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CAR FIRMS AND LOW-EMISSION VEHICLES

The evolution of incumbents' strategies in relation to policy developments



René Bohnsack

Car firms and low-emission vehicles:

The evolution of incumbents' strategies in relation to policy developments

René Bohnsack

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Car firms and low-emission vehicles:

The evolution of incumbents' strategies in relation to policy developments

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Faculteit Economie en Bedrijfskunde

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1 Introduction

During the course of the 20th century, the passenger car had a significant transformative effect on societies in developed countries and, more recently, on those in developing countries. While at the beginning of the century cars were used mainly by rich people, they soon became the standard mode of personal transportation. Cars transformed activity patterns such as social interactions, employment and transportation of goods (Vilhelmson, 1999). They have provided mobility, brought freedom of movement to people and even created a collective culture around cars (Sheller, 2004). What is more, cars stimulate feelings, passions and experiences.

However, cars have been the cause for major problems as well. For example, the production of cars requires large amounts of energy, and the necessary infrastructure causes significant changes in the landscape. In particular, the usage of cars consumes large amounts of petrol, an issue that has received widespread attention in recent years (Moriarty & Honnery, 2008a). Cars' reliance on oil due to the internal combustion engine (ICE) contributes to resource depletion, energy security issues, pollution and climate change. Oil is becoming scarce and the remaining oil resources are often located in politically unstable regions of the world, threatening the reliable supply of oil. Moreover, cars contribute to climate change. In Europe, transport-related emissions alone account for 20 percent of all carbon dioxide (CO_2) emissions (European Commission, 2012). Besides, car emissions, particularly in urban areas, have negative health effects and increase the risk of death (Samet et al., 2000).

One important way to deal with these challenges are low-emission vehicles (LEVs), such as hybrid cars, electric cars or fuel-cell cars. Yet, LEVs pose significant challenges to established car manufacturers, also referred to as incumbents. For example, they threaten the dominance of the internal combustion engine and the competencies that car manufacturers have built up for over a century. What is more, LEVs pose a chicken-and-egg problem; that is, LEVs are not built on a large scale if the necessary recharging/refuelling infrastructure is not in place, but the infrastructure is not built without adequate demand for LEVs (Romm, 2006).

Therefore, governments have stepped in and stimulated LEV development. For the last two decades, governments in multiple countries have increasingly tried to stimulate a move towards low emission vehicles. They have done so by providing platforms to develop LEVs; adopting new regulations targeting fuel efficiency and emissions; and implementing incentives for consumers to purchase LEVs (Mikler, 2010). Considering the international operations of incumbents in the industry, these policy developments pose significant challenges for car firms and are critically observed in the industry. Harry Pearce, Vice Chairman of General Motors uttered (Baker, 1998: 14):

> 'Government cannot and should not dictate the market. [...] It can serve as a catalyst providing leadership and financial incentives; educating the public in a balanced way; creating rational, market-based tax and regulatory policies; and supporting long-term technology research.'

Nevertheless, the various policy interventions have spurred car firms' LEV efforts around the world, and in the late 1990s, LEVs emerged on a larger scale for the first time. The engagement in cleaner, more climate-friendly technologies has grown very rapidly, and new products and markets have been emerging. Yet, the plethora of government interventions, fast technological development, uncertain market demand, and, not least, competitive moves have created considerable uncertainty for car firms that largely operate on an international scale. John Wallace, Ford's alternative fuel vehicle programs 1998, acknowledged this development (Sedgwick, 1998: 26):

> 'The industry is fragmenting. We are going to see a lot of different powertrains and fuels simultaneously in the market. It's really going to be a big change. It will be a very complicated world. We won't have one fuel and one type of powertrain.'

The two statements above from industry practitioners point to three issues. First, car firms have moved from a relatively stable situation with regard to government regulation to an environment in which they face multiple policy interventions related to LEVs. Considering international operations of incumbents in the industry, these interventions create challenges to the firms—e.g., which technologies they should engage in—and great uncertainty about how the situation will evolve. At the same time, firms might gain a competitive advantage by pre-empting policies. For example, Toyota gained a competitive advantage by bringing the Prius to the market. The firm is now considered innovative and relatively sustainable.

