Exploring strategic responses of the automotive industry during the transition to electric mobility: a system dynamics approach

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Abstract

This paper outlines a model archetype that can be used to assess the effects of future policy making and the future transition towards electric vehicles on the automotive sector, while taking into account insights from innovation, transition literature and the multilevel perspective. In order to show the flexibility of the model structure and tackle the gap on how the automotive industry normally responds on those factors, the approach is then used together with historical data to generate insights on how industry has responded to pressures in the regime in the past. For that a case study approach is taken when a timelines for the automotive regime and landscape are presented and then put in relation to a timeline of BMW's activities. While the study is in an early stage, still it is shown how first quantitative parameters can be identified. The article concludes with an outline of future work.

Keywords

Policy making, automotive industry, transition scenarios, diffusion, economics, model architecture

1. Introduction

This paper presents how the transition of the automotive industry towards electric road transport can be explored with the help of a system dynamics driven approach, while drawing on knowledge from transition science and especially the multi-level perspective approach. While those qualitative approaches provide insights on experiences on past transitions as well as means to structure systems that are in transition, our work has the aim to discuss the effects of transitions in a quantitative way. For that we propose a system dynamics model structure that is tailored towards the research problem. After a presentation of the different components, the model structure is then taken as a basis to explore the nature of the system and especially of the stakeholder 'automotive industry'.

1.1 Background

Over the last years the automotive industry has been experiencing a number of different pressures. Not only are they increasingly perceiving the first effects of oil scarcity, but, more and more, these industries are getting aware of changing customer expectations and behaviour and are challenged by governmental policies driven by climate change issues. As a result, high fuel prices or the on-going discussion on emissions has led and will lead to a variety of changes in behaviour, responses in strategies and products in the automotive industry; especially as light-duty vehicles, such as automobiles are responsible for a high amount of energy-related GHG emissions (26% in OECD) (IEA 2010a, WEC 2011). One way of addressing those pressures is the introduction of technologies such as HEVs, PHEVs, BEVs and FCVs (D. Howey & Martinez-Botas. 2010, IEA 2010b) as it is argued that the whole spectrum of those electric powertrain technologies are likely to be needed in a future decarbonised road transport system, each playing a different role (IEA 2010b, McKinsey & Company, 2010). Scenarios, such as those analysed by the IEA and World Energy Council, highlight futures with a fast rapid diffusion of PHEVs, BEVs and FCEVs (IEA 2010a, WEC 2011). As a result the automotive industry will be faced with consequences that are difficult to predict, implying risks, but also opportunities (especially for new actors). They are facing high uncertainty with regard to decisions concerning future technologies and strategies (Bailey et al. 2010, Hellman & van Den Hoed 2007, Whitmarsh & Köhler 2010).

Due to the potentially significant changes to the current structure of the automotive industry that a transition to electric mobility would induce, it is clear that for national governments this becomes a question of industrial policy just as well as of energy and environmental policy. With a transition towards electric mobility this paper means a move away from internal combustion engine vehicles (ICEVs) towards cleaner vehicles, such as hybrid electric (HEVs), plug-in hybrid electric (PHEVs), battery electric (BEVs) or hydrogen fuel cell electric vehicles (FCEVs).

While energy and environmental policy goals are largely similar across European countries, industrial policy goals can be expected to reflect the particular structure and strategy of national industries and therefore vary more significantly. This hypothesis is supported by the fact that recent policies aimed at promoting electrification of road transport have taken somewhat different forms in different European countries (Elzen & Wieczorek 2005, Huétink et al. 2010, Santos et al. 2010, Stern 2007, van den Hoed 2007).

But even then, current road transport policies seem to have failed to address those mentioned issues in an appropriate way, especially as the uptake of electric cars has been slow (Huétink et al. 2010, Santos et al. 2010, van den Hoed 2007).

However, the problem (or second issue) is that the specific impact and efficiency of those measures is uncertain. So it is difficult to link specific developments with the effects of individual policy measures, especially as those policies (and the whole transition itself) not only affects uptakes of technologies, but also have significant impact on a whole system of relevant stakeholders including the automotive OEMS or their suppliers. Therefore, in order to understand the consequences and outcomes of those policies, it is necessary to understand the transition process with its different stakeholders, their behaviours as well as the relations between them. Only then it will be possible to assess the efficiency of measures and choose the most efficient ones. This is also of relevance when decision makers want to feedback the outcomes of their policies into reviews of those policies, creating feedback loops.

This knowledge is also of interest to the various industrial players, whose short-term strategies currently seem to lock them to combustion engines, limiting their investments into alternative technologies and waiting for anticipated spill-over's from other companies who are executing this research (E4tech March 2007, Santos et al. 2010). Understanding the complex system they are in as well as knowing the consequences of their own strategies and decisions, can decrease those uncertainties, in order to reach their business objectives.

1.2 Understanding transitions of the automotive sector

There are two major ways to discuss the transition processes; qualitative studies mainly based upon insights of innovation sciences, and quantitative studies that use modelling to explore and to compare the various effects.

Qualitative studies such as (Bakker 2010, Collantes 2007, Farla et al. 2010, Pinkse & Kolk 2010, Santos et al. 2010, van den Hoed 2005, van den Hoed 2007, Wiesenthal et al. 2010), for example, outline the challenges as well as relationships between the various actors, and describe their roles and significance for the diffusion of electric mobility (Collantes & Sperling 2008, Kieckhafer et al. 2009, Schwanen et al. 2011). For that, a variety of studies ((Nykvist & Whitmarsh 2008, Suurs et al. 2009)) describe and formalize transition systems with the help of innovation management (mainly based upon (Geels 2002, Geels & Schot 2007, Rip & Kemp 1998)).

