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Pinkse, J.; Bohnsack, R.; Kolk, A.

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**THE ROLE OF PUBLIC AND PRIVATE PROTECTION IN DISRUPTIVE INNOVATION:
THE AUTOMOTIVE INDUSTRY AND THE EMERGENCE OF LOW-EMISSION VEHICLES**

Jonatan Pinkse, René Bohnsack & Ans Kolk

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Abstract

In the automotive industry the need to move towards more sustainable trajectories of innovation has received much attention. Car manufacturers have started to develop lower-emission alternatives for the internal combustion engine, particularly electric, hybrid and fuel-cell vehicles. They face the challenge, however, of how to make a potentially disruptive, systemic, and societally embedded technology such as a low-emission vehicle attractive to mainstream customers. While literature has suggested that companies can empower the initial stages of disruptive innovation by creating protected spaces themselves and/or by taking advantage of such spaces created by public actors, the specific role of these different types of protection levers – private and/or public – has remained unclear. This article therefore investigates to what extent and how private and public protection levers affect firm-level strategies to increase the attractiveness of disruptive and systemic innovations to mainstream customers. This is explored empirically through a multiple case study of the emergence of low-emission vehicles within three car manufacturers – Daimler, General Motors and Toyota – in the context of European, Japanese and US policies. The empirical analysis is conducted on a dataset consisting of more than 9,000 articles from two trade magazines, a car magazine and a financial newspaper for the period of 1997 to 2010. As main findings, the article identifies regulation, tax incentives, and public-private partnerships as the public protection levers that impose or stimulate ‘new’ performance metrics such as fuel economy and vehicle emissions. It also finds that resource allocation, niche occupation and collaboration-integration act as the main private protection levers. Besides, two protection levers emerge from the data that are rather prominent in this context: the use of regulation imposing large-scale commercialization of low-emission vehicles and dumping of products in the market below cost price. The article concludes with two different protection trajectories – a public protection trajectory and a private protection trajectory – which explain how car manufacturers leverage the various protection levers to deal with disruptive technology. The main implication of the two trajectories is that while the public protection trajectory stalled due to the systemic, socially embedded technological impediments of electric vehicles and fuel-cell vehicles, the private protection trajectory picked up the remains of the public protection trajectory and has gained momentum, continuing until today.

Introduction

In recent times, attention has grown for the need to move towards more sustainable trajectories of innovation and to reduce dependence on fossil fuels. One of the industries in which this has come to the fore rather prominently is the automotive industry, where, as a substitute for the internal combustion engine (ICE), low-emission vehicles (LEVs) – electric, hybrid and fuel-cell vehicles – have seen bouts of interest (Bakker et al., 2012; van Bree et al., 2010). Despite widespread government support aimed at stimulating corporate innovation in LEVs, however, a major transition has not taken place yet. Due to their centrality and dominant market shares, incumbents in the automotive industry have a vested interest and seem to defend their current positions and business models, thus forming a significant barrier to change (Kemp et al., 1998). Nevertheless, there are also indications that these same companies acknowledge the need to come up with alternative cars to survive in the longer run. This is reflected in a steep increase in launches of new models based on LEV technology (Bakker et al., 2012). Regardless of the exact motive for carmakers to invest, the question remains how they can make a potentially disruptive technology such as the LEV attractive to mainstream customers (cf. Christensen, 1997; Moore, 1991). In the case of LEVs, this is all the more challenging since it concerns systemic innovation (Chesbrough and Teece, 1996; Garud and Kumaraswamy, 1995); that is, product innovation of the vehicle alone will not be enough for a transition because vehicle technology is highly interdependent with complementary technologies such as a fueling infrastructure, customer usage, and concomitant rules and regulations (van Bree et al., 2010).

The ways in which companies can pass the initial stages of disruptive innovation have been subject of debate in several streams of literature. One stream on firm-level innovation management has studied how companies can cope with disruptive change and launch

products that are not complementary to their portfolio and could cannibalize sales (Danneels, 2004). Scholars have suggested several levers to protect early-stage innovations from internal competition for resources and external competition for market share. Christensen (1997) argued that companies could structurally separate disruptive innovation activities from core business, while Moore (1991) proposed a niche approach to obtain market leadership in a well-chosen segment. What this literature leaves largely unanswered, however, is how companies manage the initial stages of disruptive innovation when it is *systemic* (Afuah, 2000; Garud and Kumaraswamy, 1995). That is, how do car companies mobilize suppliers, customers and complementors, such as fuel infrastructure providers, to also embrace the uptake of LEVs? Another stream on societal-level technological transitions argues that the government could play a pivotal role in this regard (Geels, 2002; 2004; Kemp et al., 1998). These scholars foresee a role for the government in coordinating the innovation activities of the various actors involved, in particular through the creation of niches in which systemic innovations are protected in their early stages, for example through public procurement rules, tax incentives, or subsidies (Kemp et al., 1998; Smith and Raven, 2012). What is not addressed, however, is how government policy affects firm-level innovation, which leads to the question how car companies leverage government policies in the development of LEVs.

While these two disparate literatures suggest that incumbents can empower the initial stages of disruptive innovation by creating protected spaces themselves (Christensen, 1997; Moore, 1991) and/or by taking advantage of such spaces created by public actors (Schot and Geels, 2007), the specific role of these different types of protection levers – private and/or public – has remained unclear. Therefore, this article brings together these two literatures to shed light on how and to what extent private and public protection levers affect firm-level strategies to increase the attractiveness of disruptive and systemic innovation to mainstream customers. To explore this empirically, the article focuses on the global automotive industry,

more specifically the emergence of LEVs by three main incumbents – Daimler, General Motors and Toyota – in the context of European, Japanese and US policies. Using evidence from a longitudinal study, it examines under which circumstances these companies have decided to use private and/or public protection levers and how this has affected their innovation strategies towards LEVs. Before moving to the results of the empirical study and the implications, the next sections first present a synthesis of the disruptive innovation and technological transitions literatures, and describe the method and data collection.

Literature review

Disruptive innovation and private protection levers

A critical managerial challenge related to disruptive innovation, defined as “technology that changes the bases of competition by changing the performance metrics along which companies compete” (Danneels, 2004, p. 249), is how to attract mainstream customers in the early stages of technology development (Christensen, 1997; Moore, 1991). By definition, disruptive innovations do not only change the performance metrics on which companies compete, but also underperform on those attributes that satisfy the current needs of mainstream customers (Danneels, 2004). At the time of introduction, disruptive innovations therefore tend to be attractive to only small market segments that consist of more ‘forward-looking’ customers. There is the assumption, however, that disruptive innovations will – over time – also perform well on these existing attributes or influence which attributes are valued most by the mainstream market, thus ‘redefining’ customer needs (Govindarajan and Kopalle, 2006). But before such innovations may have a transformational impact and disrupt the market, they first need to mature and reach sufficient scale. That is, in the early stages, disruptive innovations are still vulnerable to competition from within and outside and thus require some form of protection.

In case of ‘autonomous’ innovation that can be pursued independently (Chesbrough and Teece, 1996), scholars have proposed what this article refers to as *private protection levers* that companies can use to this end. Christensen (1997), who also first coined the term disruptive innovation, argued that incumbents should set up a separate business unit and thus detach disruptive innovation structurally from the core business. This allows companies to allocate resources without the common profitability requirements and thus cross-subsidize technologies that have not yet become profitable by themselves (Danneels, 2004). Moore (1991) emphasized a marketing-based approach to deal with competition from outside and attract attention from mainstream customers. He proposed a niche market approach, in which companies create a shock effect in the mainstream market by launching a product that fully satisfies customer needs, generates a word-of-mouth effect, and creates a sense of market leadership, even though it only concerns a niche. Moore’s main argument is that perceived market leadership in a specific segment will attract mainstream customers who prefer to buy from market leaders. Both the organizational and the niche market approach assume, in principle, that a company can create the protection required for the disruptive innovation to mature.

