platform in the advanced region induces its diffusion in the emerging region. For example, improvements in the performance of the hybrid platform, due to R&D, incentivise consumers of the advanced region to purchase this platform. Then, the growth of sales of the hybrid platform in the advanced region helps the car manufacturer gaining experience in its production and also achieving economies of scale, which reduces the purchasing price of the hybrid platform. This fosters the diffusion of the hybrid platform in the emerging region. The results of the behavioural analysis show that when there is not a difference in consumers’ preferences, then the hybrid platform always diffuses first in the advanced region and later in the emerging region.

Second, the rate of growth of the emerging region is higher than that of the advanced region. The growth of the vehicle market in the emerging region is principally sustained by consumers that purchase for the first time a vehicle platform (new to industry vehicle sales). In the advanced region most of the vehicle sales are replacement sales. This is important because consumers already driving the incumbent or the hybrid platform demand a higher level of performance of the radical platform to switch to it, than consumers that for the first time decide which vehicle platform to adopt. Therefore, by the time the radical platform has improved its performance through R&D and is able to compete with the other two platforms. This vehicle platform finds a better market niche in the emerging region because: 1) consumers there have increased their income level, 2) the share of new to industry vehicle sales in considerably high and 3) the hybrid platform has not been diffused at a significant level. In the advanced region, the radical platform finds more opposition because the hybrid platform has already been diffused at significant levels. However, this does not mean that the radical platform always diffuses more successfully in the emerging region than in the advanced region. In fact, depending on other factors, such as: the preferences of consumers, the behaviour of the car manufacturer and the development

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9 This occurs due to social exposure; new consumers compare more evenly the three vehicle platforms because the level of social exposure they have to the three platforms is the same as that of the market. Consumers that are driving one of the vehicle platforms are fully familiar with the performance of their platform. Thus, this increases the performance gap between their platform and the other platforms, equation 6 chapter 2.
potential of the three vehicle platforms, new to industry vehicle sales in the emerging region could benefit any of the three vehicle platforms.

If the difference in consumers’ preferences is such that consumers in the advanced region are proficiency oriented and consumers in the emerging region are price oriented. Then, the hybrid platform always diffuses at a significant level earlier in the advanced region, than in the emerging region. In the emerging region, the pattern of diffusion of the hybrid platform shows a delay and a lower penetration level with respect to the advanced region. The more inclined consumers of the emerging region are towards price, the longer the delay and the lower the level of diffusion of the hybrid platform. The radical platform also shows a similar pattern. Therefore, in these cases, in the advanced region there is a two phased diffusion. First, the hybrid platform is introduced and succeeds, and second, the radical platform is introduced. In the emerging region, the radical platform in most of the cases fails to reach a level of sustained diffusion. In this case, the growing vehicle market of the emerging region is divided between the incumbent and hybrid platforms.

If the difference in consumers’ preferences is such that consumers in the advanced region are price oriented and consumers in the emerging region are proficiency oriented. Then, several different diffusion patterns of AVPs are possible. These alternative diffusion patterns are different depending on the contextual scenarios in which the transition takes place. The results of the analysis show that:

- In cases in which the three platforms have a similar development potential, then in the emerging region takes place a two phased transition. The hybrid platform succeeds first, and afterwards the radical platform is introduced and diffused at a considerable level. In the advanced region, only the hybrid platform succeeds.
- In cases in which the car manufacturer behaves as a market driven investor, several diffusion patterns are possible. For example, if the incumbent platform has a higher development potential than the other two platforms. Then, AVPs succeed in the emerging region, but they fail in the advanced region. Also, if the hybrid platform has the highest development potential, the radical platform fails in both regions. The hybrid succeeds at the global level and it diffuses at the same time in the advanced and the emerging region. Finally, if the radical platform has the highest development potential, then the hybrid platform succeeds in the advanced region and fails in the emerging region. On the contrary, the radical platform succeeds in the emerging region, and only diffuses at a very low level in the advanced region.
If the car manufacturer behaves as a balanced investor, additional alternative diffusion patterns are possible. For example, if the three platforms have a similar development potential, then in the emerging region a two phased diffusion takes place. In the advanced region only the hybrid platforms succeeds. If the incumbent platform has the highest development potential, the radical platform fails in both regions, and the hybrid platform diffuses at a higher level in the emerging region than in the advanced region. Finally, if the radical platform has the highest development potential, then a quick two phased transition takes place in the advanced region. In the emerging region the hybrid platform fails and the radical platform diffuses at a higher level than in the advanced region.

Alternative patterns of diffusion for the radical platform also occur when consumers are proficiency oriented in both regions and when the development potential of the radical platform is higher than the potential of the other two platforms. In these cases, the diffusion of the radical platform occurs first in the emerging region, and full diffusion of the radical platform occurs at the global level.

The analysis has also show that the diffusion of AVPs becomes less uncertain when the car manufacturer behaves as a balanced investor. On the contrary, when the car manufacturer behaves as a market driven investor, the diffusion of alternative vehicle platforms becomes much more uncertain. In these cases, if consumers are price oriented, then the diffusion of AVPs fails in both regions, regardless of their development potential.

Regarding the development potential of the vehicle platforms, if the development potential of the three vehicle platforms is similar among the three vehicle platforms, then market differences have a strong influence in their diffusion patterns. However, the more unbalanced the development potential of the three platforms is, the less determinant in diffusion patterns, market differences become.

Other important elements of this transition case are the transition mechanisms through which consumers, suppliers and the vehicle platforms interact. The behavioural analysis has also provided some important lessons about the importance of these mechanisms in this transition context.

There are two types of transition mechanisms. First, those mechanisms through which consumers, suppliers and the vehicle platforms interact within their own market niche, these are: social learning and fuel infrastructure driven change. Second, those mechanisms through which consumers, suppliers and vehicle platforms interact at a global level, these are: R&D driven change, experience driven change and scale driven change. Lessons about the former group of transition mechanisms are discussed first.
The process of social learning is a key mechanism of change in this transition context. Since the vehicle market is initially dominated by the incumbent vehicle platform, consumers are assumed to be fully familiar with the performance attributes of the incumbent platform. However, initially consumers are not familiar with the alternative platforms, thus they are not fully aware of the attributes of these platforms. Therefore, when they compare AVPs against the incumbent platform to make their purchasing decisions, they underestimate the performance of AVPs. This gives an enormous advantage to the incumbent platform over the alternative platforms (Struben, 2006).

Familiarity with the alternative vehicle platforms grows through the word of mouth of consumers driving these platforms, through the word of mouth of consumers not driving them, but seeing them on the road, and also through marketing campaigns; the more consumers decide to purchase AVPs, the higher the level of familiarity with these platforms (Struben & Sterman, 2008).

The process of social learning creates a systematic delay in the diffusion of the AVPs, which has important effects on the diffusion process. For example, although technically the performance of AVPs can be superior to the performance of the incumbent platform, still consumers may prefer the incumbent platform over AVPs because they are not familiar with them. The results of this research show that increasing consumers’ familiarity with AVPs through social learning is essential to reach levels of sustained diffusion of AVPs.

The development of the fuelling infrastructure is important because it expands the driving range of the vehicle platforms. The driving range of the vehicle platforms increases as the number of fuel stations increases. The driving range of the incumbent and hybrid platforms is always the maximum possible because they only use gasoline as a fuel source, and because the fuelling infrastructure has already been built in both regions. However, the fuelling infrastructure driven change is quite significant for the radical platform. Initially, the storage capacity of electrical batteries is only enough to power small distance trips. In order to power longer distance trips, the radical platform uses gasoline as a supplementary fuel. Therefore, initially the radical platform is a hybrid with the incumbent platform and it can use the fuel infrastructure of the incumbent platform (as in the case of a plug-in hybrid). As a result, initially the driving range of the radical platform is the same as that of the incumbent and the hybrid platforms.

The storage capacity of electrical batteries increases through R&D. This reduces the dependence of the radical platform on gasoline, until a point in which the radical platform has the technical potential of powering all trips using electricity. At this point, if the battery recharging stations are not enough for sustaining the driving range of the radical platform, then the driving range of the radical platform
diminishes, which affects negatively its diffusion process. The magnitude of the impact of this effect depends on three factors: 1) the level of diffusion of the radical platform, 2) the comparative advantages of the other two platforms over the radical platform and 3) the familiarity of consumers with the radical platform. For example, if the radical platform has achieved full electricity mobility and competitive prices before consumers are fully familiar with it, and before achieving significant levels of diffusion, then the impact of the this driving range effect is limited. If the radical platform takes several decades to achieve full electricity mobility and competitive prices, but it has been diffused at a considerable level (>10%), then the impact of driving range is significant and it can cause that the diffusion of radical platform stagnates.

Lessons about the mechanisms through which consumers, suppliers and vehicle platforms interact at the global level are discussed next.

The R&D driven change depends on the allocation of resources by the car manufacturer. These resources are important because the development of AVPs reduces their performance disadvantages against the incumbent platform, thus becoming more attractive to consumers in both regions. The R&D driven change is particularly important in the initial phases of the transition process because the earlier the AVPs reduce their performance disadvantages against the incumbent platform, the more likely their diffusion becomes. The R&D driven change is especially important for the radical platform since its initial performance disadvantages in terms of purchasing price against the other two platforms difficult its successful diffusion.

The uncertainties about the development potential of the alternative platforms can influence importantly the diffusion patterns of AVPs. However, it has been found that when there is a balanced allocation of resources to the R&D of the alternative platforms, then diffusion patterns of the alternative platforms become less uncertain.

The effect of knowledge spillovers has also been considered in this research. It has been widely reported in the literature that spillovers exist in R&D processes of AVPs (Frenkena, Hekkerb, & Godfroijc, 2004). For example, Struben (2006) makes an extensive analysis of the effect of knowledge spillovers in diffusion patterns of AVPs, and it shows that the stronger the spillovers among platforms the more intertwined their diffusion processes. In this research a conservative position on spillovers has been taken (chapter 2, section 2.7.1). The results of this research show that the performance of the vehicle platforms improves through spillovers between the hybrid and the radical platforms, but never to such extent that this can induced diffusion of any of the alternative vehicle platforms.
The car manufacturer becomes more experienced in producing the alternative vehicle platforms, as more consumers decide to purchase these types of vehicles. This experience helps the car manufacturer to become more efficient in producing the vehicle platforms. Thus, as the car manufacturer accumulates more experienced, the purchasing price of the alternative vehicle platforms reduces.

This experience driven change is important in the later phases of the diffusion of the alternative platforms. Once alternative platforms have been diffused at a significant level and have also improved their performance through R&D, a reduction in their purchasing price makes them more attractive to consumers. This strengthens the diffusion process of the alternative platforms.

The experience driven change can also work in favour of the incumbent platform. In this case, even though the car manufacturer is already quite experienced in producing the incumbent platform. If the volume of sales of the incumbent platform continues increasing, this experience can still help the car manufacturer finding opportunities to further reduce the purchasing price of the incumbent platform.

The scale driven change depends on the rate of sales of each vehicle platform. If the volume of sales of a given platform increases, then scale economies in their production can be achieved. If the volume of sales diminishes, the effect of scale economies also diminishes. These scale economies help reducing the production cost of the vehicle platforms, thus reducing their purchasing prices.