A number of authors point out the challenges for the industry, which is facing uncertainty with regard to the decision concerning future technologies and strategies (Bailey et al. 2010, Hellman & van Den Hoed 2007, Whitmarsh & Köhler 2010). Their activities are interpreted as a response against pressures from external actors, like regulators, consumers or competitors. Less than 5% of their R&D funding is directed towards technologies focusing on electric power trains (Wiesenthal et al. 2010). The short-term strategies of industry lock them into using combustion engines, avoiding extensive investments into alternative propulsion technologies, as they anticipate and wait for spill-overs from other companies executing this research (E4tech March 2007, Santos et al. 2010).

Quantitative approaches commonly use modelling techniques to simulate different diffusion pathways for electric transport technologies. They asses the influence of various scenarios on the simulated transition outcomes and derive from that recommendations for policy makers.

In system dynamics the transition process is modelled in a top down-approach, where the different processes are modelled on an aggregated level (with the help of differential equations). This equation based model assumes that agents are well mixed. It has been demonstrated for complex systems, especially where feed-back loops are significant. Aggregated equation-based models (see for rank, probit, stock approaches in (Norton & Bass 1987, Stoneman 2002), etc.) can be easily utilized in this approach. However, it is difficult to describe interaction between individual actors, as this model operates on an aggregated basis. Agent-based modelling, where stakeholders are represented as individual agents, is illustrative of a bottom-up approach. Agents can be goal-directed (behaving with respect to their utility), reactive (responding to changes in the environment) and capable of interacting with other agents. Agent-based modelling is seen to be the most complex and elaborate diffusion model to date (Frenzel & Grupp 2009). Both, the system based approach (e.g. in (Keles et al. 2008, Meyer & Winebrake 2009, Struben & Sterman 2007)) as well as the agent-based modelling approach (e.g. in (Safarzynska & van den Bergh 2010, Sullivan et al. 2009)) were already applied to simulate different transition path of sustainable technologies. In certain cases, both approaches were combined in order to take advantage of both models strengths (Kieckhafer et al. 2009, Kohler et al. 2009).

In summary, quantitative approaches can provide policy makers with information concerning the consequences of policies in terms of the diffusion of certain technologies (Holtz 2011). For instance, they describe the transition with regard to the evolution of infrastructure policies (Huétink et al. 2010, Meyer & Winebrake 2009, Park et al. 2011, Struben & Sterman 2007). In addition, the influence of the customer on transition outcomes, and especially the effects of marketing, word-to-mouth and how these are affected by policies, can be simulated (Struben & Sterman 2007). For example, through such simulations, (Charalabidis et al. 2011, Holtz 2011, Keles et al. 2008, Meyer & Winebrake 2009, Park et al. 2011, Sullivan et al. 2009) one can outline and compare the influence of provision of a suitable infrastructure and the application of subsidies in order to achieve a transition towards a fuel cell based mobility.

Although in current quantitative studies, different actor types are addressed in individual ways, manufacturers are only formalized as aggregated providers of technologies and new vehicles. But their actual behaviour and their effect on the transition, as well as how they are affected by the transition process itself, is not extensively discussed, although their significant role in the whole process has been emphasized. Also, how their individual goals, such as their market share or capacities are affected, has not been discussed further. However, in order to describe the transition process, it is necessary to get a better understanding of all relevant actors, and especially of the industrial actors, as they have a substantial influence on the diffusion/transition process. Also their influence on the transition itself is of interest. Here we present a model structure that allows these issues to be explored.

Hence, in this work we do not intend to outline an approach where future transition or diffusion scenarios shall be the outcome, but instead present a model structure with very narrow boundaries that focus on the behaviour of actors with respect to exogenous transition and diffusion scenarios in order to explore how industrial players, such as the automotive industry would react to those scenarios.

1.3 Aims, methods and structure of the paper

While transitions, and especially the effects of policies on the system and on the automotive industry, have been discussed by transitions science in a qualitative way, it is still difficult to attribute the consequences of certain policies or events to specific outcomes or effects. While the qualitative methods can indeed provide some additional insights on those matters, the complexity of the discussed socio-technical system requires, in our opinion, a quantitative approach.

Hence, in this paper we propose a system dynamics model structure as a quantitative approach that could be used to describe, to attribute and to assess individual consequences (such as transition pathways and patterns) and their causes (such as policy measures and industrial behaviour) in order to explore and understand different transition scenarios.

The choice of transition theory as a framework for the analysis is justified by its ability to capture all key dimensions of a transition process such as the one under study, which other disciplines are not able to do (this is further discussed in Section 2.1). A variety of works (Geels 2005a, Ieromonachou et al. 2007, Nykvist & Whitmarsh 2008) already discuss transitions in road transport from a historical point of view, with current research (Van Bree et al. 2010) outlining possible transition futures and scenarios (and future technology choices), using the Multi-level perspective (MLP) drawing upon insights from historical transition pathways (Geels & Schot 2007).

The structure of the paper is as follows. Section 2 presents the proposed model structure with the different domains that define its system boundaries. Section 3 presents an adapted proposed model structure and discuss a case study based upon that model structure. Section 4 concludes with a discussion of the approach and summarizes future work.

2 A model structure to understand the strategic responses of the automotive industry

This section presents the proposed model structure. Before describing the model itself, it will first introduce the theories it is drawing from: especially multi-level perspective and transition science.