In case of systemic innovation, however, a go-it-alone approach no longer seems tenable. As Chesbrough and Teece (1996, p. 68) argued, “[w]hen innovation depends on a series of interdependent innovations – that is, when innovation is systemic – independent companies will not usually be able to coordinate themselves to knit those innovations together.” A disruptive change of systemic technologies thus relies on a significant transformation of the whole network of suppliers, customers, and complementors (Afuah, 2000; Garud and Kumaraswamy, 1995). Companies will not only have to develop new technologies, but also need to stimulate the development of a new ecosystem of suppliers and complementors. Besides, they should change the inertia of customers by promoting new

product usages and emphasizing alternative performance metrics. Hence, scholars have proposed other private protection levers for companies to mobilize these actors. Afuah (2001) argued for dynamic boundaries; that is, to enable a systemic disruptive change, companies need to become vertically integrated with suppliers of new complementary technologies and vertically disintegrate from old technology suppliers. Since the underlying knowledge tends to be tacit in the early stages of disruptive technology development, companies will depend on frequent interactions with new technology suppliers, which can be enabled by vertical integration (Afuah, 2001). Garud and Kumaraswamy (1995) proposed a private protection lever based on modular upgradability. By changing some product components while retaining others, companies create an enabling environment in which suppliers, customers and complementors can adjust to the systemic change. Modular upgradability allows suppliers of old technologies to change incrementally because some of their old technologies are still used; and likewise, customers do not need to change their product usage all of a sudden (Garud and Kumaraswamy, 1995).

Finally, a disruptive systemic change could also be protected through cooperation between companies that are horizontally interdependent, i.e. between rivals. Strategic allies may help each other to protect the disruptive innovation, because this enables them to share risks and knowledge (Dyer and Singh, 1998). Individual companies may not have all the capabilities necessary to effectuate a systemic change, and can thus protect early technology development by drawing on the complementary capabilities of rivals (Garud and Kumaraswamy, 1995). The systemic aspect implies that companies also search for new industry standards in the form of a new dominant design (Anderson and Tushman, 1990). Through cooperation with rivals, companies can attain the critical mass for gaining acceptance of the new industry standard, and thus attract mainstream customers (Chesbrough and Teece, 1996).

Disruptive innovation and public protection levers

While the systemic nature of technologies often derives from interdependence with other technologies, this can also be the result of their embeddedness in society. Social embeddedness implies that attributes of the product itself not only affect customer preferences, but also the context in which these products are used (Geels, 2002). Products and services related to energy and mobility, in particular, require infrastructures, rules, norms and regulations that shape disruptive innovations' ability to attract mainstream customers (Yu and Hang, 2010). In view of the social embeddedness of systemic technologies, scholars studying technological transitions emphasize the role of the government in coordinating innovation activities of the network of companies, suppliers, customers and complementors (Geels, 2002; Kemp et al., 1998; Smith and Raven, 2012). That is, the government is seen as able to solve the collective action problem inherent to systemic innovation (Chesbrough and Teece, 1996). Besides, governments push for displacing technologies that are harmful to the environment or health, and thus intervene to motivate mainstream consumers to adopt disruptive innovations that are beneficial for societal well-being (van Bree et al., 2010).

Accordingly, technological transitions scholars have proposed what this article refers to as *public protection levers*. Because disruptive technologies still face difficulties competing with the dominant design in the market (Anderson and Tushman, 1990), this literature emphasizes the facilitating role of the government to pro-actively create niches in which these technologies are protected in their early stages, for example through public procurement rules, tax incentives, or subsidies (Geels, 2002; Kemp et al., 1998; Smith and Raven, 2012). In contrast to Moore (1991), who viewed the niche as a space for companies to create market leadership, this literature instead highlights the nurturing and learning aspect of the niche (Kemp et al., 1998); not only for the company itself, but also for suppliers, customers and complementors (Geels, 2004; Smith and Raven, 2012). That is, the niche

serves as an ‘incubation room’ for design and development of disruptive technologies. By initiating research programs or subsidizing corporate R&D, the government gives companies the opportunity to learn and get insight into design issues, user preferences, new ways of using the technology, as well as impacts on the environment, production and maintenance (Geels, 2002; Hoogma et al., 2002). Through this process, commercial and technological uncertainties are reduced (Rice et al., 2002), internal development processes mature, and support mechanisms – such as adequate regulation and infrastructure – can emerge.

With its emphasis on public protection levers for technology development, this approach largely assumes that such learning and proto-testing will generate demand and supply in and of itself, and thus eventually lead to the creation of a mainstream market. Protection is no longer seen as necessary at the stage of commercialization, and hence supposed to cease after a controlled phase-out (Weber and Hoogma, 1998). The product advances, generally in an incremental way, to a stage in which it will be able to compete with the dominant design and enter mainstream markets. Moreover, as the niche market gradually matures and there is sufficient demand as well as concomitant regulation and infrastructure, the disruptive technology may replace the dominant design (Geels, 2002). It can be doubted, however, whether the government can create viable markets by only supporting the technology development phase. More recently, the role of the government in bridging the gap to mainstream markets has gained attention. Instead of nurturing the disruptive innovation in the initial stages, the government can help in empowering the innovation by creating (tax) incentives to influence customers’ buying behavior (Smith and Raven, 2012).

The influence of private and public protection levers on firm-level innovation: A framework

Hence, it seems that there are multiple private and public protection levers to help companies to cross the early stages of disruptive technology development. However, different protection

levers may be more effective under certain circumstances than under others (see Table 1).

[Add Table 1]

On the one hand, the stage in the innovation process – i.e. development or commercialization – affects the usefulness of each protection lever. In the initial stages of development, disruptive technologies will not yet have culminated into marketable products and thus depend more on fundamental research and a search for complementary knowledge and capabilities (Afuah, 2001). The kind of protection levers that will be most effective during these initial stages are those that enable companies to either shield the innovation from competition for resources within the organization or leverage access to complementary capabilities (Christensen, 1997; Dyer and Singh, 1998). In the later stages, when commercializing disruptive innovation, what will be more pertinent is gaining mainstream customer acceptance and stimulating the emergence of a new ecosystem of suppliers and complementors (Afuah, 2000; Geels, 2002). In other words, companies are in need of protection levers that enable them to mobilize others actors in the network.

On the other hand, and as shown in the second dimension included in Table 1, the type of disruptive innovation – i.e. autonomous, systemic, or socially embedded – influences the effective use of protection levers (Chesbrough and Teece, 1996; Garud and Kumaraswamy, 1995). In case of autonomous innovation, companies can effectuate a disruptive change fairly independently, while systemic and socially embedded innovation requires coordination with others. The main difference between the latter two types is that systemic innovation mainly involves coordination with suppliers, customers and complementors, while socially embedded innovation implicates government involvement.

In the remainder of this article two main research objectives guide the analysis. The first objective is to gain more insight into how the different protection levers have affected firm-level innovation in the case of carmakers' efforts to develop LEVs and thus explore why

certain protection levers seem to have been more effective than others. Besides, while each protection lever has been presented in isolation, in practice there is likely to be interaction between private and public protection levers in their influence on firm-level innovation. The second objective, therefore, is to identify specific protection trajectories that may prove to be more or less successful in initiating disruptive change of a systemic kind and attract mainstream customers.

Methodology and sample

Although the two literatures this article draws upon as well as the framework derived from them provide useful suggestions about the effectiveness of private and public protection levers under different circumstances (see Table 1), the aim of the empirical analysis is to further elaborate the theoretical depiction presented in the framework (Pratt, 2009). Since the main objectives were to understand how and why private and public protection levers as well as the interaction between them have affected carmakers' LEV innovation process *over time*, qualitative process data were collected, which “consist largely of stories about what happened and who did what when - that is, events, activities, and choices ordered over time” (Langley, 1999, p. 692). Using process data, the aim was to identify patterns in the way in which companies use private and public protection levers. To track developments over time, the multiple case study was limited to three incumbents in the automotive industry that have made significant investments in LEVs: General Motors, Toyota, and Daimler.