The scale driven change is important for the alternative platforms because a reduction in their purchasing prices, makes them more attractive for consumers. This strengthens their diffusion process. Scale economies can also work in favour of the incumbent platform, but its effect is less significant compare to the effect of scale economies on the purchasing price of the alternative platforms. This mechanism of change helps sustaining the diffusion of the alternative platforms.
4. CONCLUSIONS

This research has extensively analyzed the effect of market differences between advanced and emerging economies on the diffusion of alternative vehicle platforms (AVPs). This has been done using a system’s approach. Specifically, the Actor-Option framework of Yücel (2010) has been used to conceptualize and frame this transition context. Based on the building blocks of this framework, a System Dynamics model was built and used to explore this transition case through simulation experiments. This model considers two generic regions resembling advanced and emerging economies, and three generic vehicle platforms: incumbent, hybrid and radical platforms. In addition, within the boundary of analysis, the model considers the interaction of several feedback mechanisms (Social Learning, R&D, Learning by Doing, Network Externalities and Scale Economies); as well as technical factors of the vehicle platforms, consumers’ preferences and car manufacturers’ behaviour. The analysis of several simulation experiments has been useful to understand how the interaction of these system elements, combined with market differences, can create unexpected and interesting diffusion patterns. This chapter presents the main findings of the research.

4.1 EFFECTS OF MARKET DIFFERENCES

Market differences between advanced and emerging economies can influence diffusion patterns of AVPs in three main ways:

First, the difference between the income level of consumers in the advanced and emerging region creates a systematic delay in the diffusion of AVPs in the emerging region. In the advanced region, the income level of consumers makes AVPs economically affordable earlier than in the emerging region. Thus, AVPs penetrate the market earlier in the advanced region. The early adoption of AVPs in the advanced region reduces its prices and increases its performance, inducing its diffusion in the emerging region.

Second, the difference between the rate of growth of the vehicle market in the advanced and the emerging region creates a stronger market niche for the radical platform in the emerging region. In the advanced region the radical platform finds strong barriers to penetrate this market. On the one hand, consumers driving the incumbent or the hybrid platforms are more reluctant to adopt the unknown developing radical platform. On the other hand, the growth of the vehicle market in this region stagnates; most vehicle sales are replacement sales. Thus, it becomes difficult to find consumers willing to purchase the radical platform. In the emerging region, the opposite occurs, the vehicle market grows
steadily and most of vehicle sales are from consumers that for the first time purchase a vehicle platform. First time buyers are equally willing to purchase any of the AVPs. Thus, the radical platform finds a strong market niche in the emerging region, which can compensate for the stagnation of the vehicle market in the advanced region. In this case, the emerging region has the potential to catch up with the advanced region in the diffusion of AVPs, and in some cases, to even surpass the advanced region in this transition. However, how this market niche is exploited depends significantly on the preferences of consumers. In this regard, if consumers are priced oriented, the transition towards AVPs becomes less likely, especially in the emerging region. On the contrary, if consumers are proficiency oriented, the transition towards the radical platform becomes more likely in both regions. In this case, the emerging region injects a strong impulse to the global diffusion of AVPs.

Third, the difference in consumers’ preferences can significantly influence diffusion patterns. Two relevant cases exist:

I. If consumers in the advanced region are proficiency oriented and consumers in the emerging region are price oriented. Then, in the advanced region, the hybrid platform still is likely to penetrate the market at high levels, but the radical platform only does it at very low levels because the vehicle market stagnates. In the emerging region, the hybrid platform penetrates at modest levels due to the impulse receive by its diffusion in the advanced region, but the radical platform fails. In this case, the incumbent platform benefits from the growing vehicle market in the emerging region.

II. If consumers in the emerging region are proficiency oriented and consumers in the advanced region are price oriented. Then, the advanced region lags behind in the diffusion of AVPs. In the advanced region the diffusion of the hybrid platform is delayed and the radical platform struggles to find a market niche. In the emerging region, the diffusion of AVPs is also delayed due to the lack of the initial impulse of the advanced region. However, in this case, the radical platform finds a strong market niche and penetrates the market at high levels. Several diffusion patterns are possible, being the most interesting that in which the hybrid platform succeeds only in the advanced region and the radical platform succeeds only in the emerging region.

Market differences combined with other uncertain factors such as the behaviour of the car manufacturers and the development potential of AVPs can also create alternative diffusion patterns. First, it has been found that a balanced allocation of R&D resources to AVPs reduces the uncertainty around the technical potential of each vehicle platform. If R&D resources are early allocated to AVPs,
both the car manufacturer and consumers discover earlier the potential of each vehicle platform. This reduces the initial systematic disadvantages of AVPs against the incumbent platform, and guarantees that the potential of AVPs is exploited by consumers and by the car manufacturers. Which, in many cases, remains unexploited if car manufacturers wait for market signals to invest in the development of AVPs. Second, it has also been found that if the development potential of the three vehicle platforms is comparable, then market differences have a strong influence in their diffusion patterns. However, the more unbalanced the development potential of the three platforms is, the less determinant market differences become.

4.2 POLICY RELEVANCE

The results of this research show that both regions are important for fostering a transition towards AVPs. It is clear that advanced economies are key players for supporting the transition towards AVPs. The early diffusion of AVPs in advanced economies can enhance the international commercialization of AVPs by making this technologies cheaper and increasing its performance. In principle, this improvement of AVPs can induced its diffusion in emerging economies. However, the results of this research show that this initial inertia in advanced economies can be exhausted, and thus threaten the diffusion of AVPs. This occurs because the vehicle market in advanced economies is expected to hardly grow in the future. Thus, when consumers of advanced economies adopt hybrid vehicles, the second phase of this transition towards electrical vehicles can be severely slowed down due to the lack of a market niche for these new vehicles. In this specific aspect, the importance of emerging economies becomes apparent. In contrast to advanced economies, in emerging economies, the vehicle market is expected to grow significantly. Moreover, in these economies most of vehicle sales will be from consumers that for the first time purchase a vehicle. Thus, emerging economies have the potential of offering a complementary market niche for electrical vehicles which cannot only enhance its diffusion, but also accelerate it.

This is the general setting of this transition. However, several factors make this transition uncertain and ambiguous. Thus, the situation previously described can only be expected to occur in some specific cases. These cases point to the very importance of each actor in this transition case. The preferences of consumers are a key element in this transition. If consumers are proficiency oriented in both regions, then the situation described can be materialized. In the advanced economies, common sense indicates that education and income levels of consumers make them proficiency oriented. However, in emerging economies this is hard to imagine. In fact, it is less likely that consumers in emerging economies are proficiency oriented. However, if this transition towards AVPs is to occur regardless of other contextual
factors, then it is desired that consumers in the emerging are proficiency oriented. This is quite relevant for policy makers. Here, attention must be paid to fostering the environmental awareness of consumers in emerging economies and to implementing measures that can make consumers more conscious of their fuel consumption. For example fossil fuel taxes, GHG emission taxes and road pricing (OECD, 2008). In addition, it is important to consider that first time vehicle sales in the emerging region will be probably from young-middle age consumers in emerging economies. These consumers are at the moment infants or have not actually been born. Therefore, also long term environmental educational efforts in emerging economies are worth policy measures.

There also relevant aspects of this research for firms. In this case, it has been shown that a balanced allocation of R&D resources to the AVPs yields the most promising results for this transition case. Specifically, the results show that it is important for car manufacturers to support the development of the radical platform before the vehicle market in emerging economies becomes as big as that of the advanced economies. If this is not done, then valuable time will be wasted and the transition towards AVPs will be compromised. This can actually become a matter of survival for some car manufacturers. If consumers in both regions become more proficiency oriented, then the vehicle market will be extremely permissive to the introduction of AVPs. In this case, if car manufacturers bed at maintaining the system’s locked-in with the internal combustion engine, not even cheap and fuel efficient conventional vehicles will prevent the transition towards AVPs. And the most experienced and advance manufacturers with AVPs will benefit the most. The rest may actually face a lengthy process of collapse. The policy relevance of this aspect is clear. In this case, policy makers and car manufacturers should guarantee that there are enough R&D resources for the development of AVPs in the coming decades, and to carefully understand the scope and potential of the development of each vehicle platform. Public-private partnerships and the development of the required human capital are probably adequate instruments in this regard. Moreover, in this aspect, advanced economies are key players both in the R&D process of AVPs and, ideally, in the technology transfer process towards emerging economies (UNEP; EPO; ICTSD, 2010).

As in all previous studies in the field, this research showed that the development of the fuelling infrastructure for electrical vehicles is a strong factor that can foster its diffusion. However, how important infrastructure becomes in the future depends on how important consumers consider long distance trips. For example, urban drivers may seek in the future fuel efficient vehicles that can provide a driving range large enough to cover their small urban trips. Or it might be possible that technological improvements of electrical vehicles make less significant the existence of fuelling infrastructure (e.g. solar cars). Nevertheless, as long as these changes remain speculative, the strategy that can yield the
highest benefits is to early develop the necessary supporting fuelling infrastructure for electrical vehicles. This fuelling infrastructure will not be profitable during the first phases of this transition. Thus, implementing public policies that can foster the development of this infrastructure during this phase are essential.

To conclude, the transition towards alternative vehicle platforms is a huge challenge that requires the effort of all actors involved in this process (e.g. suppliers, drivers, regulators). Several actions are already being taken by many countries to succeed in this endeavour. However, this research has shown that market differences between advanced and emerging economies can make these actions futile; success of AVPs in one region does not imply that they would succeed in the other region. This can put at stake our GHG reduction objectives. In fact, the process of diffusion of AVPs might be enriched and strengthened if it is seen as a complementary process between advanced and emerging economies.

Finally, in order to achieve our common global GHG reduction targets, it is necessary that both regions transit towards a more sustainable mobility system. AVPs are a powerful tool to meet this end. Great responsibility in this area lies on the shoulders of advanced and emerging economies alike, as well as on the private sector. There is no room for an attitude of wait and see in this matter. More importantly, it seems that in this transition case, in addition to market signals, actors need to look for other social and technical signals to be able to respond as needed for this transition.

### 4.3 LIMITATIONS

The conclusions presented in the last section should take on account several limitations on the usefulness of the results. In this section, these limitations are presented, along with recommendations on how to address these limitations for future research in the topic. One part of the recommendations concerns how to translate this generic research into an applied policy study. Another part deals with the usefulness and applicability of the results of this research into the study of the transition towards AVPs.

The first limitation concerns the level of aggregation of the model, which it very high. For example, regions have been conceptualized at a macro level, while in reality even within advanced and emerging economies there are ample sources of market heterogeneity (e.g. level of income, gender, education, age). If these factors are taken into account, then probably a more differentiated picture of diffusion will emerge. Second, the utility curves used in the model to conceptualize the decision making process of consumers are not backed up with empirical data and are not included in the sensitivity analysis. One way in which this could be tackled would be by conducting a more robust and exploratory analysis of the
model; for example, by exploring the behaviour of the model using several different utility curves. Another possibility is to conduct field experiments and/or surveys to determine the shape of these curves. Third, there are also several limitations regarding the conceptualization of the transition mechanisms of this research. The majority of the processes used in this research are based on the work of Struben (2006), especially those concerning R&D and social learning. Struben (2008) provides several evidence of validation to his work; for example, by reproducing past transition cases in the automobile industry, in different countries. However, those processes needed to be simplified to meet the generic nature of this research, which detach this research from the validation of Struben (2008).