2.1 Characteristics and specification of the model

In contrast to the approaches outlined in section 1.2 the model structure that is presented in this paper does not intend to describe the behaviour of the whole transport sector with respect to a transitions but instead focuses on the dynamics in the automotive industry and especially the behaviour of individual automotive stakeholders, such as regime OEMs, suppliers or niche actors. Also our approach does not have the aim to predict future diffusion scenarios, but instead to use those predicted futures to create scenarios whose impact on the automotive industry will be then tested. The system dynamics based model structure that we present shall accommodate the following aspects (that will be presented and discussed in the subsequent sections):

- Exogenous diffusion and transition scenarios as input (2.1.1)
- Incorporation of the characteristics of potential vehicle technologies (2.1.2)
- Based upon multilevel perspective (2.1.3)
- Transition pathways and patterns (2.1.4)
- Simple model representation to facilitate interaction with automotive actors (2.1.5)

2.1.1 Exogenous diffusion and transition scenarios as input

As mentioned in section 1, there is already a variety of studies that use methods from agent-based modelling or system dynamics to model transitions (Huétink et al. 2010, hyeong Kwon 2012, Keles et al. 2008, Meyer & Winebrake 2009, Park et al. 2011, Shafiei et al. 2012, Shepherd et al. 2012, Struben & Sterman 2007, Sullivan et al. 2009), some of them also take into account insights from MLP (e.g. (Papachristos 2011)). Those models explore the aspects of infrastructure, subsidies or policy making and have in common that they aim to assess the consequences of those events or effects on the diffusion of electric road vehicle technologies. They try to assess the impact on future diffusion scenarios and give insights (or forecasts) into which alternative drive train technology might be the winner in the future.

In contrast, our work aims to assess the effects of diffusion or transition scenarios on the automotive industry, and especially its strategic behaviour towards changes in its environment. As a result, the above mentioned diffusion scenarios act (at this stage) as exogenous model inputs, which then then provide scenarios to test automotive actors' behaviour. As a source for those scenarios, our approach draws on two sources. The first, in order to calibrate the model, are historical timelines (as presented in section 3) outlining events that are relevant for automotive industry actors. In order to explore the effects of possible futures this work draws on widely accepted scenarios such as those outlined by the IEA and World Energy Council, describing different timelines for market shares for PHEVs, BEVs and FCEVs (e.g. (IEA 2010a, IEA 2010b, McKinsey & Company, 2010, WEC 2011)).

However, those studies normally only outline quantitative diffusion scenarios for the different vehicle technologies and to certain extent also for the corresponding infrastructures, whereas in our case we are discussing transitions of the whole system. That is necessary as those diffusion scenarios do imply more than just changes in numbers of vehicles but instead do also affect the whole system. The implications for that have been discussed in innovation sciences with the help of the multilevel perspective that will be further discussed in section 2.3

2.1.2 Incorporation of the characteristics of potential vehicle technologies

Electrification relies on a range of vehicle powertrain technologies such HEVs, PHEVs, BEVs and FCVs. It is argued that the whole spectrum of electric powertrain technologies are likely to be needed in a future decarbonised road transport system, each playing a different role (IEA 2010b, McKinsey & Company, 2010). Each of those technologies has advantages and disadvantages in terms of energy density, price or infrastructure requirements (D. Howey & Martinez-Botas. 2010, Offer et al. 2010). As a result it is necessary to characterize the products of the observed automotive company and its capabilities to deliver one of those technologies, as well as their portfolio.

2.1.3 Socio-technical systems and the MLP

This section briefly introduces the multi-level perspective that will be used in our model to structure the system. The multilevel perspective (MLP) has been already used to discuss aspects in transport. (Whitmarsh 2012) provides a summary on its contribution to that domain.

A transition towards electric road transport affects a number of actors such as automotive OEMs and suppliers, providers of infrastructures (such as oil, gas and utility companies/suppliers), and owners of the vehicles, forming a cluster of elements that is characterized by the presence of feedback loops and path dependence. Such a cluster is called a ‘socio-technical system’ (Geels 2005b).

The model structure that is presented in this paper is based upon the “multi-level perspective” approach, a major strand of current innovation research, developed by Geels, Kemp, Schot (Geels 2005b, Rip & Kemp 1998) and others in the Netherlands since the first half of the 1990s. It largely builds on evolutionary theories of technological innovation (Geels, 2002). The MLP approach is used as a basis for research on transitions, leading to typologies of transition pathways (Geels & Schot 2007) and patterns (De Haan & Rotmans 2011). It describes socio-technical systems as divided into three distinct but closely related levels: the landscape, regime and niche level.

In the case of electric mobility the landscape represents external effects such pressures due to climate change, rising oil prices or changed perceptions towards sustainability; however, it is generally stable and takes a long time to change (i.e.: in the order of years or decades). Niche and regime actors experience changes in the landscape as external pressures and respond to them accordingly. The current transport regime is defined by a set of elements such as the use of fossil fuels and combustion vehicles and appropriate fuel and production infrastructures as well as beliefs and habits that are consistent with those, forming together the current road transport system. Regimes can change under certain conditions (i.e.: pressures arising from the landscape or from niches). Such changes, where significant, go under the name of a socio-technical transition. Though they change faster than landscapes, regimes mainly generate incremental innovations. In contrast to that, the generation and development of radical new innovations is often situated in the so called niches. Niches are seedbeds for change and are normally relatively protected market or technological domains, where new systems and practices appear or are tested, providing a room where new networks and the exchange of learning processes can arise Regimes can be challenged and replaced by new regimes emerging from niches, especially as pressures, induced from the landscape, can open windows of opportunity for the new regimes (Geels 2002, Geels & Schot 2007, Kemp & Loorbach 2003, Rip & Kemp 1998, Smith et al. 2005, Tukker & Butter 2007).

For transition science the MLP has provided a mean that allowed to structure socio-technical systems. Based upon that and the study on past transitions, transition science has identified a number of stereotypic transition pathways and transition patterns. Section 2.1.4 provides an overview of those.

2.1.4 Transition pathways and patterns

As mentioned in section 2.1.3, the MLP provides a way to structure the observed system into different levels. Combining it with historical observations of transitions of real systems, transition science (Geels & Schot 2007) has identified a variety of triggers and drivers for those transitions as well as barriers that support the stability of regimes. (Geels & Schot 2007) provide a typology of transition pathways. The different types are based on the nature and timing of interactions between the landscape, the niches and the regime (see section 2.1.3 for an explanation of the various levels). Additionally to the definition of four stereotypic transition pathways, the typology also outlines the main actors involved and the types of interactions; providing insight that can be used as a basis for policy making (i.e. what to target). However, transitions are not limited to purely one pathway type but also a combination of those (depending on the persistence of the pressure induced by the landscape and the adaptability of the regime). While (Geels & Schot 2007) provide 4 widely accepted stereotypic transition paths, recent work (De Haan & Rotmans 2011) introduces a set of common transition patterns and system states (i.e. conditions such as pressures on the system). Their typology is classified by the source of transition pressure (Reconstellation, Empowerment or Adaption) and for each of those a number of possible transition processes are outlined.