These three companies were selected because they have been the respective leaders in developing the three most prominent LEV technologies: electric vehicles (EVs), hybrid vehicles (HVs) and fuel-cell vehicles (FCVs) (Oltra and Saint Jean, 2009). In addition to the preference for different technologies, they also have their headquarters and main R&D departments located on different continents and thus display many contrasting results that

allow for theoretical replication in a multiple case study (Yin, 2009). The main challenge arising from this replication method, however, is that the fact that the companies are headquartered in different countries and mainly invested in different LEV technologies, potentially inhibits comparisons. Nevertheless, given the oligopolistic nature of the automotive industry and the global spread of the main players it was almost impossible to isolate the companies in one regulatory context. If the decision would have been made to analyze how the three companies were providing private protection and/or responding to public protection in the one country context only, for example, it would not have been possible to fully understand the LEV development process. In other words, the analysis is based on the assumption that large multinationals are, more or less, affected by and affect government policy and rivals' strategic behavior in home and host countries (Pinkse and Kolk, 2012). Understanding can thus be enhanced by embracing these interactions between markets and regulatory contexts, even though this 'real-life' approach that recognizes diversity also complicates the analysis.

To collect data, two trade magazines were selected – Automotive News and Ward's AutoWorld – and a car magazine – Autoweek – as they focus on the car industry from a well-informed outsider perspective. An analysis of their contents can thus provide insight into industry and company perceptions and offer rich descriptions of technologies and of developments within incumbents and relevant policies. Furthermore, the Financial Times was chosen because of its focus on business strategies and its attention for environmental issues as well as the broader political and economic contexts. Data were collected from magazines and newspapers instead of company sources such as public announcements and annual reports to prevent a corporate, fully self-perceived, bias. To enhance the external validity of the findings, representative data were analyzed that contain divergent perspectives on the main developments in the car industry. Moreover, magazine and newspaper articles are seen

as a stable source as they existed prior to the start of the case study; they thus provide good insight into the main themes of interest for this article and allow the collection of data that can be used for triangulation (Yin, 2009).

To build the dataset, a keyword search was performed for the period 1997-2010 using search terms of the different LEV technologies, i.e. hybrid, electric vehicle and fuel cell. In this way a dataset was generated of more than 9,000 articles over a period of 14 years. As data prior to 1997 was only accessible online for the Financial Times, this source was used for events before 1997, supplemented with information from available academic literature on the topic of LEVs or retrospective data provided by the other sources. This enabled tracking the development from 1990 onwards as good as possible. Since the dataset consists of articles from two trade journals, a car magazine and a newspaper, it represents the industry and public discourse on LEVs and might thus omit developments that are of little interest to the respective audiences. However, by using a variety of sources the attempt was made to compensate for this caveat as good as possible. Furthermore, while an initial set of more than 9,000 articles was used, not all articles turned out to be relevant. The article ended up having 6,663 coded excerpts that were used for the analysis.

To analyze the articles the qualitative data analysis software Atlas.ti 6.2 was used, which can manage large datasets and enables users to define the length of selected quotations and thus fully capture the richness of the information. For the data analysis a three-step approach was followed. In the first stage, all relevant policy interventions from 1997 until 2010 found in the dataset were tracked and, to complete the picture, interventions from 1990 until 1996 were added drawing on historic accounts in the dataset and academic literature. Policy interventions were labeled as protection lever if they were affecting the development of LEVs. In the second stage, for each company, the LEV technology development processes and strategies from 1997 until 2010 were analyzed as well as the impact of the public

protection levers. What was particularly looked at were the LEV technologies they engaged in and until what stage they continued developing LEVs, i.e. concept/prototype, test/production ready, or mass production. Then the strategies of the case companies were analyzed, not only examining their generic, production, development, commercialization and political strategies, but also evaluating the impact of and reaction to competitive moves of rivals. Besides, it was examined how the case companies managed resource allocation, lobbying efforts and project development.

In the third stage, the emerging protection levers – public as well as private – were analyzed and their interplay. First the relevant public protection levers were tracked that affected the case companies. Then the private protection levers were identified, including for example internal resource allocation for LEV technology development, inter-firm collaborations and market niche creation. All protection levers and their interactions were summarized in a matrix and illustrated visually on a timeline. Based on the visual timeline, narrative descriptions were constructed for the protection levers over time and across areas (Bourgeois and Eisenhardt, 1988). The two narrative profiles and the graphic timeline were combined to create two trajectories. These trajectories were juxtaposed with the protection matrices as well as the relevant literature and refined accordingly. Finally, the trajectories were simplified to emphasize the landmark points into a new graphic illustration, thus increasing the explanatory power while keeping richness as much as possible.

Findings

This section presents the findings as they have emerged from the data.¹ It starts out by outlining the main policy interventions that have functioned as public protection levers. It presents these by distinguishing the three main markets for the case companies, i.e. the US, EU and Japanese contexts, and identifies the relevant government-business interactions.

Subsequently, it examines strategic behavior of the three case companies more in-depth; it traces how the public protection levers have affected their LEV development process and which private protection levers have been put in place. The discussion then focuses on the interaction between public and private protection levers and suggests two protection trajectories.

[Add Table 2]

Public protection levers and LEV development

Table 2 presents the main policy interventions in the US, the EU and Japan. Based on the data, regulation, tax incentives, and public-private partnerships were identified as the main public protection levers that imposed or stimulated ‘new’ performance metrics such as fuel economy and vehicle emissions. Carmakers have not been shielded in the same way in the various markets, because they perceived the interventions differently in terms of protecting their innovations. When governments pushed for new performance metrics on which specific carmakers were still scoring low, this was often viewed as far-reaching and obtrusive. For those companies that had already taken steps to implement these new performance metrics, however, even radical measures were protective as these gave them a head-start.

The US context. Since the US was the largest car market in the world in the period under study, the US government (federal and state) had an impact on carmakers well beyond those headquartered in the US. The California Air Resource Board (CARB) initiated the first public protection lever that affected carmakers from all over the world through stringent regulation. In 1990, CARB used its privilege to regulate vehicle emissions independently from the federal government’s Clean Air Act when it mandated zero emission vehicles (ZEVs) in an attempt to fight smog in the Los Angeles Bay Area, which in practice meant imposing marketable EVs. The ZEV program required the largest carmakers – i.e. GM, Ford,

Chrysler, Toyota, Nissan, Honda, and Mazda – to sell 2% of their total sales as ZEVs by 1998; this would increase to 10% in 2003. The car industry did not see this intervention as protection, however, and disputed the program. In response to the lobbying, CARB tempered its aspirations significantly over the years. It reduced the required percentage of ZEVs several times, allowed HVs and FCVs as well, and offered the possibility to comply with neighborhood electric vehicles (NEVs). Eventually, the car industry and CARB stopped the legal ‘war’. While the original objective of the ZEV program had basically been dissolved, it has been a significant stimulus for the car industry to start developing LEVs. As Table 2 shows, the ZEV program stimulated GM and Toyota to develop electric vehicles, while Daimler bought a NEV producer.