The validation of the model used in the research is another problematic issue. In this regard, an exhaustive sensitivity analysis and several extreme value tests were performed to guarantee the correct functioning of the model. In addition, all parameters used for describing the attributes of the vehicle platforms, as well as the demographic and economic characteristics of the regions are backed up with empirical data. However, given the generic nature of the model, it is difficult to empirically validate the results of the model. First, the results of the model deal with an issue that is currently unfolding and that it has a long term orientation. Therefore, finding adequate empirical data that could be used to validate the output of the model is difficult. Second, other conceptual issues would need to be taken on account, for example, defining criteria on how to properly cluster advanced and emerging economies. An empirical validation of the behaviour of the model is important because it can increase the relevance and usefulness of the study.

The results of the model have been interpreted in qualitative way, mainly focussing in transition patterns and end states of the system. However, several other metrics could be used for analyzing the changes in the system. For example, it would be interesting and very useful to define metrics to assess when an alternative platform has past from a fragile state of diffusion to a sustain process of diffusion. Also, other metrics to measure the influence of each one of the transition mechanisms on the diffusion process of the alternative platforms would be useful. These metrics would allow for a more in deep statistical comparison of the results of the study, which could shed light on new interactions and relations that might have been omitted in this research.

There are also important factors that need to be considered regarding the boundary of the system. For example, in this research it has been assumed that there is not a causal link between the behaviour of the car manufacturer and the development potential of the alternative vehicle platforms. Probably, the car manufacturer learns about the development potential of each vehicle platform through R&D.
Therefore, if there is a technology with a superior development potential, the car manufacturer might react on this information. However, how this process is and what implications it has in this transition context is probably better suited for another research topic constrained specifically to the R&D dynamics of the industry.

The conceptualization of the development potential of the three vehicle platforms is also another area of possible improvement. In this research, the processes through which investments in R&D translate into technological improvements have been conceptualized in a complete theoretical way. Probably this aspect of the research could be improved by analyzing the correlation between investments in R&D, patents counts and technology improvements in alternative vehicle platforms.

The spatial and geographical factors that influence consumers’ adoption of a vehicle platform have also been simplified in this research. However, Struben (2008) shows that spatial consideration are important; for example, according to his research the diffusion of alternative vehicle platforms in rural areas can induce and support the diffusion of alternative vehicle platforms in urban areas. This is particularly important for this research because advanced and emerging economies also differ importantly in their share of rural population. If this aspect is taken on account, the influence of a new source of market heterogeneity in diffusion patterns could be studied.

Finally, the car manufacturer has been conceptualized as one supplier serving both regions. However, this is not necessarily the case; for example China and India have built up local vehicle manufacturing capabilities that are aimed at producing low cost gasoline vehicles (OECD, 2009). While the production levels of these car manufacturers are still low compare to those of the global manufacturers, it is probably interesting to study how their involvement in this transition case could influence diffusion patterns. Therefore, this could also create industry heterogeneity between advanced and emerging economies, which could also enrich the analysis of this research.

This research has taken a strong market approach to this transition case, by neglecting the influence of the regulators on the system (e.g. government, policy makers). In reality, regulators also interact with consumers and suppliers in this transition case; for example, if the alternative vehicle platforms do not accomplish certain milestones, then regulators could implement stricter actions to induce the transition towards alternative vehicles. In fact, the interests, the resources and the interdependencies of regulators are also different between advanced and emerging economies, and thus represent another source of market heterogeneity. While it would be difficult to include these factors in a system dynamics model,
conducting further research in this area could enrich the qualitative interpretation of the results, which would shed more light into the importance of market heterogeneity in this transition context.

Finally, it is important to discuss lessons learned about applying the system dynamics method in this transition case. First, initially the model was of a considerable size. However, throughout the sensitivity analysis it resulted that several variables in the model were redundant, thus the model was simplified and still the behaviour of the model did not change. This was an important modelling lesson, showing that when applying the system dynamics methodology it is important to always keep in mind the scope and level of aggregation of the analysis. Second, the way in which the system dynamics method was used in this research has strong limitations for obtaining accurate results, thus it would be very difficult to use the model to design specific policy measures. Probably in this case more constrained system dynamics model, statistical models or econometric models that follow the same causal structure are more appropriate. Third, the method is very strong tool for learning and exploration. Throughout the experimentation phase with the model, performing several simulation experiments and exploring its different facets made the author more acquainted with the dynamics of this transition case. As the research progressed, the author realize that some of the outcomes could be inferred before performing more simulation experiments, by using the knowledge already acquired in the experimentation phase. This shows that the system dynamics method could be used as a powerful tool of learning and discovery for policy analysts and policy makers. For example, these types of actors could go through similar learning processes that would make them more acquainted with this transition case and which would prepare them to assess more holistically the information regarding this transition context (e.g. the role of R&D, importance of new to industry sales, opportunities in the emerging region, etc).
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I. MODEL DESCRIPTION

This section presents a brief description of the model used for this research. A copy of the model can be sent to those readers that wish so. In this case please write to the following e-mail address: edmundo_unam@hotmail.com

The model used for this research consists of 11 subsystems:

1. Development of vehicle platforms - Includes process by which investments in R&D translate into new knowledge, and how this knowledge is used to improve the vehicle platforms. It also includes process through which the car manufacturer acquires experience and achieves economies of scale.

2. Adoption and demographics Region A - Includes the decision making process of consumers in the advanced region, as well as the demographic and economic variables.

3. Formation of fuelling infrastructure F1 [A] - Includes the processes for the formation of fuelling infrastructure of fuel type 1 (gasoline) in the advanced region. This fuel type can be used by the three platforms, primarily by the incumbent and the hybrid platform.

4. Formation of fuelling infrastructure F2 [A] - Includes the processes for the formation of fuelling infrastructure of fuel type 2 (electricity) in the advanced region. This type of fuel is used by the radical platform.


7. Adoption and demographics Region B - Includes the decision making process of consumers in the emerging region, as well as the demographic and economic variables.

8. Formation of fuelling infrastructure F1 [B] - Includes the processes for the formation of fuelling infrastructure of fuel type 1 (gasoline) in the emerging region. This fuel type can be used by the three platforms, primarily by the incumbent and the hybrid platform.

9. Formation of fuelling infrastructure F2 [B] - Includes the processes for the formation of fuelling infrastructure of fuel type 2 (electricity) in the emerging region. This type of fuel is used by the radical platform.


In the following section some examples of relevant causal structures in the model are presented:
I.1 DEVELOPMENT OF VEHICLE PLATFORMS

From allocation of resources to knowledge

- Potential knowledge spillover to pj-pk
- Time for knowledge to spread
- Strength of knowledge spillovers pj-pi
- Strength of knowledge spillovers pk-pi
- Effective advancement of knowledge pi

Knowledge pi

- Returns to resource allocation pi
- Reference resources pi
- Initial knowledge pi
- Required knowledge for technology development
- Initial stage learning curve pi
- Learning coefficient technology development pi
- Rate of development pi

OEMS resources allocated to pi

<Required knowledge for technology development>

<Required knowledge for technology development>

<Potential knowledge spillover to pi-pj>

<Potential knowledge spillover to pi-pk>

<Substitutability of K from pj to pi>

<Substitutability of K from pk to pi>

<Effective advancement of knowledge pi>

<Strength of knowledge spillovers pj-pi>

<Strength of knowledge spillovers pk-pi>
From vehicle sales to allocation of R&D resources
From sales to accumulation of experience

- Experience pi
  - <Sales of vehicles pi [A]>
  - <Sales of vehicles pi [B]>
  - Gain in experience pi
  - Initial experience with pi
  - Returns of experience to technology cost pi
  - The effect of experience on technology development pi

- Experience pj
  - <Sales of vehicles pj [A]>
  - <Sales of vehicles pj [B]>
  - Gain in experience pj
  - Initial experience with pj
  - Returns of experience to technology cost pj
  - The effect of experience on technology development pj
  - Required experience for technological development

- Experience pk
  - <Sales of vehicles pk [A]>
  - <Sales of vehicles pk [B]>
  - Gain in experience pk
  - Initial experience with pk
  - Returns of experience to technology cost pk
  - The effect of experience on technology development pk
  - <Required experience for technological development>
I.2 ADOPTION AND DEMOGRAPHICS

From vehicle’s attributes to utility

Utility of pj [A]
Fuel attractiveness of pj [A]
Utility derived from cost of pj [A]
Utility derived from fuel attractiveness of pj [A]
Utility derived from driving range of pj [A]
Imp of price of pi, pj, pk for consumers [A]
Imp of fuel attractiveness of pi, pj, pk for consumers [A]
Imp of driving range of pi, pj, pk for consumers [A]
Value of cost of pj to GDP PPP [A]
Value of fuel attractiveness of pj [A]
Value of driving range ofpj [A]
Compared driving range of pj [A]
Compared fuel attractiveness of pj [A]
Compared cost of pj to GDP PPP [A]
Fuel attractiveness of pi [A]
Fuel attractiveness of pk [A]
Fuel efficiency of pj [A]
Effective average kms driven by vehicle fleet pj [A]
Effective average kms driven by vehicle fleet pi [A]
Effective average kms driven by vehicle fleet pk [A]
Purchasing price pj
Purchasing price pk
Purchasing price pi
GDP per capita [A]
Price of fuel for F1 [A]
Effective average kms driven by vehicle fleet pk [A]
Compared technology cost pj
Value of compared technology cost pj
Value of cost of pj [A]
Value of compared technology cost pj
Value of cost of pj [A]
Perceived utility of drivers of pj about pj [A]
WtC pj by drivers of pj [A]
Value of compared technology cost pj
Value of cost of pj [A]
From perceived utility to adoption decisions
1.3 FUELLING INFRASTRUCTURE

From fuelling infrastructure to driving range

- Effective average kms driven by vehicle fleet $pi$ [$A$]
- Total fuel demand for $F1$ [$A$]
- Effect of coverage on driven kms $F1$ [$A$]
- Desired average kms driven in [$A$]
- [Fuel station capacity $F1$ [$A$]]
- Induced driven kms by GDP per capita growth $pi$ [$A$]
- [Growth of GDP per capita [$A$]]
- Net change in fuel supply $F1$ [$A$]
- Effect of GDP per capita on driven kms [$A$]
- Effect of coverage on marginal change of fuel supply $F1$ [$A$]
- Marginal change in fuel supply $F1$ [$A$]
- Coverage of required fuel market $F1$ [$A$]
- Required fuel market $F1$ for full driving range [$A$]
- [Fuel efficiency of $pi$]
- [Fuel demand of $pk$ for $F1$ [$A$]]
- [Fleet of vehicles $pj$ [$A$]]
- [Fuel efficiency of $pj$]
- Effect of GDP per capita on driven kms [$A$]
- [Fleet of vehicles $pi$ [$A$]]
- Desired average kms driven in [$A$]
From fuel demand to entering and exiting of fuel stations
1.4 SOCIAL LEARNING

- Share of potential market pj [A]
- Word of mouth of drivers pj [A]
- Effectiveness of marketing for pj [A]
- Word of mouth from non drivers pj [A]
- Strength of WoM of drivers of pj [A]
- Strength of WoM between non drivers of pj about pj [A]
- WtC pj by non drivers of pj [A]
- Gain in WtC due to social exposure pj [A]
- Loss in WtC due to social exposure pj [A]
- Base WtC loss rate pj [A]
- WtC pj by drivers of pj [A]
- Share of non drivers of pj [A]
- Initial WtC pj by non drivers of pj [A]
- Potential vehicle market [A]
- Fleet of vehicles pj [A]

The effect of social exposure on WtC loss pj [A]
II. SENSITIVITY AND BEHAVIOURAL ANALYSIS

This section presents a detail sensitivity and behavioural analysis of the contextual scenarios reviewed in this research.