While the typologies have been used to discuss transitions towards electric road transport derived possible futures (e.g. (Van Bree et al. 2010)), in one of our past studies ((Mazur et al. 2013)) those typologies have been applied to perform an ex-ante qualitative assessment of government policies in the area of electric mobility. While those studies discussed the problem from a qualitative point of view, the work presented here draws upon those insights to translate projected diffusion scenarios into transition scenarios in order to identify aspects that are relevant for automotive actors and to describe the dynamics of those aspects. Another important point is that the model structure is adaptable to any type of transition pathway.

2.1.5 Simple model representation to facilitate interaction with automotive actors

The model structure we propose in the paper was created in such a way that it allows scenarios to be readily created that can then put forward to actors in the automotive industry, so that they can give feedback towards the conclusions. The aim is to bring in professionals from industry into the process at two stages: first, in the formalization of their behaviour towards certain situations and secondly in the evaluation and discussion of the results. In the long term, the aim is to create based upon this model structure a survey. Findings such as the ones presented in chapter 3 shall be then put forward to stakeholders in the automotive industry who would be asked to respond to those claims.

2.2 Archetype of system dynamics model

In this section we present the model that shall be applied to examine the effects of transitions and especially of policy making on automotive actors, such as established regime OEMs and suppliers or niche actors, while incorporating the characteristics and specifications outlined in section 2.1.

Fig. 1 illustrates the general archetype of model presented here. It allows simulating the actors' behaviours over time. It is composed of 5 main components. The variable AUTOR CHARACTERISTICS represents the current state of the studied actor (automotive player). A characteristic can be an aspect such as the existence of knowledge in Fuel Cell technology or a division working on fuel cells, or whether the company already offers PHEVs or not, or indicators such as the average fleet emissions. On the other side a set of REGIME CHARACTERISTICS has to be defined that correspond to the ACTOR CHARCTERISTICS and vice versa. At this point, the insights from transition theory come into play, as they allow deriving those corresponding and relevant characteristics from projected diffusion pathways (as provided by IEA). The regime and landscape characteristics are then compared with the actor's characteristics in order to determine DISCREPANCIES.

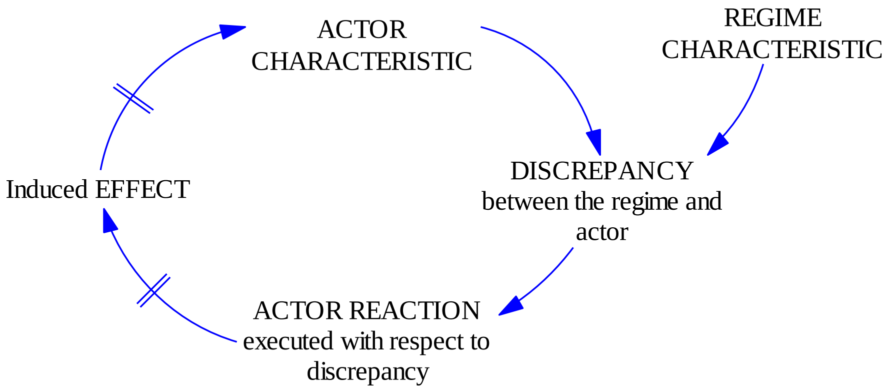

Fig. 1: General archetype of proposed model

Fig. 2: General archetype of proposed model

These are then used as an input to determine actor responses (ACTOR REACTION) to those pressures. The reactions or decisions provide favoured goals for ACTOR CHARACTERISTICS (e.g. the decision to provide a PHEV). The induced EFFECT captures the transient behaviour of the system. This can be, for example, the time it takes until a production capacity is created, or the time it takes to develop a first demonstrator. So this can be parameters derived from historic data, as well as learning curves or economies of scales, depending on the nature of the variable and goals.

As one can see the definition of the relevant ACTOR CHARACTERISTICS and REGIME CHARACTERISTICS is crucial. Here insights from transition science help defining the system boundaries. In the term ACTORS REACTION it is necessary to determine, how actors react towards certain discrepancies. For that, insights from literature, surveys, as well as the application of the model itself, can provide inputs (see section 3).

In comparison to Fig. 1, Fig. 3 illustrates a more problem specific model. In this step the influence of expectations on the regime and landscape are taken into account, as they play a crucial role in the decision process of the automotive industry (Bakker et al. 2012, Budde et al. 2012). Furthermore, this model architecture differentiates between the PRESSURES the different DISCREPANCIES induce. This helps answer the question; do automotive actors respond to different pressure and incentives in different ways, depending on their own CHARACTERISTICS and options (e.g. currently available resources)?