The first important public protection lever that operated at the federal level was a public-private partnership: the Partnership for the New Generation Vehicle (PNGV). PNGV started in 1993 to develop LEV technology that would enable conventional passenger cars to drive at 80 miles-per-gallon (mpg); it foresaw the first prototypes in 2000 and mass-produced cars in 2004. The ‘Big Three’ – GM, Ford and Chrysler – suggested the formation of PNGV to the Clinton Administration in exchange for leaving the Corporate Average Fuel Economy (CAFE) standards unchanged. However, it was also a way to become less ‘uncompetitive’: US carmakers felt they were at a disadvantage because Japanese companies were allowed to collaborate in their domestic context (Lynn, 2004). Interestingly, PNGV made an exemption to antitrust regulation and allowed collaboration by US carmakers. It also brought the Big Three, government agencies and research institutes together and allowed the use of national research free of charge (Lynn, 2004). The public protection of PNGV thus operated on different levels, not only providing research funds, but also enabling inter-firm cooperation and access to government resources. Nevertheless, the partnership favored domestic companies and could also be seen as a protectionist measure instead of a stimulus for

disruptive innovation. Since PNGV was not very successful, in 2001 first a reorientation was suggested towards fuel-efficient technologies in all kinds of vehicles; at the beginning of 2002, it was terminated and replaced by a new program called FreedomCAR (Freedom Cooperative Automotive Research). Interestingly, PNGV had limited direct influence on LEV development by US carmakers, but as will be argued below it helped to set off Toyota's development of the hybrid Prius (see Table 2).

While PNGV mainly protected LEV technology development, another policy instrument – tax incentives for car buyers – pushed commercialization, after being included in the 2005 Energy Policy Act. Tax credits for HVs were capped at 60,000 cars per carmaker, unlike FCV tax credits. The caps were perceived as beneficial for US carmakers. Once Japanese companies, which reached their caps first, had depleted the allotted incentives, the set-up provided other (i.e. US) carmakers with an advantage that they might not have had in a system with other requirements (e.g. overall caps in numbers without limitation per carmaker). Nevertheless, the Energy Policy Act helped both GM and Toyota to commercialize different LEVs (see Table 2). Other relevant policy developments were the government's amendment of the CAFE standards in 2007 (for the first time in 32 years), as well as the 2008 bailout of \$25bn for the Big Three in the context of the financial crisis. Alongside this bailout of GM and Chrysler, the 2009 American Recovery and Reinvestment Act provided funds for green technologies, including development funds for advanced battery technologies and tax incentives for EVs, HVs, and plug-in hybrids.

The Japanese context. Domestic companies have always dominated the Japanese car market; foreign companies' market share has been below 10% (Japanese Automobile Importers Association, 2009). As a result, policy instruments of the Japanese government affected domestic companies in particular. The first public protection lever of significance emerged in 1991, when the Ministry of International Trade and Industry (MITI) issued a

target to have 200,000 EVs on the road by 2000. To this end, MITI organized research consortia including incumbents and universities, which not only provided funding but also facilitated knowledge spillovers (Åhman, 2006). It was extended under the Advanced Clean Energy (ACE) program in 1997 when hybrid technology was added to the research agenda – influenced by the launch of the Toyota Prius in that same year (see below). Besides research, MITI also supported commercialization by setting up a Purchasing Incentive Program (PIP) in 1996, which subsidized 50% of the additional costs of EVs. In 1997, Japan increased its budget for LEV incentives to \$68m, while PIP was continued under the Clean Energy Vehicle program in 1998, and extended to include HVs as well (Åhman, 2006), which helped Toyota to further commercialize the Prius.

As another public protection lever, MITI created the Fuel Cell Vehicles Commercializing Strategic Study Group in 1999, which forecasted that cumulative sales of FCVs would be around 5m cars in 2020. Following this line of thinking, the Japan Hydrogen & Fuel Cell Demonstration (JHFC) Project was initiated to gain insight into hydrogen production and performance, and its environmental and safety impacts. Although MITI abandoned an FCV target in 2006, because “not many people believe this scenario anymore” (Treece and Soda, 2006), the JHFC Project was continued and more car incumbents joined, and all three case companies tested FCVs under the umbrella of this project (see Table 2). In 2008, the focus of the Japanese government shifted to EVs, requesting cities to be ‘model districts’ and providing funds for infrastructure. It also stated its aim to have 50% of all cars powered by non-petrol sources by 2020. Japan implemented another incentive for green cars via an ‘eco-car tax break’ that gives \$1,025 to buyers of cars that emit 15% less than standard cars and waives purchase taxes on LEVs.

The EU context. It was only in 1995 that the EU and the European Automobile Manufacturers’ Association (ACEA) started collaborating on CO₂ emissions reductions. In

1998, this culminated in a voluntary agreement whereby European carmakers, including subsidiaries of US companies, committed to reducing the fleet average of CO₂ emissions by 20% to 140g/km in 2008 (from 186g/km in 1995). One year later, Japanese and Korean carmakers committed to a similar arrangement. Initially the EU had planned a 30% reduction goal, but ACEA strongly opposed this, arguing that it would by no means be “commercially viable” (Treece, 1998). Since there were no penalties or fees if the targets were not met, there was only a threat of future legislation. In 2003, the first review of the voluntary agreement took place and average fleet emissions turned out to be 165g/km. Due to repeated failure of ACEA members to reach the voluntary targets, the EU finally implemented CO₂ performance standards of 130g/km in 2008, with a further reduction objective to 95g/km in 2020 (European Federation for Transport and Environment, 2010). When the CO₂ performance standards were voluntary they did not provide public protection for LEVs, and the companies merely improved ICEs; once they became mandatory this trend mostly continued.

Besides the ACEA agreement, various other public protection levers for cars emerged, although mostly at the level of the Member States. In 2002, for example, two public-private partnerships started: the Clean Energy Partnership in Germany and Clean Urban Transport for Europe. The Clean Energy Partnership aimed to obtain experience with fuel cells, and several carmakers participated with fuel-cell prototypes. As part of Clean Urban Transport for Europe, various European cities tested fuel-cell buses, which were almost all provided by DaimlerChrysler. Around the same time, several Member States, including Germany, Italy and the UK, began to offer tax incentives for buyers of HVs and EVs.

In summary, the public protection levers that were launched in the US seem to have affected the three case companies most. The Japanese levers appeared to have mainly influenced home-based Toyota; while the EU levers appeared too weak most of the time to have real impact on companies’ innovation efforts.

Private protection levers and LEV development

Table 3 presents the main private protection levers that GM, Toyota and Daimler have used while developing LEVs. Based on the literature, resource allocation, niche occupation and collaboration-integration were identified as the main levers. While LEV technology developments was in part a response to public protection levers – as the preceding section outlined – they were complemented by various private protection levers.

[Add Table 3]

General Motors. GM's first journey into LEVs took place in the wake of the oil crises of the 1970s, yet without notable outcomes. It was not until 1985, when GM acquired Hughes Aircraft, a company specialized in space and missile technologies, that GM's LEV activities took off. In 1986, GM was invited to participate in the Australian Solar Challenge, in which it involved Hughes. A team was created with engineers from different GM divisions and the aircraft company AeroVironment, which built the Sunraycer that subsequently won the competition. Based on these insights, the head of that team proposed to build an electric car. Supported by GM's top management, Hughes led a team of AeroVironment and GM engineers that built the Santana, later known as the Impact EV. In 1990, this prototype was presented to the press and, as it was received positively, GM announced to take the car into production. In 1996 an enhanced version, the EV1, followed, making GM market leader in the new niche for electric vehicles (Moore, 1991).

Although GM first intended to sell the EV1 on the market, it only made it available for lease in specific areas: first in California and later also in Arizona. Covering production costs of the EV1 project itself, GM allocated significant resources with the purpose of learning. It was regarded as a valuable investment, considering the statement that it “is expensive, and cash [...] had to come from our core business [...] but we have been looking for field experience in this technology” (Jackson, 1998). Not long after, California and other

local institutions started to provide tax incentives for EVs, including the EV1, which made it more affordable to customers, enabling GM to lower the price. While the initial EV1 price was \$33,995, tax incentives reduced the price considerably, resulting in a final price of \$25,595, which translated into a \$399 three-year monthly lease. To compare, initially the monthly lease was \$530, and GM had reduced this from its own funds to stimulate demand (Autoweek, 1997). Nevertheless, in 1997, only around 300 people leased the EV1 and GM stated that increased support from governments was needed for the EV1 to be more successful. While the ZEV program was an important stimulus for the EV1, GM maintained a negative stance towards CARB and commented that “CARB focuses on one technology at an exclusion of everything else we’re trying to do” (Stoll, 2000). In response to CARB’s decision to let neighborhood electric vehicles qualify for credits, GM began selling golf carts in California to earn credits; it even went so far as giving them away for free under the condition that they were used in restricted areas only.