II.1 SCENARIO 2

This section presents the behavioural analysis of scenario 2 (Figure 36). This scenario indicates that the preference structure of the car manufacturer is balanced oriented, which means that it allocates equal resources to the development of each vehicle platform ($\lambda_{\text{market dominance}}=0$, $E_{\text{incumbent}}=1/3$, $E_{\text{hybrid}}=1/3$, $E_{\text{radical}}=1/3$, Equation 9). Finally, this scenario takes a conservative view on the technology potentials of the three vehicle platforms (learning coefficients=40%). And, initially the incumbent platform is considered to be a mature technology, while the alternative platforms are considered to young technologies.

As a point of departure, the preference structure of consumers in both regions is considered to be price oriented. This means that consumers only consider the price of vehicle platforms in their purchasing decisions ($\lambda_{\text{purchasing price}}=1$, $\lambda_{\text{operational cost}}=0$, $\lambda_{\text{driving range}}=0$, Equation 1). First, the behaviour of this case is explained first. Afterwards, the effect of market heterogeneity is explored in scenario 2.

In scenario 2, initially more resources are allocated to the development of the alternative platforms than in scenario 1, because an equal and constant amount of resources is allocated to the development of the three vehicle platforms. In scenario 2, even when consumers are price oriented in both regions, the transition towards hybrid vehicles occurs earlier (Figure 37) than in scenario 1. This happens because the
hybrid platform develops at a faster rate than in the previous scenario. This gives the hybrid platform the opportunity of activating the mechanisms of change in its favour; especially, by reducing its purchasing price through experience and scale driven changes (chapter 2, section 2.7.1). The dynamics of change for the hybrid platform are not different from what has already been discussed in scenario 1. However, an interesting thing in this transition path is that the radical platform fails in both markets. Why does this happen if both platforms receive equal amount of resources to be developed?

This occurs because the hybrid platform is a more mature technology than the radical platform. In this scenario, both technologies are considered to have the same development potential (learning coefficient=40%). However, the hybrid platform is ahead than the radical platform in the learning curve. Therefore, even though both platforms receive equal amount of resources, the hybrid platform has an initial advantage that the radical cannot overcome. This is more accentuated when consumers in both regions are price oriented. Figure 38 shows how the purchasing prices of the different platforms evolve in this scenario. In contrast to scenario 1, the radical and the hybrid platform reduce their price differences with the incumbent platform.

Figure 37. Diffusion of alternative vehicle platforms: scenario 2, price oriented consumers
So far, the behaviour of scenario 2 shows that the preference structure of the car manufacturer can influence favourably the diffusion of the hybrid platform. Perhaps, a first question to explore in this scenario, before analyzing the impact of market heterogeneity, is: how different the preference structure of the car manufacturer has to be, in comparison to scenario 1, to create such conditions for the hybrid platform? These are side observations to the main focus of the research, which is market heterogeneity. However, it is important to analyze this aspect of the transition context to gain a better understanding of it.

In order to answer this question, a simulation experiment of 50 different instances is used. This is done by creating a vector $\alpha = \{0, ..., 1; \Delta = 0.05\}$, such as in each simulation experiment, the preference structure of the car manufacturer is as follows: $\lambda_{\text{market dominance}} = 0 + \alpha \ E_{\text{incumbent}} = 1/3, \ E_{\text{hybrid}} = 1/3, \ E_{\text{radical}} = 1/3$, for all elements in $\alpha$. The extreme case of this experiment is when the car manufacturer is a market driven investor, which is scenario 1. The results of this experiment (Figure 39, Figure 46 annexes) show that there is a decreasing sensitivity to changes in the preference structure of the car manufacturer. For example, the first line apart from the behaviour line of scenario 1, in Figure 39, corresponds to a preference structure in which market dominance represents 90% of the allocation decision of the car manufacturer, and it already shows a noticeable deviation from scenario 1. The dynamics behind this behaviour are quite interesting. If the share of sales of each vehicle platform becomes a less dominant factor for the resource allocation decision of the car manufacturer, the hybrid platform can access resources that can improve its overall performance (R&D resource driven change). As the hybrid platform becomes more attractive for consumers, it can benefit earlier from experience and scale driven
changes, and thus, become more competitive against the incumbent platform (Figure 46, annexes). The important point to notice in these runs is that the diffusion of the hybrid platform is quite responsive to initial stimulus to its development. On the contrary, the radical platform requires a greater stimulus to overcome its disadvantages against the incumbent and hybrid platforms.

![Figure 39](image.png)

**What is the effect of market heterogeneity in scenario 2?** The effect of changes in the preference structure of consumers in advanced region is treated first. For this first experiment, the preference structure of consumers in the emerging region is defined as price oriented, and 67 different instances are simulated for the preference structure of consumers in the advanced region. This is done by using a vector \( \alpha = \{0, ..., 0.37; \Delta = 0.01\} \), such as, in each simulation run the preference structure of consumers in the advanced region is as follows: \( \lambda_{\text{purchasing price}} = 1 - \alpha \), \( \lambda_{\text{operational cost}} = 0 + \alpha/2 \), \( \lambda_{\text{driving range}} = 0 + \alpha/2 \) for all elements in \( \alpha \). The extreme case of this experiment is when consumers of the advanced region are proficiency oriented.

The results of this experiment (Figure 47 annexes) show that as consumers in the advanced region become more proficiency oriented, the diffusion of the hybrid platform in the advanced region is accelerated. This occurs because a greater share of consumers in the advanced region is interested in acquiring the hybrid platform due to its low operational cost. If consumers are proficiency oriented, the competition between the hybrid and the incumbent platforms is more balanced. This encourages the technological improvement and diffusion of the hybrid platform in the advanced region. In addition, the levels of diffusion of the radical platform are also improved (Figure 40). This happens because the car
manufacturer supports its development and because the operational cost of the radical platform also results attractive to proficiency oriented consumers in the advanced region.

The volume sales of the alternative vehicle platform in the advanced region fosters a reduction in their purchasing price, due to the accumulation of experience and the presence of economies of scale. This reduction in the purchasing price of the alternative vehicle platforms fosters their diffusion in the emerging region. In particular, the boost of the radical platform in the advanced region also accelerates the process of adoption of the radical platform in the emerging region. However, the purchasing price of the radical platform never is such that its diffusion can be sustained in the emerging region (Figure 48 annexes). Therefore, its diffusion in the emerging region never reaches significant levels.

So far, the analysis of scenario 2 shows that market heterogeneity generates another alternative diffusion pattern. The results of the experiment reviewed in this section show that, when the preference structure of consumers in the advanced region is more inclined towards proficiency than the preference structure of consumers in the emerging region. Then, both the hybrid and the radical platform are diffused in the advanced region. While in the emerging region only the hybrid platform succeeds. This alternative diffusion pattern is summarized in

Table 8, and it is shown in Figure 41.
Table 8 Alternative diffusion patterns in scenario 2

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Full diffusion of the hybrid platform in the advanced region, followed by the emerging region. Initiation of diffusion process of the hybrid platform in the advanced region, failure of the radical platform in the emerging region (Figure 41).</td>
<td>• Difference in consumers’ preferences: Proficiency oriented consumers in the advanced region, price oriented consumers in the emerging region.</td>
<td>• Balanced investor</td>
<td>• Conservative technological potentials</td>
</tr>
</tbody>
</table>

The analysis now turns to the emerging region. For this experiment, the preference structure of consumers in the advanced region is set as price oriented. For the preference structure of consumers in the emerging region 67 different instances are simulated. This is done by using a vector $\beta = \{0, ..., 0.37; \Delta = 0.01\}$, such as in each simulation run, the preference structure of consumers in the
emerging region is as follows: $\lambda_{\text{purchasing price}} = 1 - \beta$, $\lambda_{\text{operational cost}} = 0 + \beta/2$, $\lambda_{\text{driving range}} = 0 + \beta/2$. The most extreme case in this experiment is when consumers of the emerging region are proficiency oriented.

The results of this experiment show that, in contrast to scenario 1, the early support of the car manufacturer to the development of the hybrid and radical platforms accelerates even more their diffusion process in the emerging region (Figure 51, annexes). In the most extreme cases, the effect is such that the radical platform is able to enter the market quicker and compete with the hybrid platform in the emerging region (Figure 52, annexes). This occurs when the purchasing price of radical platform reaches a level, such that combined with its much lower operational cost, in comparison to the hybrid and incumbent technology, offsets its disadvantages in terms of driving range and purchasing price. The mechanisms of change that boost this reduction in the purchasing price are scale and experience driven changes. This experiment shows that when the preference structure of consumers in the emerging region is inclined towards proficiency, then the radical platform starts its diffusion process earlier in the emerging region than in the advanced region. Once again, this effect is explained by the increasing number of new vehicles sales in the emerging region, which give an opportunity for the radical platform to quickly increase its presence in the market (Figure 42).

![Figure 42. New sales of vehicles in advanced and emerging region, scenario 2 sensitivity](image)

The results of this experiment show that it is possible to find an additional alternative diffusion pattern when the preference structure of consumers in the emerging region is more inclined towards proficiency than the preference structure of consumers in the advanced region. In this case, due to difference in consumers’ preferences and observed market difference, the diffusion of AVPs in the emerging region occurs at a larger extent than in the advanced region. The main feature of this diffusion pattern is that the radical platform starts a strong diffusion process in the emerging region, while it stagnates in the advanced region (Table 9).
Table 9. Alternative diffusion patterns in scenario 2

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
</table>
| C. Success of the hybrid platform and strong initial diffusion of the radical platform in the emerging region. Success the hybrid platform and failure of the radical platform in the advanced region  (Figure 43) | • Observed market difference: Rate of growth of vehicle market in the emerging region  
• Difference in consumers’ preferences: Proficiency oriented consumers in the emerging region, price oriented consumers in the advanced region. | • Balanced investor | • Conservative technological potentials |

The effect of market heterogeneity has been discussed separately for the advanced and the emerging region, but still a deeper exploration is necessary. For the following experiment, the same methodology as in the case of scenario 1 is followed. For this experiment, 200 instances are simulated using a sample of all the possible combinations of the vectors α and β.
The behaviour envelops of this experiment for the hybrid platform (Figure 55, Figure 56, annexes) provide general interesting insights into the dynamics of the system in scenario 2. First, if the car manufacturer behaves as a balanced investor, then it is quite likely that the hybrid platform diffuses in both the advanced and the emerging economy. Second, difference in consumers’ preferences in scenario 2 can accelerate this process of diffusion. However, depending on the consumers’ preference structure in each region, different alternative diffusion patterns emerge. On the contrary, the behaviour envelops for the radical platform (Figure 44) show that under scenario 2, the conditions for the diffusion of the radical platform are more favourable in the emerging region than in the advanced region. However, success in the sustain diffusion of the radical platform is hard to achieve and it is only likely to occur when the preference structure of consumers in the emerging region is significantly inclined towards proficiency.