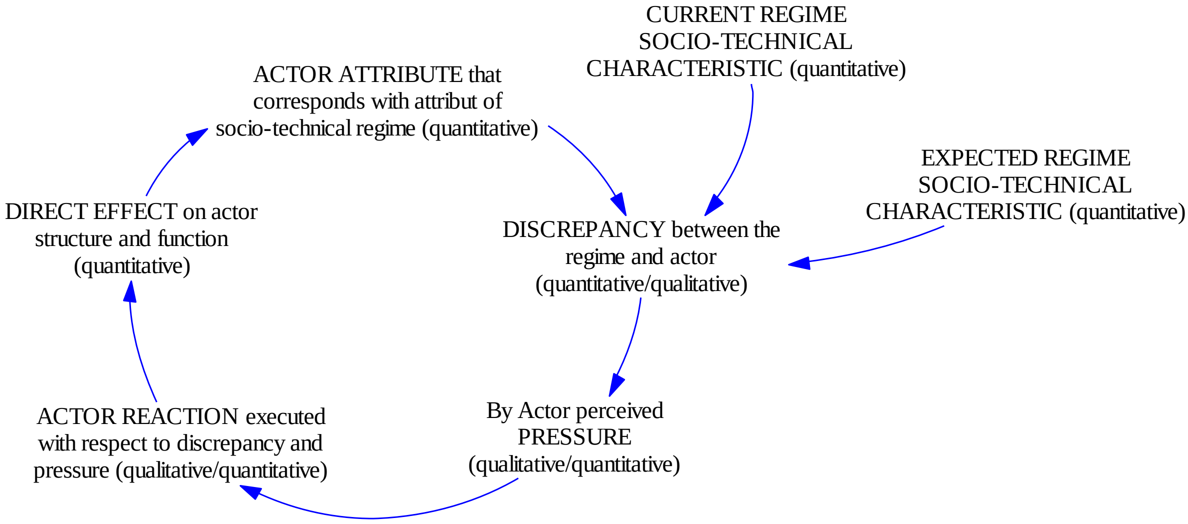

Fig. 3: Detailed archetype of proposed model

It can be seen that the model presented here is a simple illustration of the decision process of automotive actor facing changes in the regime or landscape, and who has to respond towards those pressures. Not only is it a simple decomposition of the whole problem and focuses on the crucial aspects of the system, but also a simple illustration of the problem, making it usable for the communication and interaction with actors (e.g. interviews).

There is no feedback from the actor towards the regime itself at this stage (for instance, influence on market due to success of a product, or possible lobbying).

3 Understanding the automotive industry: the case of BMW

Section 2 presents the model structure that was used to explore the effects of different transition scenarios as well as policy making on the automotive industry. To illustrate the flexibility of the model structure a study with the aim to generate model parameters was carried out. As mentioned before the behaviour of the automotive industry is not well understood. In order to fill that gap, we have adapted the model structure outlined in section 2, so that it can be applied to understand that actors' behaviour (see Fig. 4 for the adapted model).

First the adapted model will be presented in section 3.1. This will be followed by the description of a study on BMW's behaviour during the last 20 years, based upon the model.

3.1 Methodology

The model presented in section 2 has the aim to assess the effects of policy making and future transitions on industrial actors, taking into account future scenarios. In such a case different projected timelines (by IEA and others) represent model inputs to explore how the system reacts to those inputs. However, in order to execute such a simulation the other various components have to be specified first. While the effects within the automotive industry (actor attributes) can be derived from literature it is difficult to retrieve objective insights on how decisions are taken within the industry and what pressures or goals play a dominant role.

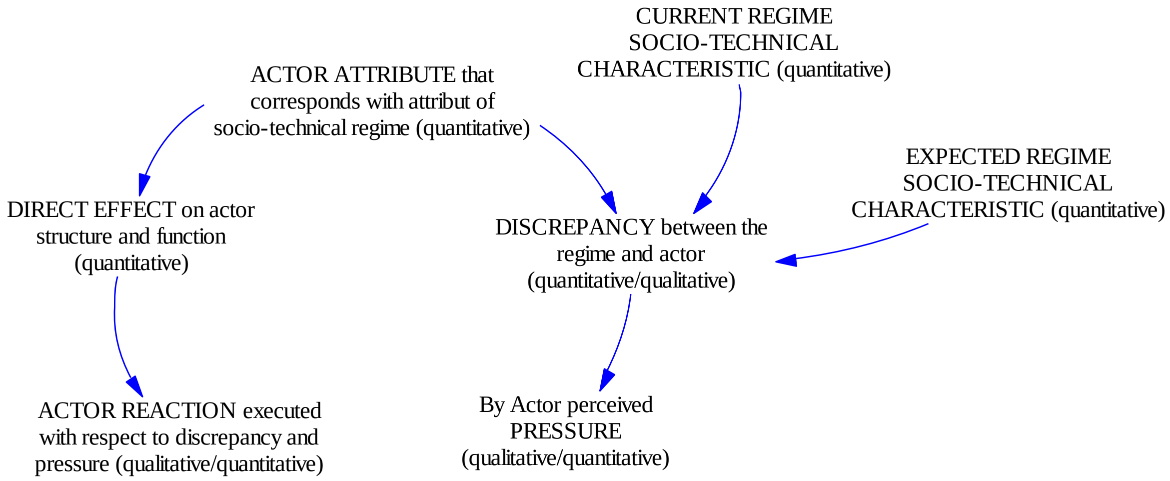

Fig. 4: Adapted model for application in case study

In order to obtain that data for our future work, historical insights are used as a basis for the determination of that behaviour. So instead of using projected data for the regime and landscape variables, this study applies available historical data in order to understand the past behaviour of automotive actors. For that, the loop was interrupted at the position where the behaviour of the actor is normally described. Then information on the landscape, the regime and the automotive actors (in this case BMW) is extracted from the literature, journals or BMW's annual reports, and timelines for both sides are created: BMW and its action on the one side, and what was happening around BMW on the other. Those are then aligned to obtain (at this stage) qualitative insights on how BMW responded towards the various events and pressures and how the companies' characteristics (such as knowledge or products) were affecting those.

While the study is of qualitative nature at this point, it still represents an important step on the way towards the quantification of the whole system and its dynamics.