Although GM had put \$350m into developing the EV1, it stopped the project in 2003 arguing that demand was too low. Impediments for large-scale commercialization were batteries’ low range, high costs and lack of charging infrastructure. Nevertheless, GM was able to monitor usage and driving patterns and therefore gained knowledge for future projects. When GM stopped the EV1, it also cancelled all existing lease contracts and scrapped the cars, because maintaining service and parts would be too expensive. The program cost approximately \$1bn and in retrospect GM summarized the EV1 project by emphasizing the learning process (Truett, 2001): “On most traditional programs, an intended high-volume type vehicle program, measuring sales and profitability is the right way to view a program's success. With the EV1, that was never the intent of the program. We never expected it to grow to high volume. It was never intended to be a profit unit. We had a negotiated loss on the vehicle because we felt the learning and some of the image that we

would create by producing a vehicle of that type was worth the investment that we were going to make. We had a very defined technical learning set of objectives that we set for ourselves. And we have accomplished those absolutely in spades. So from my perspective, as the leader of advanced technology vehicles, I am focused on what we are doing in the marketplace, certainly, but a lot of my focus is what we are doing to advance the technology for future applications. The EV1 program was an unqualified success.”

GM also engaged in other technologies, first FCVs and later HVs. Between 1997 and 2009, GM presented several FCV models under the banner of project HydroGen. The HydroGen1 concept was introduced in 1998 using methanol with an onboard transformer, which was tested on a small scale in Irvine, California. In 1999, in reaction to Daimler’s lead in fuel-cell technology (see below), GM began collaborating with Toyota on FCVs (this ended in 2006). In total, GM tested around 100 FCVs, sometimes together with governments, for example, in 2008 with the German Clean Energy Partnership. GM introduced its first hybrid variant in 2005, in the Silverado pick-up truck, but this was in the form of a mild-hybrid which merely supports the ICE, but does not allow driving on battery power alone. To counterbalance Toyota’s success in the US with its full hybrid Prius (see below) and stimulated by new tax incentives granted by the Bush Administration in 2006, GM began to collaborate with Daimler to develop a full hybrid. It formed the Global Hybrid Cooperation (which BMW joined later as well) to accelerate development and share investments. The first GM full hybrid became available in 2008, 11 years after the introduction of the Prius.

Beginning in 2006, GM increasingly lost market share and faced additional financial troubles due to healthcare liabilities that apparently were not foreseen properly. The Board decided on a new strategic direction aimed at fuel efficiency, and decided to introduce a dozen hybrid models, stating that “We are setting ourselves the goal of being the fuel efficiency leader in every category in which we compete” (Mackintosh, 2006). In 2007, GM

presented the Chevy Volt, an electric car with a range extender, which is a small ICE that charges the battery when it is close to depletion. The company lobbied for government support for research on alternative battery technologies; the Bush Administration subsequently included \$42m in its 2008 budget for this purpose. While GM first sourced batteries from external suppliers, it moved towards vertically integrating battery production later. To develop EVs for the Asian market, the company also briefly collaborated with the start-up Reva. In 2008, GM had to file for bankruptcy, however, and pressed for low-cost loans from the government which were granted under the condition that it would further develop and implement LEV technologies.

Toyota. Until the Prius, Toyota was not known as a pioneer, but as a risk-averse, fast follower (Taylor III, 2006). In developing LEVs, however, Toyota has been the most successful car manufacturer in terms of commercialization, as it has sold more than a million Prius hybrids since its launch in 1997. The foundation of the Prius dates back to 1993 when PNGV was formed in the US. Toyota was not allowed to join, but instead started its own project called Global 21st century (G21), as it feared a technological lead from the Big Three (Benjamin, 2010). The goal was to develop a small fuel-efficient car for the global market. The Board of Toyota put together a team that had to develop a concept car within 12 months, for presentation at the Tokyo Motor Show in 1995. The Prius was revealed as planned with as main technological feature a propulsion system called Energy Management System, the predecessor of hybrid technology. In 1997, Toyota announced the small-scale production of the Prius , i.e. 1,000 cars per month for sale in Japan only. This enabled the company to test the technology and fix possible problems with the battery pack very close to the production site. In 2000, when Toyota had already sold 70,000 Prius models in Japan, it was made available for the world market.

In these first years, Toyota benefitted not only from the Japanese Purchasing

Incentive Program, but also cross-subsidized commercialization of the Prius with internal resources. The Japanese press suggested that the break-even point of the Prius would be around \$42,000, a figure that was denied by Toyota's president Okuda (Treece, 1997). ING Barings estimated losses at \$6,670 per car at a sales volume of 1,000 vehicles per month. The car was launched with a price tag of \$16,525 in Japan, basically 'dumping' the car below cost price. One Toyota Board member commented that "Right now, the cost is rather high" (Simonian, 1997) and that Toyota would therefore not integrate the technology in other models until costs became significantly lower. The company argued that it did not intend to make a profit but wanted to advance the technology. Around 2000, when Toyota started to sell the Prius in the US for \$19,995, it declared that the break-even point of the Prius was reached at sales figures of 200,000 vehicles. Commercialization in the US was accelerated by a careful targeting of car rentals and fleet markets, niche markets in which it became the leader.

Besides pioneering HVs, Toyota also engaged in other LEV technologies, including EVs and FCVs. The main projects in EVs were the RAV4-EV, based on an SUV, and the E-Com, an electric two-seater for urban traffic. In 1997, the RAV4-EV was made available in Japan for fleet users, and in California under the ZEV program. Nevertheless, Toyota regarded the ZEV program as counterproductive, stating that hybrids would work much better. The RAV4-EV program lasted until 2003, when Toyota announced that it would decline further orders in view of low customer acceptance and technical issues regarding the battery. Still, the company was the first one that met California's regulation that required carmakers to commercialize EVs between 1998 and 2000. Toyota did not sell NEVs to earn credits in California as it was eventually able to earn credits with its hybrid technology. Furthermore, the company invested in fuel-cell technologies. Starting in 1996, Toyota built a fuel-cell hybrid vehicle on the basis of the Highlander. In total, it developed six different

fuel-cell hybrid models, which were tested in the US and Japan. While other concept cars were presented as well, such as the Fine-N fuel-cell concept, the 1/X hybrid, and the A-Bat pick-up hybrid, none ever left the concept stage.

In Europe, Toyota was affected by the voluntary CO₂ emissions standards it had committed to through the agreement with the EU. In order to comply, the company started to produce mini-cars together with Peugeot, a model that later become known as the Aygo. However, this was seen as unattractive because profit margins on small cars were significantly lower than those on larger cars. Hence, from 2003 onwards, Toyota started to apply knowledge and expertise from the Prius to other models and offer hybrid technology for all models, pushing the hybrid as the dominant design in LEV technology. This was further reinforced by the fact that former opponents of hybrids, such as GM and Daimler, also announced their own HVs. GM's Volt put pressure on Toyota to build a plug-in hybrid, giving in to customer demands that it initially set aside. Toyota also started to collaborate with the French utility EDF to test plug-ins in France and the UK and took a 10% stake in Tesla, a small EV producer from California.