Scholars have studied the developments of LEVs; however, they have focussed in particular on the technological aspects of LEVs (Frenken, Hekkert, & Godfroij, 2004; Rajashekara, 1994); the future of mobility (Eggers & Eggers, 2011; Kosugi, Tokimatsu, & Yoshida, 2005; Moriarty & Honnery, 2008a, 2008b); and more recently also on the competitive forces that shape innovation trajectories (Wesseling, Faber, & Hekkert, 2013). Yet, to the author's knowledge, no study has provided a comprehensive review of the evolution of LEVs considering the interplay between businesses and policies on an international level and examined the potential transition towards LEVs.

Second, LEVs, in addition to being technologically challenging, have much higher production costs than cars with an ICE. But to be appealing to the mass market, LEVs should not be more expensive than conventional cars. Thus, LEVs need to be protected initially—that is, subsidized by governments or firms—until they can compete with ICE cars. For instance, in order to learn about and improve hydrogen cars, governments have provided real-world testing platforms, invested in infrastructure and educated users. Car firms have also funded the expensive technologies themselves—e.g., Daimler built one of the largest fuel-cell test fleets in the world. Recently a few car manufacturers have also committed to the production of electric vehicles (EV)s.

The existing literature has studied different government protection mechanisms and the respective responses of car manufacturers (Åhman, 2006; Koopman, 2010; Pilkington, 1998; Shiau, Michalek, & Hendrickson, 2009), such as the effect of emission regulation, demonstration projects (Ahman, 2006; Harborne et al., 2007; Mikler, 2005) and government incentives (Bento, 2010; Beresteanu & Li, 2011; Serra, 2012). Yet, existing studies predominantly apply a top-down perspective considering a one-directional influence from the government towards firms. Hence, these studies have not fully addressed the bi-directional interplay between car manufacturers and governments protecting early LEV development. Besides, with regard to EVs there is no clear insight into incumbents' strategic motivations—next to government policies—to engage in EV production.

Third, LEVs are, in some respects, fundamentally different from cars with an ICE, and therefore require changes in car manufacturers' business model, such as in pricing, the value chain, or the required infrastructure. However, firms have routines, resources and capabilities that impede easy changes in their business models. For instance, Nissan partnered with the start-up Project Better Place to provide mobile-phone-like payment plans for EVs. In addition, the firm obtained generous government funds from different countries to build component plants. These required a divergence from common business practices—for

instance increasing the distance between the location of the assembly and the production of core components. Scholars have shown that incumbents face more constraints in designing innovative business models (Ahuja & Lampert, 2001; Bettis & Prahalad, 1995; Bower & Christensen, 1995) and also portrayed new business models which could suit LEVs (Wells, 1991; Wells, 2004; Wells & Nieuwenhuis, 2004; Williams, 2006). What remains unclear, however, is how a firm's path dependence and government support influence the design of new business models for LEVs.

The issues laid out above are examined in more detail in this dissertation. It explores how the interplay between policy interventions and car firms' strategies has evolved over time and how firms have adapted their innovation strategies and business practices. This dissertation aims to improve the understanding of the developments in the international car industry in the past 15 years with regard to low-emission vehicles. More specifically, it seeks to understand the strategies of car manufacturers and especially the interplay between incumbents and governments. Specific attention will be paid to electric vehicles.

The author attempts to contribute to selected scholarly debates. Most importantly the dissertation seeks to contribute to the stream of literature on LEVs in general, shedding light on the evolution of LEVs in an international context. Next, it attempts to link the socio-technical systems literature (Geels, 2002, 2004; Kemp, Schot, & Hoogma, 1998) with the strategic management of innovation literature (Christensen, 1997; Keupp, Palmié, & Gassmann, 2012). Also, it adds to the burgeoning literature on business models and contributes to the understanding of sustainable innovations. To this end, the dissertation will focus on the following four questions:

1. How have low-emission vehicles evolved internationally over the years, and in what way have *government policies influenced firm innovation*?

2. In the trajectory of low-emission vehicles, what has been the influence of *protection mechanisms* of governments and incumbents, respectively?

3. In designing business models, how have incumbents dealt with the tension of the *disruptive character of electric vehicles and the influence of government intervention*?

4. Considering the disruptiveness of low-emission vehicles, what have been the *strategic motivations* of car firms to engage in electric vehicles?