This finalizes the analysis of scenarios that considered conservative technological development potentials for the three vehicle platforms. The behavioural analysis of these two sections has shown interesting results of the effect of market heterogeneity in the diffusion of alternative platforms. First, the observed market difference generates a delay in diffusion of the hybrid platform in the emerging region that cannot be overcome, regardless of variations in the preference structure of consumers in both regions. Two, difference in consumers’ preferences can influence importantly diffusion patterns of the alternative platforms. The more consumers are inclined towards proficiency, the more opportunities for the diffusion of the alternative platforms exist. Two, the allocation of earlier resources to the development of the alternative platforms can increase significantly their odds of success in both markets. This is especially true for the case of the radical platform, which finds a strong niche for development in the emerging region, where the rate of new sales is considerably greater than in the advanced region (observed market difference). Nevertheless, cases in which the radical platform manages to reach levels of sustain adoption are scarce and only occur when consumers in the emerging region have a preference structure that is notably proficiency oriented.

How much these results can change if the technological potential of the incumbent platform and the alternative platform differ from what has been considered until now? This is discussed next.
Figure 44 Behaviour envelopes share of radical platform in advanced region and emerging region
Composition of Vehicle Market in B

Figure 45

Figure 46
Figure 47

Figure 48
Figure 49

Composition of Vehicle Market A

Figure 50

Composition of Vehicle Market in B
Scenario 3

Figure 51

Figure 52
Composition Vehicle Market A

Composition Vehicle Market in B

Figure 53

Figure 54
Figure 55

Figure 56
II.2 SCENARIO 3

In scenarios 1 and 2, the technological potential of the three vehicle platforms is considered conservative. The incumbent vehicle platform is considered to be a mature technology with little extra potential to exploit. The alternative vehicle platforms are considered to be young technologies with ample potential to exploit. However, the analysis of transition paths towards alternative vehicle platforms forcefully requires of an ample consideration in this regard. For this reason, in the following sections the boundary of analysis is expanded to explore different technological scenarios. This is done to gain a better understanding of the effects of market heterogeneity on the diffusion of alternative vehicle platforms.

In previous scenarios, the incumbent platform is considered to be quite ahead its learning curve. However, this may not be the case. For example, according to IEA (2008), the fuel efficiency of internal combustion engine vehicles can still progress to a point where it can match the fuel efficiency of current hybrid vehicles. Also, the IEA (2008) argues that internal combustion engine vehicles can be expected to become considerably cheaper and more fuel efficient, due to the combination of enhance fuel efficient engines with small and light vehicle designs. These technological considerations have been conceptualized in this analysis by using the initial position of the incumbent platform in its learning curve. If the initial position of the incumbent technology is set to an earlier position than in scenarios 1 and 2, it is possible to depict an incumbent platform that indeed becomes cheaper and more fuel efficient.
efficient than in the previous scenarios. This is done in scenario 3 in which the context of a high potential incumbent platform is explored (Figure 58).

Scenario 3 also indicates that the preference structure of the car manufacturer is of a market driven investor, which means that it allocates resources to the development of each vehicle platform based on the individual share of sales of each platform \( \lambda_{\text{market dominance}}=1, E_{\text{incumbent}}=0, E_{\text{hybrid}}=0, E_{\text{radical}}=0 \), Equation 9). Finally, the initial position in the learning curve of the incumbent platform is set to 50%. In contrast to the scenarios 1 and 2, in this scenario the incumbent vehicle platform has more scope for development. As in previous scenarios, the alternative platforms are considered to be young technologies with the same technological potential (initial position hybrid=20%, initial position radical=0%, learning coefficients=40%).

Similarly to previous sections, the exploration of scenario 3 begins by considering that the preference structure of consumers in both regions is price oriented. In this case, due to its high technological potential, the competitive position of the incumbent platform is strengthened against the possible entry of the alternative platforms. It occurs that the alternative platforms are not diffused in none of the regions (Figure 66 and Figure 67, annexes). This occurs basically because the price of the alternative platforms never becomes competitive enough to hinder the position of the incumbent platform. In contrast, the incumbent platform reduces its purchasing price considerably, increasing the gap between its purchasing price and that of the alternative platforms, as shown in Figure 59.
The constant decline of the purchasing price of the incumbent platform, especially during the first decade of the simulation, causes that consumers driving the hybrid platform switch to the incumbent platform (Figure 60). In addition, all new vehicle sales in the advanced, and more importantly, in the emerging region go for the incumbent technology (Figure 68, annexes). Therefore, the alternative platforms never manage to access enough resources for their development. This sustains the system’s lock-in with the incumbent platform.
This special case of diffusion, in which the alternative platforms fail in both regions, is another special case of diffusion that shows the importance of the preference structure of consumers and the contextual circumstances. This case is summarized in Table 10.

**Table 10. Special diffusion patterns in scenario 3**

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Factor influencing the diffusion pattern</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>II. Fail of alternative platforms in both regions</td>
<td>• Price oriented consumers in both regions.</td>
<td>• Market driven investor</td>
<td>• High potential incumbent platform</td>
</tr>
</tbody>
</table>

There is no doubt that the maturity of the incumbent platform is an important factor to consider in this transition case. One important question to ask at this moment is: how different, from previous scenarios, the maturity of the incumbent platform has to be for creating such an effect of permanent lock-in?

To answer this question, 30 instances are simulated by changing the the level of maturity of the incumbent platform. This is done by using a vector $\alpha = \{0.5, \ldots, 0.8; \Delta = 0.01\}$, such that in every simulation run, the level of maturity of the incumbent platform is equal to $\alpha$, for all elements in $\alpha$. The most extreme case of this experiment is when the incumbent technology is considered to have the same maturity level as in scenario 1.

The results of this experiment indicate that the diffusion of the alternative platforms in this scenario is quite sensitive to changes in the level of maturity of the incumbent technology (Figure 69 and Figure 70, annexes). In fact, when consumers are price oriented, the level of maturity of the incumbent platform only needs to be 5% less to be able to block the diffusion of the alternative platforms. This occurs because the incumbent platform has an enormous initial advantage over the alternative platforms in terms of resource allocation and purchasing price. Therefore, the incumbent platform counts with more than enough resources to realized its new potential, which further increases the gap in terms of purchasing price with the alternative platforms.

**How market heterogeneity can change the diffusion patterns presented so far for scenario 3?** Similarly to previous cases, the analysis begins with the advanced region. For this purpose, the preference structure of consumers in the emerging region is set as price oriented, but for the case of the preference structure of consumers in the advanced region 67 different instances are simulated. This is done by using a vector $\alpha = \{0, \ldots, 0.37; \Delta = 0.01\}$, such as in each simulation run, the preference structure of
consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1 - \alpha$, $\lambda_{\text{operational cost}} = 0 + \alpha/2$, $\lambda_{\text{driving range}} = 0 + \alpha/2$, for all elements in $\alpha$. The extreme case of this experiment is when consumers of the advanced region are proficiency oriented.

The results of the experiment show three interesting things. First, that the incumbent platform can still be displaced by the hybrid platform if consumers in the advanced region are proficiency oriented. However, in contrast to the case where the incumbent platform is considered to be a mature technology (scenario 1 and 2), in this scenario, there are fewer cases in which the hybrid platform diffuses in the advanced region. For this to happen, consumers need to be considerably proficiency oriented (Figure 61). Second, the radical platform does not succeed in any case in this experiment (Figure 71, annexes). Third, the diffusion of the hybrid platform can still be possible in the emerging region where price oriented consumers exist, but it can only occur when the diffusion in the advanced region is such that the mechanism of change (R&D driven change, experience driven change, scale driven change) work in favour of the hybrid platform to make it more attractive for consumers in the emerging region. Nevertheless, in this case, the delay in diffusion increases and for many years the hybrid platform remains stagnated in the emerging region (Figure 72, annexes).

**What occurs if consumers’ preference structure in the emerging region changes towards proficiency?**

For this experiment, the preference structure of consumers in the advanced region is kept as price oriented, and for the case of the preference structure of consumers in the emerging region, 67 different instances are simulated. This is done by creating a vector $\beta = \{0, \ldots, 0.37; \Delta = 0.01\}$, such as in each simulation run, the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing}}$
price\(=1-\beta\), \(\lambda_{\text{operational cost}}=0+\beta/2\), \(\lambda_{\text{driving range}}=0+\beta/2\), for all elements in \(\beta\). The extreme case of this experiment is when consumers in the emerging region are proficiency oriented.

Similarly to the results of the previous experiment, the analysis shows that there is only a few number of cases in which the hybrid platform reaches a level of significant diffusion in the emerging region (Figure 62). If the preference structure of consumers in the emerging region is inclined towards proficiency it is possible to reach a level of sales of the hybrid platform that can activate the mechanisms of change in its favour, by reducing the purchasing price of the hybrid platform (Figure 73, annexes). Consumers in the advanced region are very responsive to changes in the purchasing price of the hybrid platform. However, by the time the volume of sales of the hybrid platform in the emerging region manages to reduce its purchasing price, the advanced region has already lost considerable time, and the market share of the hybrid maintains at very low levels throughout the simulations (Figure 74, annexes). In contrast to the previous experiment, in this case the hybrid platform can only be diffused significantly in the emerging region. Moreover, proficiency oriented consumers in the emerging region encourage the diffusion of the radical platform, reducing even more the share of the incumbent platform (Figure 75, annexes).

![Figure 62](image)

The dynamics behind the results of this experiment are very interesting. In this scenario of high potential of the incumbent platform, the two attributes that the incumbent platform can improve are: its purchasing price and its operational cost. The purchasing price is an important factor that makes the incumbent platform more competitive than the alternative platforms, but this is just temporary. If consumers are proficiency oriented in the emerging region, as they become wealthier, the advantage of price of the incumbent platform diminishes. This encourages consumers in the emerging region to
purchase the hybrid platform, but also to some extend the radical platform. In this case, again, new to industry vehicle sales (observed market difference) in the emerging region play a major role in changing the structure of the vehicle market. The increasing number of new sales in the emerging region allow for a more rapid change in the allocation of R&D resources. These resources boost the improvement of the alternative platforms by reducing their purchasing prices and by increasing their fuel efficiency. The fuel efficiency of the alternative platforms widens their difference in terms of this attribute with the incumbent platform. Since consumers are proficiency oriented, this reduces even more the competitive advantage of price of the incumbent platform over the alternative platform. This is another alternative diffusion pattern (Table 11).

Table 11. Alternative diffusion patterns in scenario 3

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Success of the hybrid and the radical platforms in the emerging region. Failure of the hybrid and radical platforms in the advanced region (Figure 63)</td>
<td>• Observed market difference: Rate of growth of vehicle market in the emerging region • Difference in consumers’ preferences: Proficiency oriented consumers in the emerging region, price oriented consumers in the advanced region.</td>
<td>• Market driven investor</td>
<td>• High potential incumbent platform</td>
</tr>
</tbody>
</table>

Figure 63. Alternative diffusion patterns scenario 3
So far, the effect of market heterogeneity has been discussed separately for each region. However, it is also important to consider several combinations of difference in consumers’ preferences. Moreover, in combination with difference in consumers’ preferences, a richer exploration of scenario 3 needs to consider also different cases of maturity for the incumbent platform. For this reason, 500 different instances are simulated. This is done by randomly creating simulation instances resulting of combining the following three vectors. For the preference structure of consumers in the advanced region, a vector $\alpha = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1-\alpha$, $\lambda_{\text{operational cost}} = 0+\alpha/2$, $\lambda_{\text{driving range}} = 0+\alpha/2$. For the preference structure of consumers in the emerging region, there is a vector $\beta = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}} = 1-\beta$, $\lambda_{\text{operational cost}} = 0+\beta/2$, $\lambda_{\text{driving range}} = 0+\beta/2$. Finally, there is a vector $\gamma = \{0.4, ..., 0.6; \Delta = 0.01\}$, such as the maturity level of the incumbent platform is equal to $\gamma$.