Daimler. Concerning LEVs, Daimler has mainly focused on fuel-cell technologies. This started in 1985 when it acquired a stake in aerospace company Dornier, which engaged in fuel-cell technology for spacecrafts. One year later, Dornier received an order from the European Space Agency to develop a spacecraft using fuel cells. The head of this project also envisaged an electric car without a battery. This idea about a fuel-cell vehicle was recognized as having the potential to safeguard Daimler's position of technological excellence in the future (Gray and Balmer, 1998). Project NECAR (New Electric Car) was top secret and Daimler's Board decided that no third-party funding was allowed; it would thus have to be funded with corporate money only, in close collaboration with Dornier. The development team contacted Ballard, a Canadian fuel-cell producer, to provide the necessary technologies.

In 1994, the NECAR 1 was presented to the public and the focus shifted to commercializing the technology. At this time, the German Ministry of Research and Technology became involved and provided funds.

In 1997, Daimler invested \$310m in a joint venture with Ballard to further develop the fuel-cell powertrain and produce an FCV within eight years. Subsequently, various versions were presented and prototypes participated in test environments provided by governments, such as the California Fuel Cell Partnership, the Japan Hydrogen and Fuel Cell Demonstration Project, the Clean Urban Transport for Europe, and the Clean Energy Partnership. In reaction to CARB's decision that NEVs would qualify for credits and could be commercialized instead of full-scale EVs, Daimler acquired GEM, a NEV producer that sold golf-buggy-like vehicles. In response to the ACEA agreement, Daimler further developed fuel-efficient technologies, ranging from more efficient engines and incremental improvements, such as tires with low rolling resistance, up to vast investments in micro-cars. In addition, Daimler bought Smart, a company that built small, fashionable two-seater vehicles, thus reducing its CO₂ fleet average.

For a long time, Daimler strongly opposed hybrids, which it regarded as a transition technology. In 2009, however, the company launched its first HV as a result of the Global Hybrid Cooperation with GM and stated its intention to launch two hybrids per year up to 2015. In 2009, Daimler sold 9.1% of its shares to Aabar Investments with the intention to cooperate in developing EVs. Subsequently, it bought a 10% stake in Tesla to collaborate on building electric Smarts. In 2009, Daimler also launched the first mass-produced hybrid with lithium-ion batteries and entered an alliance with the German utility RWE to test EVs in designated areas. However, Daimler also continued its commitment to FCVs as it presented the F-Cell in 2009, a car to be tested on a small scale in the US in 2010, with commercialization aimed to start between 2012 and 2015.

Discussion and conclusions

This article aimed to understand the role of public and private protection levers in the firm-level challenge to target mainstream customers with disruptive innovations. While the extant literatures on innovation management (Afuah, 2001; Christensen, 1997; Garud and Kumaraswamy, 1995; Moore, 1991) and technological trajectories (Geels, 2002; Kemp et al., 1998; Smith and Raven, 2012) identified various public and private protection levers to cross the initial stages of the innovation process, this was further elaborated on through an in-depth study of the development of low-emission vehicles in the car industry. As starting point the article argued that in the case of LEVs gaining a foothold in mainstream markets is particularly difficult, because it not only involves innovation that is disruptive, but also systemic and socially embedded.

The influence of public and private protection levers, and their interaction

As shown in Tables 2 and 3, several public and private protection levers were identified in the car industry, used with varying degrees of success. Most of these levers corresponded, to some degree, to the ones derived from the literature (see Table 1). Through internal resource allocation, for example, the three companies all established separate structures to deal with the disruptive nature of LEV technology in the initial stages (Christensen, 1997). Besides, they first targeted specific market segments (Moore, 1991); this often involved a geographically-bounded area to test the market. Toyota also deliberately, and successfully, targeted car rentals and fleet markets. The systemic aspect seemed to play a role as well. GM, for example, recently tried to reconfigure its boundaries to manage the supply of batteries (Afuah, 2001). Nevertheless, it was the social embeddedness of the technology in particular that led to the prevalence of public protection levers and involvement of the government (Geels, 2002; Smith and Raven, 2012). While incubation tended to take place within public-

private partnerships such as PNGV, tax incentives in various countries empowered prospective buyers of LEVs.

In addition, two protection levers emerged rather prominently from the findings that deserve further attention; that is, the use of regulation imposing (large-scale) commercialization of LEVs (public protection lever), and dumping of products in the market below cost price (private protection lever). As argued above, imposing mandatory regulation could be perceived as a protection lever because it rewards first movers. Nonetheless, the collective resistance of the car industry against the ZEV program and the EU-ACEA voluntary agreement to avoid mandatory legislation suggest the opposite. A case in point is GM. Even though the ZEV program matched the launch of the EV1, the company did not give up its resistance to regulation. Nevertheless, the ZEV program gave the car industry such an impulse that one could argue that without it, the whole development of LEV technologies would not have taken off in the 1990s (Oltra and Saint Jean, 2009).

Regarding the additional private protection lever that were found, both GM and Toyota appeared to use dumping to gain access to mainstream markets. Interestingly, they refused to be fully transparent about it; instead of acknowledging that it was a way to gain a foothold in the market, they emphasized the necessity to incur losses for the sake of learning about the technology. The effectiveness of dumping can be questioned, however, because this private protection lever alone seemed insufficient for both companies to gain access to mainstream customers. GM even dropped the EV1 quite rapidly despite further government incentives. For Toyota, however, dumping seemed to have paid off eventually, at least in the Japanese and US markets. Nevertheless, findings for the US indicate that other private protection levers such as market leadership in the car rental and fleet markets may have been complementary. Hence, our findings suggest that the interaction of public and private protection levers is pivotal in the further development of disruptive systemic innovations.

Public and private protection trajectories

To gain further insight into the interaction between public and private protection levers and their sequencing, two protection trajectories are suggested, derived from the analysis (see Figure 1). The first trajectory is largely driven by the international diffusion of government regulations and programs, thus labeled ‘public protection trajectory’. The second trajectory is mainly shaped through internal resource allocation and global competition between companies, hence referred to as ‘private protection trajectory’. What distinguishes the two paths is (1) the main trigger and continuing source of influence along the path, i.e. public or private protection levers,² and (2) the technological focus in terms of the type of disruption for the industry.

[Add Figure 1]

The *public protection trajectory* was largely driven by a regulatory push effect (Rennings, 2000); that is, through public-private partnerships that nurtured disruptive technology development and mandatory regulation that imposed commercialization, the car companies were incentivized to pursue LEVs. The ZEV program essentially marked the beginning of LEV development in 1990 and pushed for disruptive change, because it imposed a performance metric – zero emissions – that could not be attained with existing technology. While the program shook up the car industry (Oltra and Saint Jean, 2009), it also led to pervasive resistance, because even frontrunners did not perceive it as providing public protection. CARB could be criticized in hindsight because it immediately went for commercialization of a disruptive innovation, while the companies involved were still in a developmental phase. Besides, targeting the six largest car companies while ignoring the need to also create a new ecosystem of suppliers and complementors to develop batteries and a charging infrastructure hampered the effectiveness of the program.

Despite the mismatch between the public protection and companies’ innovation

needs, the ZEV program did push the public protection trajectory forward, because other governments imitated the initiative (see Table 2). In response to the program, Japan initiated an aggressive, revised battery-powered electric vehicle program (Åhman, 2006), while in Europe, it led to local initiatives, including an EV project in Rügen, Germany that helped speeding up Daimler's engagement in FCVs. With the decline of the ZEV program at the end of the 1990s, confidence in the electric vehicle tempered, however, and it was no longer regarded as the future solution. Nevertheless, while EVs lost momentum, FCVs became more popular. With regard to fuel-cell technology there was a better fit between the public protection lever and company needs. Firstly, the public-private partnerships put in place, e.g. the California Fuel Cell Partnership, Japan Hydrogen and Fuel Cell Demonstration Project, and Clean Energy Project in Germany, all nurtured technology development. Besides, the systemic and socially embedded nature of FCVs was acknowledged. The partnerships developed small-scale ecosystems of producers, users and infrastructure providers to test the technology and create the concomitant regulatory framework (Geels, 2002; Smith and Raven, 2012). Moreover, FreedomCAR, which took the place of PNGV, also focused on the development of new technologies and shifted attention to fuel cells. The public protection trajectory basically stalled around 2000 when GM discontinued the EV1 and Daimler revised its commercialization goal for FCVs. While cost issues and infrastructure problems started to loom already in 1999, these intensified in the following years, causing incumbents to repeatedly postpone deadlines for commercialization. After an initial hype for each technology, expectations sobered.