3.2 The case of BMW

With respect to the model that has been presented in section 2, this section will in brief outline how the landscape and regime have developed over the last 20 years, and provide relevant milestones that BMW has experienced during that period. Both are then put in relation to each other and based upon a brief comparison, a set of insights are derived. There are a variety of dimensions that describe the socio-technical system for road transport. This study only concentrates on the major aspects that have been identified to have major impact on strategies in the automotive industry. Extracted from a number of studies (Bakker & Budde 2012, Bakker et al. 2012, Collantes & Sperling 2008, Dijk & Yarime 2010, Hacker et al. 2009, IEA 2011, Köhler et al. 2012, Mazur et al. 2013) those aspects include technology trends and hypes, national and international policies, BMW's competitors, economic pressures, fuel prices and infrastructures. As expectations play an important role I the automotive industry (Budde et al. 2012, Konrad et al. 2012), the timeline shall also give what mood was perceived during the respective period of time. The summaries and timelines that are presented here are mainly based upon these papers, and are additionally supplemented with actual data on economic growth or fuel prices as well as the perception of the media (mainly drawing from articles of major German (car) journals and newspapers such as the Spiegel, Focus, Autobild or Handelsblatt and Frankfurter Allgemeine Zeitung with (Auto Bild 2002, BMW GROUP 2003, Der Spiegel 1996, Der Spiegel 2005, Der Spiegel 2006, FOCUS 2009, Frankfurter Allgemeine Zeitung 2001, Frankfurter Allgemeine Zeitung 2005a, Frankfurter Allgemeine Zeitung 2005b, Frankfurter Allgemeine Zeitung 2008, Handelsblatt 2009, Spiegel Online 2003, Spiegel Online 2006, Spiegel Online 2011, VDI Nachrichten 2010) as few important articles, mainly around the International Automobile Exhibition IAA in Frankfurt or Detroit Motor Show, that outline the mood of the whole industry and the trends and fashions at those times. The information on BMW is additionally supplemented by an analysis of the annual reports of the BMW Group. The following two summaries (of the landscape/regime and BMW) are based upon the sources outlined here until now. The main events and aspects are outlined in the figure Fig. 5.

3.2.1 The regime and landscape from the viewpoint of the automotive sector (1990 - 2012)

The Zero Emissions Vehicle (ZEV) initiative that outlined a number of emission targets and limits as well as diffusion goals for zero emission vehicles in California in 1990 was one of the first incentives pushing towards low carbon transport. Although limited to California, it had a huge signalling effect as around 25% of the US vehicle market was in California and developments in California were expected to move to further states. However, though it triggered a number of EV and FCEV prototypes being presented by the industry, the fact that those goals were not expected to be met meant it was relaxed in 1996, and a key regulative pressure on the automotive industry was relaxed. While until then hydrogen vehicles had been seen as a solution for future transport, suddenly the mood changed and interest switched towards other technologies such as to the development of battery electric drive trains. Around 1996/97, at a time where hydrogen was not seen as a winner anymore, major OEMs in Germany and Japan presented their respective solutions to deal with arising discussions on CO_2 emissions. While Daimler's launch of the NecarII hydrogen demonstrator surprisingly triggered a new hydrogen/fuel cell hype (especially in Germany), Toyota's and Honda's launch of hybrid electric vehicles (Prius and Insight) directly on the Japanese and USA markets was acknowledged by the automotive sector without having initially any disruptive effects. While the early 2000s were dominated by an economic world crisis it was not until 2004/05 that major changes were triggered in the automotive sector. The success of Toyota Prius HEV and the launch of its second generation, as well as rising fuel prices lead, to a change in the perception of the hybrid technology, that until now lead to a 'hybrid race' illustrated by the significant increase in hybrid patents, HEV/PHEV prototypes being presented at various automobile exhibitions as well as numerous announcements of HEV release dates. During that time, hydrogen technology research, though not promoted anymore, still enjoyed support by various governments (like for example the US Department of Energy Hydrogen Program). However, with the inauguration of Steven Chu as new US Secretary under President Obama in 2009 and a reassessment of all technology options, the perception and expectations concerning that technology completely changed. Only the intervention of the Congress and the Hydrogen lobby could stop USA hydrogen R&D funds being completely cancelled. During that time (a time where the financial crisis hit) governments such as the German (Nationale Platform Elektromobilität) or the UK (Ultra Low Emission Vehicles initiative) launched national programs supporting the uptake of electromobility in order to reach environmental or industrial target. Since then, HEV/PHEVs and EVs have dominated current discussions (hydrogen no longer exists in the US White House Blueprint for Secure Energy Future), and the presence of TESLA in the media, the introduction of many EV demonstrator projects (SmartEV, MiniE, and many more) as well as the recent introduction of the Chevrolet Volt, Nissan Leaf or Mitsubishi iMiEV support that impression. While the financial crisis as well as rising fuel prices in the late 2000s put the focus on the development of small and highly efficient vehicles, the current (2012/13) focus has switched again slowly but steadily towards SUVs and PHEVs and EVs figure in technology portfolios as short- or medium-term solutions.

3.2.1 BMW (1990 - 2012)

BMW is one of the major German automotive car manufacturers with more than 1.6 million cars sold, a profit of more than € 7 billion and more than 100,000 employees (2011). During the last 20 years BMW has increased its output in vehicles from less than 900,000 and increased profits nearly tenfold. Since then BMW has had some experience with hydrogen vehicles (both combustion and FCEV), battery electric Minis and is currently launching its first hybrid vehicles, and especially its i series (BMW i3). While it has been always seen as the smaller premium automobile manufacturer, its sales numbers overtook those of Daimler a few years ago. BMW's image is located around medium/large luxury and performance segment cars, a fact that is well reflected in the average fleet emissions.

While in the early 1990s ZEV regulation driven experiences with alternative vehicle power technologies were disappointing, it was not until 1996 that BMW established serious hydrogen research activities. Though it was in a time of hydrogen disappointment in the automotive sector, the decision was mainly motivated by a hydrogen vehicle demonstration by its main competitor, Daimler. Though the work focused on PEM fuel cells and later SOFC fuel cells as well, BMW presented in 1998 the BMW 750hL, a large segment vehicle with a hydrogen combustion engine and a 5kW PEM APU. Since then, BMW built more than 100 hydrogen combustion vehicles that were used at various events (such as the EXPO 2000 in Germany) and a number of demonstrator programs where those vehicles proved themselves in over more than 4,000,000 kilometres driven. Also, a petrol fuelled vehicle using a SOFC APU with a fuel processor instead of an alternator was introduced. Though BMW announced it would bring its hydrogen combustion vehicle to market in 2002, those vehicles did not go beyond the status of demonstrator fleet programs.