The first issue to notice is the spread of the results in this experiment. The behaviour envelops for this experiment show that effect of market heterogeneity in diffusion patterns of the alternative platforms becomes more uncertain if the incumbent platform has a more ample scope for development. For the case of the market share of the hybrid platform in the advanced region, it is possible to see that if the incumbent platform has a major technological potential than in previous scenarios, then this complicates the diffusion of the hybrid platform; generating mainly two types of behaviour: 1) successful diffusion of the hybrid platform or 2) failure of the hybrid platform (Figure 64, end states histogram). Of course successful diffusion only occurs when consumers are significantly proficiency oriented in the advanced region, or in both.

A similar type of behaviour results for the case of the hybrid platform in the emerging region (Figure 78, annexes). An important aspect to notice in this experiment is that, when consumers in both regions are proficiency oriented. The early diffusion of the hybrid platform in the advanced region accelerates the diffusion process of the hybrid platform in the emerging region. However, this only occurs in a minority of the cases, again only when consumers in both regions are noticeably proficiency oriented.

Perhaps the most interesting case of the effect of market heterogeneity in scenario 3 is the fact that only in the emerging region the radical platform has a chance to start its diffusion process. The behaviour envelops for this case show that the greater the potential of the incumbent platform, the more difficult the diffusion of the radical platform, only occurring in the emerging region when consumers are
noticeably proficiency oriented (Figure 65), and always failing in the advanced region (Figure 79, annexes).

This finalizes the behavioural analysis for scenario 3. The following section deals with scenario 4.
Figure 66

Composition of Vehicle Market A

Time (Year)

0 5 10 15 20 25 30 35 40 45 50

0 0.25 0.5 0.75 1

Figure 67

Composition of Vehicle Market B

Time (Year)

0 5 10 15 20 25 30 35 40 45 50

0 0.25 0.5 0.75 1
Figure 68

New sales in B

Figure 69

Share of potential vehicle market to pj [A]
**Figure 70**

**Figure 71**
Scenario 5: Sensitivity

"Share of potential vehicle market to pj [A]"

0.04
0.03
0.02
0.01
0
0
0
12.5
25
37.5
50
Time (Year)

Figure 74

Scenario 5: Sensitivity

"Share of potential vehicle market to pk [B]"

0.2
0.15
0.1
0.05
0
0
0
12.5
25
37.5
50
Time (Year)

Figure 75
Figure 76

Composition of Vehicle Market A

Figure 77

Composition of Vehicle Market in B
Scenario 3 is without doubt the most unfavourable scenario for the diffusion of the alternative vehicle platforms. In this scenario, the incumbent platform hoards most of the resources for R&D because the car manufacturer behaves as a market driven investor. This gives an enormous advantage to the incumbent platform over the alternative platforms. In this section, the effects of market heterogeneity...
are explored in scenario 4 (Figure 80), in which the car manufacturer supports equally the development of the three platforms.

The analysis of scenario 4 begins by considering that in both regions the preference structure of consumers is price oriented. The base run for this case shows that diffusion of the hybrid platform takes place in both regions. However, in a level that maintains the incumbent platform as the dominant option in both markets. The radical platform in this base run fails in both markets (Figure 85 and Figure 86, annexes). As in the case of scenario 3, the reduction in the purchasing price of the incumbent platform strengthens its position. However, the support of the car manufacturer to the other two platforms helps bridging the gap between the purchasing price between the alternative platforms and the incumbent platform. This is only beneficial in the case of the hybrid platform because its volume of sales becomes such that it can activate in its favour the experience and the scale driven changes, further reducing its purchasing price and sustaining its own diffusion (Figure 81). Therefore, in this case, already a drastic change from scenario 3 to scenario 4 is observable. In the former the alternatives platforms fail, in the later, the hybrid platform is diffused in both regions.
How important difference in consumers’ preferences can be in scenario 4, in which the car manufacturer is a balanced investor? In this regard, there is no reason to believe that dynamics resulting of this experiment will differ from what has already been presented in the previous section for scenario 5 and scenario 6. For this reason, instead of conducting independent experiments for each region, in this experiment, both regions are considered in the same experiment. Therefore, for this experiment, 200 instances are simulated. These instances are set by combining the following two vectors: a vector $\alpha = \{0, ..., 0.67; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}}=1-\alpha$, $\lambda_{\text{operational cost}}=0+\alpha/2$, $\lambda_{\text{driving range}}=0+\alpha/2$ and a vector $\beta = \{0, ..., 0.67; \Delta = 0.01\}$, such as the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}}=1-\beta$, $\lambda_{\text{operational cost}}=0+\beta/2$, $\lambda_{\text{driving range}}=0+\beta/2$.

The results of this experiment show that the behaviour of the system is quite robust for the hybrid platform in this scenario. On the one hand, in scenario 4, the hybrid platform always diffuses in both regions. Difference in consumers’ preferences can accelerate or slow down the process of diffusion in each region, depending on the preference structure of its consumers (Figure 82, Figure 88 annexes). However, in cases in which the preference structure of consumers in the emerging region is more inclined towards proficiency than the preference structure of consumers in the advanced region. Then, the hybrid platform is diffused first in the emerging region than in the advanced region. On the other hand, the odds of the radical platform in this scenario are even worse than in the case of scenarios 3 (Figure 83, Figure 89 annexes). In this case, as in all previous cases, if the radical platform diffuses, this occurs first in the emerging region, and afterwards in the advanced region. However the odds of its...
success are reduced in this scenario. A technological aspect is responsible of this; as previously described, initially the radical platform cannot drive solely using its own fuel because the storage capacity of batteries is quite limited. Therefore, it also needs to use the fuel and fuelling infrastructure of the incumbent platform. Initially this is an advantage for the radical platform because its driving range is not reduced by the inexistence of the alternative fuelling infrastructure. However, when the storage capacity of batteries improves enough to power the radical platform entirely using electricity, the driving range of the radical platform becomes much smaller than the driving range of the incumbent and hybrid platform (Figure 87 and Figure 90, annexes). At this point the lack of infrastructure slows down the diffusion process of the radical platform, since it requires building its fuelling infrastructure to continue its diffusion (Fuel infrastructure driven change, Figure 8).

![Figure 82](diagram1.png)

![Figure 83](diagram2.png)
The results of this broad experiment show that there is another family of alternative diffusion patterns. In this case, the emerging region leads diffusion of the hybrid platform. In the case of the radical platform, this stagnates in the emerging region, and fails in the advanced region. This is shown in Table 12 and Figure 84.

Table 12 Alternative diffusion patterns scenario 4

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Earlier diffusion of the hybrid platform in emerging region than in the advanced region. Limited diffusion of radical platform in emerging region. Failure of radical platform in advanced region</td>
<td>- Difference in consumers’ preferences: Proficiency oriented consumers in the emerging region, price oriented consumers in the advanced region.</td>
<td>- Balanced investor</td>
<td>- High potential incumbent platform</td>
</tr>
</tbody>
</table>

Figure 84 Alternative diffusion patterns scenario 4

The results of analyzing scenarios 3 and 4 show that variations in the technological potential of the incumbent platform create enormous disturbances in the diffusion of the alternative platforms. If the incumbent platform has more potential to develop than originally expected, this becomes a strong entry barrier for the alternative platforms. This effect is so strong that only in cases where consumers of both regions are considerably proficiency oriented, significant diffusion occurs in both regions. This barrier is accentuated when the car manufacturer behaves as a market driven investor. However, as soon as the
car manufacturer starts allocating resources to the development of the alternative platforms, these can quickly progress and become more attractive to consumers that are not price oriented, increasing the overall opportunity for diffusion of the hybrid platform. The radical platform faces greater difficulties for diffusion. It solely manages to reach a level of sustained diffusion in the emerging region, and only in cases in which consumers are proficiency oriented and the car manufacturer is a balanced investor, reducing the cases in which diffusion is possible to just a few.

![Composition Vehicle Market A](image)

Figure 85
Figure 86

Composition of Vehicle Market in B

Figure 87

Composition of Vehicle Market in B
Figure 88

Scenario 4 Sensitivity
- "Share of potential vehicle market to pj [B]"

Figure 89

Scenario 4 Sensitivity
- "Share of potential vehicle market to pk [A]"
II.4 SCENARIO 5

The following scenarios consider a hybrid platform that has much more potential than in the previous cases (learning coefficient=100%), actually the maximum possible for this system. The technological potential of the other two platforms is considered to be the same as in scenario 1. This means that the incumbent platform is considered to be a mature technology, and the radical platform is considered to have conservative technological potential (learning coefficient=40%). This first section deals with scenario 5. In this scenario in addition to the high potential of the hybrid platform, the preference structure of the car manufacturer is that of a market driven investor (Figure 91).

![Graph of effective average kms driven by vehicle fleet](image)

**Figure 90**

**Figure 91. Scenario 5: High potential hybrid platform and car manufacturer as market driven investor**
In this scenario, initially consumers in both regions are considered to be price oriented. This base run shows that the hybrid platform quickly outpaces the incumbent platform in terms of purchasing price (Figure 92). This accelerates the transition towards the hybrid platform in both regions (Figure 97 and Figure 98, annexes). The drastic reduction of the purchasing price of the hybrid platform incentivises price oriented consumers to quickly switch to the hybrid platform, or to choose the hybrid over the incumbent platform in the case of new to industry vehicle sales (Figure 99, annexes).

![Cost of Vehicle Platforms](image)

**Figure 92**

Considering the hybrid platform to have such an extraordinary potential is, without doubt, extremely optimistic. The odds of this case being true are really narrow. However, the question is: how much better, from the reference case, the hybrid platform needs to be to have such a quick transition as in scenario 5? As in previous cases, several simulation runs are used to answer this question. For this experiment, **60 instances are simulated by changing the** learning coefficient of the hybrid platform. This is done by using a vector \( \alpha = \{0.4, ..., 1.0; \Delta = 0.01\} \), such that in each simulation run, the learning coefficient of the hybrid platform is equal to \( -\alpha \), for all elements of \( \alpha \).

The results of this experiment show that when the learning coefficient of the hybrid platform is at least equal to 75%, then, the market share of the hybrid platform in both regions reaches at least 50% by the end of the simulation runs (Figure 100 and Figure 101, annexes). Therefore, in scenario 5, if the preference structure of consumers in both regions is price oriented, then, in order to displace the incumbent platform the hybrid platform must have a considerable greater potential than the other platforms.
Previous experiments have shown that when the preference structure of consumers shifts from a price orientation towards a proficiency orientation, in the advanced region, the diffusion of the hybrid platform is favour. On the contrary, in the case of the emerging region, the diffusion of the radical platform is favour. Does this observation hold under these new scenarios, in which the hybrid platform has a greater technological potential?

To understand how difference in consumers’ preferences can influence diffusion patterns in this scenario, a new simulation experiment is used. For this experiment, 200 simulation runs are used. The simulation runs result of the combination of two vectors. There is a vector $\alpha = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1 - \alpha$, $\lambda_{\text{operational cost}} = 0 + \alpha/2$, $\lambda_{\text{driving range}} = 0 + \alpha/2$. And there is a vector $\beta = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}} = 1 - \beta$, $\lambda_{\text{operational cost}} = 0 + \beta/2$, $\lambda_{\text{driving range}} = 0 + \beta/2$.