Hence, the public protection trajectory has not directly led to a breakthrough of LEVs in mainstream markets. This was not only due to a mismatch of the public protection levers and company innovation needs, but also to the high costs of developing and commercializing systemic, socially embedded technologies. The public protection levers seem to have been

insufficient to compensate companies for the high costs involved and mobilize the relevant actors. While companies responded to the public protection levers in this trajectory with private protection levers (see Table 2), in the case of the ZEV program these were discontinued when lobbying paid off and they could comply through different means. Daimler's declining investments in FCVs were the result of its global expansion plans in the late 1990s, as personnel and financial resources focused on the merger with Chrysler and the acquisition of Mitsubishi. Besides, since none of the LEVs developed in this trajectory created a large enough market, competition between rivals remained modest at best.

Competition between companies was exactly what spurred the *private protection trajectory*. That is, through resource allocation that shielded LEV technology from internal competition (Christensen, 1997), niche occupation that provided market leadership (Moore, 1991), and a regulatory pull effect from tax incentives (Rennings, 2000), the car companies thrust into the more mainstream market with largely 'autonomous' technologies. GM's lobby for PNGV triggered the private protection trajectory, because it was one of the reasons, besides financial problems due to overcapacity, for Toyota to start the G21 project and subsequently develop the Prius. GM's concern about the competitiveness of the automotive industry in the US vis-à-vis Japan led to a lobby for and subsequent launch of PNGV. In turn, Toyota was anxious that its main US competitors – the Big Three – would succeed with the help of the US federal government to build a more fuel-efficient car (Benjamin, 2010).

Regarding technology development, Toyota first decided to protect the project by separating it from core business (Christensen, 1997). The most important private protection lever in the first years of commercialization was the process of dumping. As mentioned above, Toyota's dumping of the Prius was relatively successful compared to GM's dumping of the EV1 and expanded from local dumping in the Japanese market towards dumping in the foreign US market. This dumping was first only complemented by tax incentives in Japan.

One could argue that Toyota could do with relatively little public protection because hybrid technology is fairly autonomous and stays closest to the ICE in terms of manufacturing and product usage, allowing for incremental adjustment of the surrounding network of suppliers and customers (Garud and Kumaraswamy, 1995). Hence, as figure 1 shows, the private protection trajectory stayed within Toyota's operations in Japan for some time and largely depended on private protection levers.

Moreover, around this time, competition did not seem to play a large role. Toyota's Prius was initially even belittled by the industry and not regarded as a serious competitor; when it was introduced in the US and Europe in 2000, it had low sales figures. In 2003, however, when GM had already discontinued the EV1 and doubts about fuel-cell technology increased, hybrids gained more traction. Toyota's competitors were concerned that the hybrid could become the dominant design in LEVs, and, subsequently, increased their involvement in hybrids, illustrated by Daimler and GM's alliance in HVs of 2004. The private protection trajectory was no longer just driven by dumping; it was complemented with other private protection levers such as market leadership in the car rental and fleet markets, and it profited in various markets from tax incentives that increasingly applied to hybrid technology (see Table 2). Toyota's market leadership in hybrids started to push the private protection trajectory forward, because other carmakers increasingly invested in EVs, also further stimulated by tax incentives.

Thus, while the public protection trajectory stalled due to the systemic, socially embedded technological impediments of EVs and FCVs (regarding range and infrastructure respectively), the private protection trajectory picked up the remains of the public protection trajectory and has gained momentum, continuing until today. Yet, whether EVs will this time manage to deal with the barriers from the need for systemic change remains to be seen.

Follow-up research that builds on and extends our exploratory study would be helpful to shed

more light on the dynamics between hybrids and electric vehicles as they currently unfold. While publicly available information was used, which means that the findings need to be taken with some caution, an in-depth study using field-level data from interviews and participative methods could further explore this.

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Notes

¹ Given the large number of sources for the findings presented here, the article does not provide detailed references of all statements except for direct quotes and links to the broader literature. Full referencing is available from the authors upon request.

² Although the two trajectories differ regarding the main impetus for change, it is still the interaction between government and business that drives the trajectory. Put differently, the private protection trajectory also relies on protection from the government, and does not assume an unrestrained working of the market.

Tables & Figures

Table 1 Private and public protection levers and firm-level innovation: a framework

	Development phase	Commercialization phase
Autonomous innovation	<i>'Separate entities'</i> Develop in structurally separate entities (Christensen, 1997)	<i>'Market leadership'</i> Seek market leadership in well-chosen niche (Moore, 1991)
Systemic innovation	<i>'Dynamic boundaries'</i> Establish dynamic boundaries, i.e. vertically integrate suppliers of new technologies (Afuah, 2000)	<i>'Modularity'</i> Stepwise adjust to new technology through modular upgradability (Garud & Kumaraswamy, 1995)
Socially embedded innovation	<i>'Incubation'</i> Nurture and learn in niches supported by governments (Geels, 2002)	<i>'Empowerment'</i> Empower innovations with tax incentives (Smith & Raven, 2012)

Table 2 Public protection levers and firm-level LEV innovation

Public Protection	Influence on firm innovation	Interaction with private protection	Outcome of protection
Regulations			
<i>Mandatory</i>			
1990: ZEV program (California)	<p><i>1st stage</i></p> <ul style="list-style-type: none"> GM: developed electric vehicle EV1, leased in specific areas Toyota: built EV based on RAV4 Daimler: not required to participate <p><i>2nd stage</i></p> <ul style="list-style-type: none"> GM: built Club Car Pathway DaimlerChrysler: bought GEM Toyota: used hybrid credits 	<ul style="list-style-type: none"> Incumbents subsidized the limited commercialization with their own resources GM announced giving away free leases for the Pathway to comply with regulation Car companies integrated suppliers vertically 	<ul style="list-style-type: none"> The ZEV program was too ambitious, car companies lobbied against it until the mandatory commercialization of ZEVs was abolished ZEV mandate was adopted by various other States and also to EV tests elsewhere, e.g. Rügen, Germany Stimulated BPEV expansion plan in Japan GM and DaimlerChrysler obtained court injunction and were able to freeze the regulation