While the average fleet emissions of BMW had been stable (though at a relatively a high level), emission target discussions at the European level had led in the late 90's and the beginning of the 2000's to an introduction of a variety of engine efficiency improvements as well as the higher use of diesel in the fleet, leading to a slow but steady decrease in average fleet emissions. However, hybrid or electric vehicle development was not intensified in this period of time. The acquisition of Rover brought in Range Rover SUV technology, leading to the design and production of BMW's X5 SUVs. Also, the early 2000's were more focused on the world economic crisis, the new emerging Chinese market and the opening of BMW's new production facility in Leipzig in 2005. This changed in 2005/06, mainly with the success of Toyota's Prius and rising fuel prices, causing customers to demand similar solutions. Had until then, only the hydrogen technology featured in the annual reports as a future solution for low emission vehicles, from 2005/06 on, the hybrid vehicle technology had been included in the annual reports as well. Around that time a collaboration with GM and Daimler-Chrysler was announced in order to develop a hybrid system to compete with the Japanese manufacturers. Also, in 2006/2007 BMW intensified its hydrogen combustion vehicle activities by leasing out 100 vehicles. In this period, BMW's average fleet emissions were increasingly dropping (approx. 170 gCO_2/km), however, discussions on regulations in the European Union on a limit of 130gCO_2/km increasingly created pressure. Apart from recuperating energy to its lead battery with the help of the alternator, BMW had not provided any hybrid vehicle solution so far.

In 2007, a successful year for BMW, with no signs of the financial crisis yet to come, BMW initiated a project called 'project i' (under the 'Number ONE strategy) that reviewed the technology future options. This led to a significant change in the technology strategy of BMW. Shortly after the review had finished, BMW stopped its combustion hydrogen vehicle program and announced the launch of a Mini EV trial fleet, a battery collaboration with SB LiMotive and the creation of a Joint Venture with PSA (Peugeot/Citroen). In 2010, it also announced plans to develop and produce a BEV for the mass market, while also a hydrogen and petrol hybrid vehicle prototype (using a 5kW PEM Fuel Cell, see above for APU) was presented drawing upon the experiences available in house.

Today, in the early 2010's, after a number of competitors have brought their PHEVs or BEVs to market, BMW has presented its Megacity Vehicle (BMW i3), a small lightweight BEV vehicle that is expected to reach the mass market in the end of 2013 (built in Leipzig). During that phase the acquisition of SGL Carbon, the supplier of lightweight materials for the i3 was announced. 2012/2013, in a time, where the amount of HEVs/PHEVs in BMW's portfolio is limited, BMW and Toyota have agreed to collaborate on fuel-cell systems, lithium-air batteries, lightweight technologies and electric powertrains.

Currently BMW is selling more vehicles than ever and has the highest profits it has ever made.