The results of this experiment show that if the hybrid platform has such an extraordinary potential, the impact of market heterogeneity is reduced. This means that the levels and speed of diffusion of this platform does not change significantly whether consumers are price oriented or proficiency oriented (Figure 102 and Figure 103 annexes). An important difference from previous experiments is that the delay in the diffusion of the hybrid platform between the advanced and emerging region is considerably reduced when consumers are proficiency oriented in both regions (Figure 93). Actually it is overcome when consumers are proficiency oriented in the emerging region and price oriented in the advanced region. This occurs due to the combination of two effects. First, the drastic declined in the purchasing price of the hybrid platform facilitates the affordability of this platform for consumers in the emerging region. Second, the majority of new sales in the emerging region shifts from the incumbent platform towards the hybrid platform (Figure 99, annexes). This speeds up the process of diffusion of this platform in the emerging region to such an extent that it is possible to catch up with the advanced region.

In none of the cases, the radical platform succeeds, not even in the case in which consumers are proficiency oriented in both regions (Figure 104 and Figure 105, annexes). This occurs because the hybrid platform also overcomes really quickly the operational cost of the radical platform, which is the radical platform’s prime advantage over the other platforms (Figure 94, Figure 106 and Figure 107 annexes). Therefore, the radical platform cannot hoard significant resources for its development because, in these scenarios, the car manufacturer is market oriented.
The results of the former experiment show that it is possible to find new alternative diffusion patterns in scenario 5. First, if consumers in both regions are inclined towards proficiency, then there is a parallel diffusion of the hybrid platform in both regions. Second, if consumers of the emerging region are more inclined towards proficiency than consumers in the advanced region, then the diffusion of the hybrid platform occurs first in the emerging region and afterwards in the advanced region (Table 13). Additionally, in both cases, the radical platform fails in both regions.
Table 13 Alternative diffusion patterns in scenario 5

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Parallel process of diffusion of the hybrid platform in the advanced and emerging region. Initial growth and then failure of the radical platform in both regions (Figure 95)</td>
<td>• Observed market difference: Rate of growth of vehicle market in the emerging region (proficiency oriented consumers in both regions)</td>
<td>• Market driven investor</td>
<td>• High potential hybrid platform</td>
</tr>
</tbody>
</table>
| G. Earlier diffusion of the hybrid platform in the emerging region. Initial growth and then failure of the radical platform in both regions (Figure 108, annexes) | • Observed market difference: Rate of growth of vehicle market in the emerging region  
• Difference in consumers’ preferences: Proficiency oriented consumers in the emerging region, price oriented consumers in the advanced region. | • Market driven investor | • High potential hybrid platform |

Figure 95 Alternative diffusion patterns in scenario 5

Until this point the behaviour of scenario 5 is quite straightforward. If there is an incredibly superior hybrid platform, then it will dominate both markets. Difference in consumers’ preferences will only make this happen faster or slower for both regions. However, how different this story can turn if there is a
stronger incumbent platform coexisting with this high potential hybrid platform? Will market heterogeneity be more significant in this case?

For this new experiment, **1000 instances are simulated**, using four vectors for setting the simulation runs. There is a vector $\alpha = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1 - \alpha$, $\lambda_{\text{operational cost}} = 0 + \alpha/2$, $\lambda_{\text{driving range}} = 0 + \alpha/2$. There is a vector $\beta = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}} = 1 - \beta$, $\lambda_{\text{operational cost}} = 0 + \beta/2$, $\lambda_{\text{driving range}} = 0 + \beta/2$. There is a vector $\gamma = \{0.4, ..., 0.6; \Delta = 0.01\}$, such as the maturity level of the incumbent platform is equal to $\gamma$. And, there is a vector $\eta = \{0.75, ..., 1.0; \Delta = 0.01\}$, such that the learning coefficient of the hybrid platform is equal to $-\eta$.

The results of the experiment show more variance that in the previous case. The hybrid can succeed or fail depending on the conditions in which it competes against the incumbent platform. For example, its fails when consumers are price oriented and the incumbent platform has more potential to develop, it can succeed even though the incumbent platform has more potential, when consumers are proficiency oriented, or when the hybrid platform has a high technological potential (Figure 111 and Figure 113, annexes). On contrast, the radical platform always fails in both markets (Figure 96, Figure 112 annexes). This occurs because the hybrid becomes a superior platform than the radical platform in terms of operational cost and purchasing price. In fact, the results point to an interesting point. The greater the gap in the technological potential among the three platforms, the less important market heterogeneity becomes. For example, if there is vehicle platform that has a technological potential, which compared to the rest of the platforms, is much higher, then market heterogeneity does not influence diffusion patterns. On the other hand, when the technological potential of the three vehicle platforms is more balanced, then market heterogeneity is influential in diffusion patterns.
Figure 98

Composition of Vehicle Market in B

Figure 99

New sales in B
Figure 100

Scenario 9: Sensitivity

Share of potential vehicle market to p[j] [A]

Figure 101

Scenario 9: Sensitivity

Share of potential vehicle market to p[j] [B]
Figure 102

Scenario5Sensitivity
50% 75% 95% 100%
"Share of potential vehicle market to pj [A]"

Figure 103

Scenario5Sensitivity
50% 75% 95% 100%
"Share of potential vehicle market to pj [B]"
Figure 104

Figure 105
Compared operational cost

Time (Year)

Compared fuel attractiveness of pi [A] : Scenario9
Compared fuel attractiveness of pi [B] : Scenario9
Compared fuel attractiveness of pj [A] : Scenario9
Compared fuel attractiveness of pj [B] : Scenario9
Compared fuel attractiveness of pk [A] : Scenario9
Compared fuel attractiveness of pk [B] : Scenario9

Compared driving range

Time (Year)

Compared driving range of pi [A] : Scenario9
Compared driving range of pi [B] : Scenario9
Compared driving range of pj [A] : Scenario9
Compared driving range of pj [B] : Scenario9
Compared driving range of pk [A] : Scenario9
Compared driving range of pk [B] : Scenario9

Figure 106

Figure 107
Figure 108 Alternative diffusion patterns in scenario 5

Figure 109

Vehicle market share pj in A and B

*Share of potential vehicle market to pj[A]*: Scenario10Sensitivity
*Share of potential vehicle market to pj[B]*: Scenario10Sensitivity
Figure 110

Vehicle market share pk in A and B

Figure 111

Scenario/Sensitivity
50% 75% 95% 100%
"Share of potential vehicle market to pj [A]"
The analysis now turns to scenario 6, in which the preference structure of the car manufacturer is that of a balanced investor. This indicates that the car manufacturer allocates equal resources to the development of the three platforms (Figure 114).
To understand how difference in consumers’ preferences can influence diffusion patterns in scenario 6, a new simulation experiment is used. For this experiment, 200 simulation runs are used. The simulation runs result of the combination of two vectors. There is a vector $\alpha = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1 - \alpha$, $\lambda_{\text{operational cost}} = 0 + \alpha/2$, $\lambda_{\text{driving range}} = 0 + \alpha/2$. And there is a vector $\beta = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}} = 1 - \beta$, $\lambda_{\text{operational cost}} = 0 + \beta/2$, $\lambda_{\text{driving range}} = 0 + \beta/2$.

The results of the experiment show that the behaviour of scenario 6 is quite similar to the behaviour of scenario 5 (Figure 116, annexes). It shows that the hybrid platform reaches high levels of diffusion regardless the existence of observed or difference in consumers’ preferences. The only perceived difference, between scenario 6 and scenario 5, is that the transition towards the hybrid platform occurs a bit quicker in scenario 6. However, in this scenario, the alternative platforms receive a considerable greater amount of resources from the car manufacturer than in scenario 5 (Figure 118, annexes). Through previous experiments it has been shown that the resources of the car manufacturer are indeed important because they enable a much quicker development of the alternative platforms, which supports their diffusion (Figure 119, annexes). Therefore, how is possible that a greater allocation of resources does not accelerates significantly the diffusion of the alternative platforms in scenario 6? The answer is that consumers do not have perfect information about the performance of the vehicle platforms. As explained in chapter 2, there is a process of social learning involved in the diffusion of the alternative vehicle platforms. This process of learning takes considerable time. It success depends on the number of people talking and learning about the performance of the alternative platforms and also on the marketing done in their favour (Figure 15, chapter 2). Of course, if there are consumers that are
proficiency oriented, this process can be accelerated. However, even though, the hybrid platform has a high technological potential and there are performance oriented consumers in both regions, still the diffusion of alternative platforms requires undergoing a process of social learning. This is a natural constraint in the system that inherently increases the time needed for the diffusion towards alternative platforms.

The results of the experiment also point to another interesting fact. This is that the radical platform also fails in both regions, in this scenario in which the car manufacturer supports its development (Figure 115). The radical platform does improve its performance due to the allocation of resources of the car manufacturer. It reduces its purchasing price and operational cost. It also increases the amount of kilometres that it can be driven on battery power. This occurs to such an extent that when the car manufacturer is a balanced investor, solely in 15 years it can be driven on electricity without using the fuel of the incumbent platform as support (Figure 120, annexes). However, all this improvements are not enough to compete with the incumbent platform and the hybrid platform. In terms of purchasing price, the volume of sales of the radical platform does not allow for the activation of the experience and scale driven changes. More importantly, the radical platform becomes less competitive due to the lack of fuelling infrastructure in both regions, which reduces it driving range, making less attractive for consumers (Figure 121, annexes). This special diffusion pattern is summarized in Table 14.

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Factor influencing the diffusion pattern</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>III. Fail of the radical platform in both regions</td>
<td>• Lack of fuelling infrastructure to support the radical platform. Strong hybrid competitor.</td>
<td>• Market driven investor and Balanced investor</td>
<td>• High potential hybrid platform</td>
</tr>
</tbody>
</table>
The analysis of scenarios 5 and 6 shows that, the influence of market heterogeneity on diffusion patterns can be constrained by the dynamics of the process of social learning. It can also be constrained by the technological potential of the hybrid platform. Therefore, in cases where the hybrid platform has a high technological potential compared to the other platforms, market heterogeneity does not influence the success or failure of the hybrid platform. It will only accelerate or delay the process of diffusion. However, in these scenarios, the radical platform never reaches a level of sustained diffusion. It has also been shown that the influence of resource allocation by the car manufacturer is not significant in these scenarios.

It follows that for the diffusion of the hybrid platform, the importance of market heterogeneity and resource allocation increases as the technological potential of the hybrid platform diminishes, being market heterogeneity more determinant for diffusion of the hybrid platform than resource allocation.

Figure 115. Scenario 6: Behaviour envelops diffusion of radical platform in both regions
Figure 116

Figure 117
Figure 118

Share of resources allocated to pj

Figure 119

Learning in fuel efficiency pj
II.6 SCENARIO 7

The scenarios discussed in this section consider a high potential radical platform (learning coefficient=100%). Scenario 7 is discussed first. This scenario considers that the car manufacturer is a market driven investor (Figure 122).

To understand how market heterogeneity can influence diffusion patterns in scenario 7, a new simulation experiment is used. For this experiment, 200 simulation runs are used. The simulation runs result of the combination of two vectors. There is a vector $\alpha = \{0, \ldots, 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}}=1-\alpha$, $\lambda_{\text{operational cost}}=0+\alpha/2$, $\lambda_{\text{driving range}}=0+\alpha/2$. And there is a vector $\beta = \{0, \ldots, 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the emerging region is as follows: $\lambda_{\text{purchasing price}}=1-\beta$, $\lambda_{\text{operational cost}}=0+\beta/2$, $\lambda_{\text{driving range}}=0+\beta/2$. 