<i>2004: CAFE increase for light-trucks (US)</i>	<ul style="list-style-type: none"> • GM: integrated mild-hybrid technology • Toyota: benefited from Prius credits • Daimler: paid penalties 	<ul style="list-style-type: none"> • Companies made no profit on LEV technology, but cross-subsidized with profits from light-trucks • GM collaborated with Daimler to develop full hybrids 	<ul style="list-style-type: none"> • More stringent standards stimulated commercialization of LEV technology
<i>2009: CO₂ regulation (EU)</i>	<ul style="list-style-type: none"> • Carmakers were already engaged in hybrid technology, but no plans to engage in more radical LEV technologies due to the regulation • Incumbents tried to comply partially with non-technology-related means, e.g. weight reduction or low-resistance tires and improved ICE efficiency 	<ul style="list-style-type: none"> • Required all carmakers to invest in LEV technology to comply • Daimler was particularly affected as they have the highest fleet average CO₂ emissions 	<ul style="list-style-type: none"> • Regulation achieved that incumbents engaged more in LEV technologies, but outcomes were not clear at the time of analysis. • The companies engaged in additional fuel saving technologies
<i><u>Voluntary</u></i>			
<i>1997: BPEV Expansion Plan (Japan)</i>	<ul style="list-style-type: none"> • The third electric vehicle expansion plan (BPEV) was altered and included hybrids and fuel cells 	<ul style="list-style-type: none"> • Toyota presented various fuel cell cars 	<ul style="list-style-type: none"> • Stimulated other governments to implement incentives and stimulated fuel-cell research
<i>1998: Voluntary CO₂ regulation (EU)</i>	<ul style="list-style-type: none"> • GM: average reduction achievement • Toyota: achieved highest reduction rate • Daimler: achieved lowest reduction 	<ul style="list-style-type: none"> • Toyota built plant with Peugeot for small cars (not LEVs) • Daimler bought small car firm “Smart” to support compliance 	<ul style="list-style-type: none"> • Voluntary targets did not trigger LEV commercialization
Tax incentives			
<i>1996: Purchasing Incentive Program (Japan)</i>	<ul style="list-style-type: none"> • Was targeted at EVs initially, but only 400 cars benefited, and program had little influence. • Later it included hybrids which allowed Toyota to benefit 	<ul style="list-style-type: none"> • Toyota benefited from incentives but had to subsidize the Prius also with its own resources 	<ul style="list-style-type: none"> • Toyota sold more than 70,000 hybrids until 2000
<i>2000: PowerShift grant scheme (UK)</i>	<ul style="list-style-type: none"> • Toyota: commercialized Prius in the UK • GM: n/a • Daimler: n/a 	<ul style="list-style-type: none"> • Toyota subsidized Prius sales 	<ul style="list-style-type: none"> • Stopped in 2006 as funds seemed insufficient to kick-start LEV mass commercialization
<i>2005: Energy Act (US)</i>	<ul style="list-style-type: none"> • GM: launched Silverado, Saturn Vue • Toyota: benefited from the incentives with the first 60,000 hybrids • Daimler: n/a 	<ul style="list-style-type: none"> • GM: subsidized commercialization additionally with own resources • Toyota: reached break-even after it sold 200,000 cars, so was not required to subsidize 	<ul style="list-style-type: none"> • Hybrids gained increasing popularity and large incumbents depleted the allotted incentives
Public-private partnerships			
<i>1992: Rügen EV Test (Germany)</i>	<ul style="list-style-type: none"> • Daimler and other German car producers tested 60 EVs. 	<ul style="list-style-type: none"> • Stimulated Daimler to develop fuel-cell cars and design the A-Class which was prepared to integrate 	<ul style="list-style-type: none"> • Project was discontinued in 1996.

			fuel cell or battery stacks	
1993: PNGV (US)	<ul style="list-style-type: none"> • GM: developed Precept concept • Daimler and Toyota were not allowed to participate 	<ul style="list-style-type: none"> • Toyota started G21 project to pre-empt potential competitive advantage of the Big 3; resulted in the Prius 	<ul style="list-style-type: none"> • PNGV was seen as a means to avoid CAFE standard increases • Substituted by FreedomCAR which focused on fuel cell technology 	
2002: JHFC Project (Japan)	<ul style="list-style-type: none"> • All participated to obtain real-world driving information • GM: HydroGen • Toyota: FCHV • Daimler: F-Cell 	<ul style="list-style-type: none"> • Incumbents provided cars, e.g. GM gave car free of charge for one year to FedEx 	<ul style="list-style-type: none"> • Initial target of 5m FCVs by 2020 was abandoned in 2006 • Project was phased out in 2011 	
2002: Clean Energy Partnership (Germany)	<ul style="list-style-type: none"> • GM: Hydrogen • Toyota: FCHV • Daimler: F-Cell 	<ul style="list-style-type: none"> • Incumbents provided cars 	<ul style="list-style-type: none"> • Project still operating 	

Table 3 Private protection levers and firm-level LEV innovation

Private Protection	Influence on firm innovation	Interaction with public protection	Outcome of protection
Resource Allocation			
<i>Leading</i>	<ul style="list-style-type: none"> • GM: pioneered mass-produced EVs and developed the EV1 • Toyota: developed a fuel-efficient car with the Prius • Daimler: developed fuel cell technology to support reputation of technical excellence 	<ul style="list-style-type: none"> • GM: EV1 driven by ZEV program and supported by tax incentives • Toyota: was supported by various tax incentives • Daimler: was able to test technology in various partnerships with governments 	<ul style="list-style-type: none"> • GM: EV1 not commercially viable and stopped; cars were scrapped • Toyota: Prius provided Toyota an image of being innovative and green • Daimler: FCVs not commercially viable; stimulated governments to support FCVs, e.g. California Fuel Cell Partnership and Japan Hydrogen & Fuel Cell demonstration project
<i>Learning</i>	<ul style="list-style-type: none"> • GM, Toyota and Daimler developed and tested fuel-cell cars globally 	<ul style="list-style-type: none"> • Supported by fuel infrastructure, e.g. German Clean Energy Partnership 	<ul style="list-style-type: none"> • Fuel-cell cars never left the testing phase
<i>Dumping</i>	<ul style="list-style-type: none"> • GM: launched the EV1 below cost price • Toyota: sold initially Prius at a loss, break-even assumed at 200,000 cars 	<ul style="list-style-type: none"> • GM: supported by local and national tax incentives • Toyota: supported by government incentives in Japan and US 	<ul style="list-style-type: none"> • GM: EV1 never achieved scale and was scrapped • Toyota: Prius became the best-selling hybrid
Niche Occupation			
<i>Targeting car rentals</i>	<ul style="list-style-type: none"> • Toyota: sold Prius to car rentals at no discount 	<ul style="list-style-type: none"> • Toyota: supported by tax credits, exemptions, and fast-lane usage 	<ul style="list-style-type: none"> • Toyota: Customers of car rentals were attracted by novelty, green image and

			<ul style="list-style-type: none"> additional advantages Prius became best-selling commercial vehicle in the US
<i>Targeting fleet markets</i>	<ul style="list-style-type: none"> Toyota: targeted fleet markets with Prius 	<ul style="list-style-type: none"> Toyota: supported by tax credits, exemptions, and fast-lane usage 	<ul style="list-style-type: none"> Toyota: Prius became best selling fleet-market car
Collaboration/Integration			
<i>With competitors</i>	<ul style="list-style-type: none"> GM: teamed up with Toyota in 1999 to develop fuel cell technology which was dominated by Daimler Daimler: teamed up with GM in 2004 to develop full hybrid technology to catch up with Toyota 	<ul style="list-style-type: none"> Publicly funded test platforms were available, e.g. California Fuel Cell Partnership or Japan Hydrogen & Fuel Cell demonstration project Government incentives were available for hybrids in various countries 	<ul style="list-style-type: none"> Collaboration was stopped as fuel cells proved to be far away from commercialization Developed and integrated HV technology into product portfolio
<i>With new entrants</i>	<ul style="list-style-type: none"> GM: collaborated with Reva to develop small EV for Asian market Toyota: bought 10% stake in Tesla to speed up EV development Daimler: had ZyteK retrofit 100 Smarts to EVs 	<ul style="list-style-type: none"> GM: generous tax incentives for EVs were emerging Daimler: tested Smart EV in London; benefited from free charging and tax exemption 	<ul style="list-style-type: none"> GM: ended partnership after Mahindra&Mahindra bought controlling stake Toyota: no EV at the time of this study Daimler: project still ongoing
<i>With suppliers</i>	<ul style="list-style-type: none"> GM: sourced batteries for HVs amongst others from Orion Township Toyota: started joint venture with Panasonic to build batteries for Prius Daimler: started joint venture with Ballard for fuel-cell technology 	<ul style="list-style-type: none"> GM: tightening CAFE standards in the US; tax credits Toyota: tax incentives in most markets Daimler: were able to test the technology in public tests 	<ul style="list-style-type: none"> GM: eventually built its own battery plant Toyota: increased stake from 40% to 80% Daimler: sold part of its shares in joint venture to Ford in 2007

Figure 1 Private and public protection trajectories