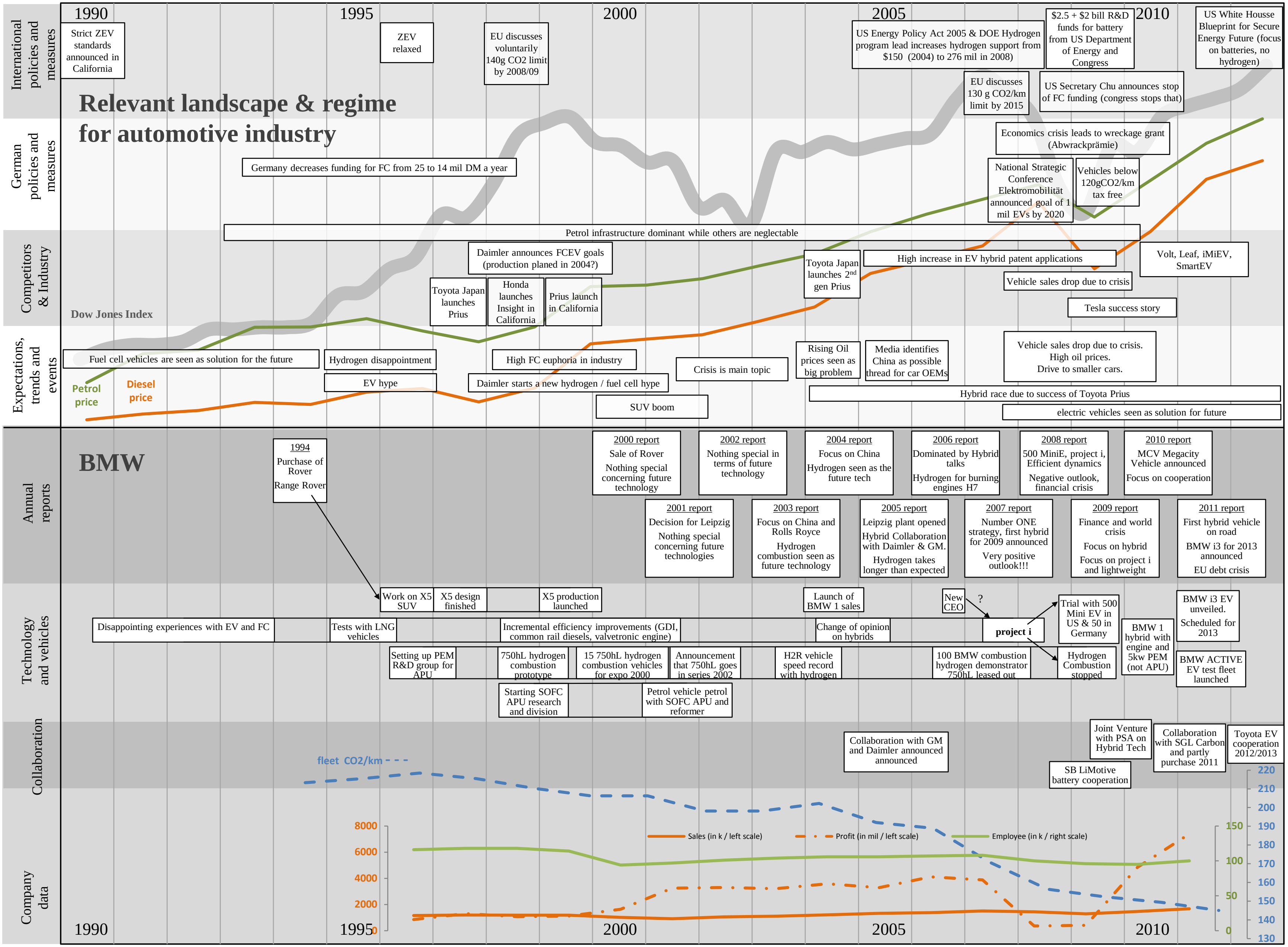

Fig. 5: Exemplary timeline of the regime and landscape relevant for an automotive OEM and BMW

3.3 Results

Based upon the system thinking outlined in Fig. 4, this section outlines the different relations that have been identified in a first study of the data provided in Fig. 5. Also it is outline how those results can be translated and used in a system dynamics model.

Two types of insights on the behaviour of this respective automotive OEM could be made based upon this case study: what are the factors that are taken into account for the choice of the direction, and when is a decision process triggered.

As an example, in terms of BMW it seems that the choice of power train technology was not affected by government research subsidies. Moreover, it chose technologies that were currently popular as well as suiting their current knowledge and product portfolio. However it did not change towars a popular technology in the moment it had become popular. Instead, triggers such as the launch of a product by a major competitoir (e.g. Necar II by Daimler) or the high pressure from the public and the success of a competitor (such as the 2nd generation Prius) were needed to trigger a change or a decision process, or just the lauch of a review project (project i). Also, oil prices or sales crisis had small influence on the research and product strategy.

So in this case the approach we have taken in this work can offer the indicators that are affecting decisions, and also what the triggers are for those decisions.

Furthermore such a study also offers insights on timelines and durations. As it can be seen by the BMW X5 project, or setting up the hydrogen PEMFC and SOFC programmes, there are common patterns in how long such processes take. Those durations can be then implemented into the future model. BMW founded a PEMFC team in 1997 and the SOFC project in 1999 and in each case they took 2 years to build a prototype APU. The existence of a division or expertise in a certain technology domain can be speciified with the help of boolean variables and then taken into account in the decision process simulation. Fig. 6 illustrates an example for the illustration of an actor.

Those are just two short examples of the type of information that can be extracted and the type of quantification can be achieved. This information can be used to parameterize the decision process in order to test the behaviour of the actor with respect to future transition scenarios.

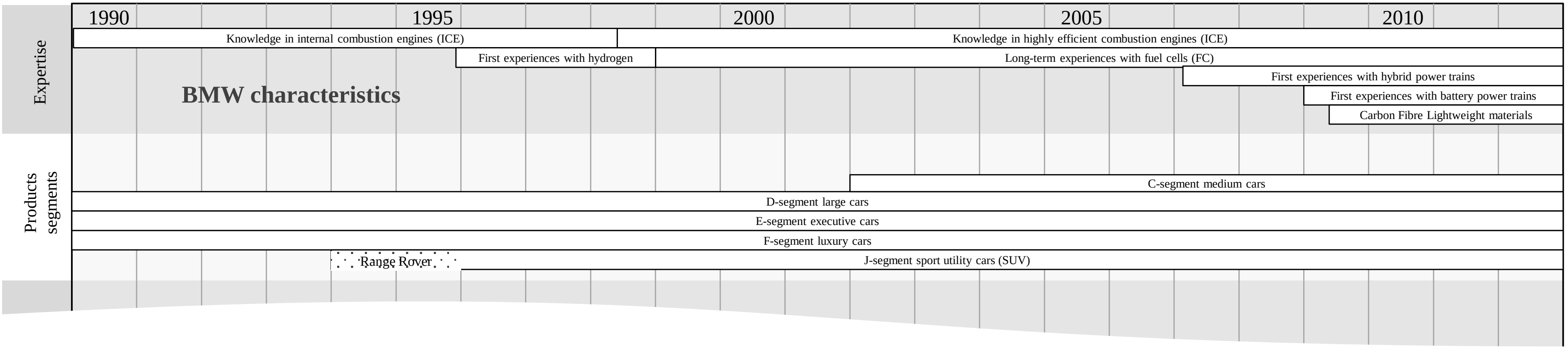

Fig. 6: Characterization of observed actor

4 Conclusion and future work

In this paper we have presented a system dynamics model archetype and approach that can be used to explore the effects of policy making and transition scenarios on actors in the automotive industry, while using insights from a variety of research domains such as transition science or the multi-level perspective. In contrast to past works where system dynamics has been used to outline the effects of certain policies or events on the diffusion of vehicle technologies, this approach has the aim to use those scenarios as input parameters in an exogenous way and to test their influence on the future behaviour of the observed actors.

However, as data on the behaviour of the automotive industry is limited, the model approach is here adapted and used to show how data from the past can be used to obtain insights on behaviour, and especially decision making. For that a case study looking the past 20 years of BMW and the relevant automotive regime has been presented.

Based upon that a set of relations is outlined, showing how approach presented here can be used to obtain insights and model parameters that can be then utilized in a model to assess future scenarios.

Our future work now concentrates on the analysis of a number of automotive actors in order to understand their behaviour and to be able to derive parameters that then allow a quantitative discussion of the effects of future transitions on the industry.

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