![Figure 120](image1.png)

![Figure 121](image2.png)
The results of the experiment show that in scenario 7, if there is difference in consumers’ preferences, then diffusion patterns of the hybrid platform are more robust than the diffusion patterns of the radical platform (Figure 129 and Figure 130, annexes). It is even possible to find a vast number of cases in which the radical platform fails, despite its extraordinary technological potential (Figure 123, Figure 131 annexes). Especially interesting are the cases in which the preference structure of consumers in both regions is inclined towards a price orientation. In these simulation cases the radical platform fails in both regions (Figure 126, annexes). This happens because none of the mechanisms of change: R&D driven change, Experience driven change, Scale driven change and infrastructure driven change works in favour of the radical platform. In these cases, the technological potential of the radical platform is not exploited because the car manufacturer does not allocate enough resources to its development, as it is behaves as a market driven investor (Figure 127, annexes). Initially, the hybrid and the incumbent platforms are considerably cheaper than the radical platform, price oriented consumers are not incentivize to purchase the radical platform. This motivates the car manufacturer to continue allocating resources to the development of the incumbent and hybrid platforms (Figure 128, annexes). Therefore, in these cases neither the car manufacturer nor the consumers realize of the high potential of the radical platform. This special pattern of diffusion is summarized in Table 15.
In cases in which the preference structure of consumers in the advanced region is more inclined towards proficiency than the preference structure of consumers in the emerging region, the results of the experiment show that the diffusion of the alternative platforms occurs first in the advanced region. However it is important to notice that this occurs only when consumers are significantly oriented towards proficiency. It is also interesting to notice that initially the hybrid platform is preferred over the radical platform. This occurs because even though the radical platform is technologically superior to the hybrid platform, the radical platform is a more immature technology than the hybrid platform. This creates a delay in the development of radical platform that is shortened as consumers become more proficiency oriented in the advanced region. In these cases, even though there is a successful diffusion of the alternative platforms in the advanced region, global diffusion is limited due to the limited diffusion of the alternative platforms in the emerging region (Figure 138, annexes). If the preference structure of consumers in the emerging region is more inclined towards proficiency that the preference structure of consumers in the advanced region. Then, the results of this experiment show that the diffusion of the radical platform occurs faster and to a greater extent in the emerging region than in the advanced region.
Similarly to the previous case, the results of this experiment show that if consumers are proficiency oriented, initially the diffusion of the hybrid platform is favoured over the diffusion of the radical platform. However, in this case the radical platform finds a better niche for its development in the emerging region because the rate of growth of the vehicle market. This diminishes the initial disadvantage of the radical platform against the hybrid and incumbent platform. Since the volume of new to industry vehicle sales is considerably high, the number of people buying for the first time a radical platform increases. Thus, through these new to industry sales, the market share of the radical platform increases, and with it, the resources allocated to its development. This accelerates the speed of the R&D driven change, and also the speed of social exposure of the radical platform, which helps it overcoming its initial disadvantage with the incumbent and hybrid platforms. In contrast, in the advanced region, the diffusion of the radical platform starts quite late. This happens because in the advanced region, there are only price oriented consumers and the slow rate of growth of its vehicle market delays the process of diffusion of the alternative platforms. Therefore, in these cases, both observed market difference and difference in consumers’ preferences create an alternative pattern of diffusion, in which the radical platform succeeds in the emerging region, but it fails in the advanced region (Table 16).

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. Success of the radical platform in the emerging region. Failure of the radical platform in the advanced region. Greater diffusion of the hybrid platform in the advanced region than in the emerging region. Radical runs of full electrical power (Figure 124).</td>
<td>• Observed market difference: Rate of growth of vehicle market in the emerging region  • Difference in consumers’ preferences: Proficiency oriented consumers in the emerging region, price oriented consumers in the advanced region.</td>
<td>• Market driven investor</td>
<td>• High potential radical platform</td>
</tr>
</tbody>
</table>

Table 16. Alternative diffusion patterns in scenario 7
Finally, the experiment also shows that in cases in which the preference structure of consumers in the advanced and emerging regions is inclined towards a proficiency orientation. The difference in the rate of growth of their vehicle markets also generates alternative diffusion patterns. In these cases the rate of growth of the vehicle market in the emerging region, combined with the proficiency orientation of its consumers, accelerates the R&D driven change of the radical platform. In this case, improvements in the attributes of the radical platform are well noticed by consumers in the advanced region, who are also proficiency oriented. This strengthens the position of the radical platform in the advanced region to such an extent that it overtakes the hybrid platform, which stabilizes at a lower level in the advanced market and in the global market (Table 17).

Table 17. Alternative diffusion patterns in scenario 7

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. In the advanced region the radical platform overtakes the hybrid platform, and the hybrid stagnates. In the emerging region success of the radical platform. Radical is 100% electrical.</td>
<td>•Observed market difference: early adoption of the radical platform in the emerging region strengthens its position in the advanced region (Proficiency oriented consumers in both regions)</td>
<td>•Market driven investor</td>
<td>•High potential radical platform</td>
</tr>
</tbody>
</table>
Figure 125. Alternative diffusion patterns in scenario 7

Figure 126
Figure 127

Cost of Vehicle Platforms

Figure 128

Allocation of resources
Figure 129

Figure 130
II. 7 SCENARIO 8

This section discusses the last scenario of the behavioural analysis. Scenario 8 depicts a context in which the car manufacturer behaves as a balanced investor and the radical platform has its maximum technological potential (Figure 132).

To understand how market heterogeneity can influence diffusion patterns in scenario 8, a new simulation experiment is used. For this experiment, 200 simulation runs are used. The simulation runs result of the combination of two vectors. There is a vector $\alpha = \{0, ..., 0.37; \Delta = 0.01\}$, such as the preference structure of consumers in the advanced region is as follows: $\lambda_{\text{purchasing price}} = 1-\alpha$, $\lambda_{\text{operational}}$
\[ \text{cost} = 0 + \alpha/2, \ \lambda_{\text{driving range}} = 0 + \alpha/2. \]

And there is a vector \( \beta = \{0, \ldots, 0.37; \Delta = 0.01\} \), such as the preference structure of consumers in the emerging region is as follows: \( \lambda_{\text{purchasing price}} = 1 - \beta, \lambda_{\text{operational cost}} = 0 + \beta/2, \lambda_{\text{driving range}} = 0 + \beta/2. \)

The results of this experiment show that in cases in which the radical platform has a superior technological potential, if the car manufacturer behaves as a balanced investor, then the behaviour of the system is much less uncertain than in scenario 7. The results show that the hybrid platform succeeds in both regions, being the advanced region where it reaches the highest level of diffusion (Figure 139, annexes). The results also show that the radical platform succeeds in both regions, being the emerging region where it reaches the highest level of diffusion (Figure 133).

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**Figure 133**

**Figure 134**

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The results of the experiment also show that in scenario 8 when the preference structure of consumers is similar in both regions, or when the preference of consumers in the emerging region is more inclined towards proficiency than the preference structure of consumers in the advanced region. Then, the diffusion of the radical platform occurs first in the emerging region. The contrary case is true for the hybrid platform, which tends to stagnates at low levels in the emerging region. This occurs because of the effect of observe market heterogeneity. In the advanced region, initially the radical platform competes with the hybrid platform, but the high technological potential of the radical platform quickly outpaces the development of the hybrid platform, being the radical the most attractive to consumers. In the emerging region, this quick improvement of the performance of the radical platform, in combination with the growing new to industry sales, accelerates the diffusion process of the radical platform in the emerging region (Figure 134). This alternative diffusion pattern is summarized in Table 18.

Table 18. Alternative diffusion pattern in scenario 8

<table>
<thead>
<tr>
<th>Type of diffusion pattern</th>
<th>Type of market heterogeneity influencing the behaviour</th>
<th>Preference structure of Car Manufacturer</th>
<th>Technology Potentials</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. Success of radical platform in the emerging region, failure of hybrid in the emerging region. Success of both platforms in the advanced region, but major diffusion of the radical platform (Figure 135)</td>
<td>•Observed market difference: Rate of growth vehicle market in the emerging region, couple with rapid affordable radical platform (price or proficiency oriented consumers in both regions, or more proficiency oriented in the emerging region)</td>
<td>•Balanced investor</td>
<td>•High potential radical platform</td>
</tr>
</tbody>
</table>
It is clear that, in scenario 8 the early allocation of resources to the development of the radical platform improves importantly its chances of diffusion. However how incline towards a balance preference structure the car manufacturer needs to be to enhance the diffusion of the radical platform in scenario 8? In order to answer this question a simulation experiment is used. This experiment is done by using a vector $\alpha = \{0, ..., 1; \Delta = 0.05\}$, such as in each simulation run, the preference structure of the car manufacturer is: $\lambda_{market\ dominance}=0+\alpha E_{incumbent}=1/3, E_{hybrid}=1/3, E_{radical}=1/3$, for all elements in $\alpha$. Consumers are considered to be price oriented in both regions.

The results of this experiment show that the car manufacturer does not need to be entirely a balance investor to enhance the diffusion of the radical platform. It shows that when the importance of platforms’ share of sales reduces by 30% in its preference structure, then the diffusion of the radical platform can reach levels similar to the previously shown for scenario 8 (Figure 136). This is because the radical platform responds quite quickly to the allocation of R&D resources, due to its high technological potential.

Scenario 7 and 8 show that, even if the technological potential of the radical platform is high, then its diffusion depends importantly on the allocation of resources of the car manufacturer and/or the preference structure of consumers. However, is it necessary for the radical platform to be far technological superior to the incumbent and hybrid platforms? Evidently, this is only meaningful for the case in which the car manufacturer is a balanced investor. Therefore, s simulation experiment is used to answer this question. For this experiment, the car manufacturer is considered to be a balanced investor.
and consumers to be price oriented in both regions. In this case 50 runs are simulated using a vector \( \alpha = \{0.40, ..., 1.0; \Delta = 0.01\} \), such that the learning coefficient of the radical platform is equal to \(-\alpha\).

The results of the experiment show that there is not a threshold at which the technological potential of the radical platform stops being influential (Figure 137). This shows that in the context of scenario 8 the preference structure of consumers has an influence in diffusion patterns that matches that of the technological potential of the radical platform.

![Figure 136](image1.png)

**Figure 136**

![Figure 137](image2.png)

**Figure 137**

This finalizes the discussion of the contextual scenarios. The following section presents an overview of the findings of the behavioural analysis.
Figure 138

Global Vehicle Fleet

- Incumbent Platform
- Hybrid Platform
- Radical Platform

% Market Share

Time (yrs)

Advanced Region

Emerging region

Incumbent Platform
Hybrid Platform
Radical Platform

% Market Share

Time (yrs)

Scenario 8

50% 75% 95% 100%

"Share of potential vehicle market to \( p_j \) [A]"

0.4

0.3

0.2

0.1

0

0 12.5 25 37.5 50

Time (Year)

Scenario 8

50% 75% 95% 100%

"Share of potential vehicle market to \( p_j \) [B]"

0.2

0.15

0.1

0.05

0

0 12.5 25 37.5 50

Time (Year)

Figure 139