Each question will be dealt with in an empirical chapter. The dissertation consists of two parts. Part One contains two introductory chapters: Chapter 2 discusses the main trends in production approaches, product development and innovation in the car industry, while Chapter 3 explains the most important LEV technologies, and briefly introduces perspectives of car companies and governments on LEVs, as precursor to Part Two, that consists of four empirical chapters (see Table 1.1). Chapter 4 provides an overview of the international developments of LEVs from 1997 until 2010, studying hybrid, electric and fuel-cell technologies and illustrates the interplay between incumbents and policies in different geographical areas and at different policy levels. Chapter 5 examines the influence of public and private protection on LEVs' development trajectory from 1997 until 2010 based on an analysis of three case firms: General Motors, Toyota, and Daimler, which have followed different trajectories. Next, Chapter 6 focuses on electric vehicles in the period from 2006 until 2010. It examines the strategic choices that car firms, incumbents as well as new entrants, made in their business models in light of the disruptiveness of the technologies and the presence of government incentives. Last, Chapter 7 explores three case firms, General Motors, Nissan and Mitsubishi from 2006 until 2010 with regard to their motivations to engage in the production of EVs. Finally, the conclusion presents the answers to the four research questions, sets forth the main implications of the research findings, addresses limitations and suggests avenues for future research.

Table 1.1: Studied periods, firm foci and technology foci of the four empirical chapters

Chapter	Title	Studied period	Firm focus	Technology focus
4	*The evolution of low-emission vehicles: Car manufacturers and policy interventions*	1997 – 2010	Incumbents	Hybrid vehicles, electric vehicles, fuel-cell vehicles
5	*The role of public and private protection in disruptive innovation: The automotive industry and the emergence of low-emission vehicles*	1997 – 2010	General Motors, Toyota and Daimler	Hybrid vehicles, electric vehicles, fuel-cell vehicles
6	*Business models for sustainable innovation: Exploring strategic choices in the case of electric vehicles*	2006 – 2010	Incumbents and new entrants	Electric vehicles
7	*Exploring incumbent motivations for producing electric vehicles*	2006 – 2010	General Motors, Nissan and Mitsubishi	Electric vehicles

References

Åhman, M. (2006). Government policy and the development of electric vehicles in Japan. *Energy Policy, 34*(4), 433–443.

Ahuja, G., & Lampert, C. M. (2001). Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. *Strategic Management Journal*, *22*(6-7), 521–543.

Baker, K. (1998). GM R&D moves ahead on clean and green. *Automotive News*, *71*(5755), 14.

Bento, N. (2010). Dynamic competition between plug-in hybrid and hydrogen fuel cell vehicles for personal transportation. *International Journal of Hydrogen Energy*, *35*(20), 11271–11283.

Beresteanu, A., & Li, S. (2011). Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles in the U.S. *International Economic Review*, *52*(1), 161–182.

Bettis, R., & Prahalad, C. (1995). The dominant logic: Retrospective and extension. *Strategic Management Journal*, *16*(1), 5–14.

Bower, J., & Christensen, C. (1995). Disruptive technologies: catching the wave. *Harvard Business Review*, (Jan-Feb), 43–53.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Eggers, F., & Eggers, F. (2011). Where have all the flowers gone? Forecasting green trends in the automobile industry with a choice-based conjoint adoption model. *Technological Forecasting and Social Change*, *78*(1), 51–62.

European Comission. (2012). CO2 emissions from new cars down by 3% in 2011. Retrieved May 27, 2013, from http://ec.europa.eu/clima/news/articles/news_2012062002_en.htm

Frenken, K., Hekkert, M., & Godfroij, P. (2004). R&D portfolios in environmentally friendly automotive propulsion: Variety, competition and policy implications. *Technological Forecasting and Social Change*, *71*(5), 485–507.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6-7), 897–920.

Harborne, P., Hendry, C., & Brown, J. (2007). The Development and Diffusion of Radical Technological Innovation: The Role of Bus Demonstration Projects in Commercializing Fuel Cell Technology. *Technology Analysis & Strategic Management*, *19*(2), 167–188.

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–198.

Keupp, M. M., Palmié, M., & Gassmann, O. (2012). The Strategic Management of Innovation: A Systematic Review and Paths for Future Research. *International Journal of Management Reviews*, *14*(4), 367–390.

Koopman, G. J. (2010). Policies to Reduce C02 Emissions from Cars in Europe. *Transport Economics*, *29*(1), 53–70.

Kosugi, T., Tokimatsu, K., & Yoshida, H. (2005). Evaluating new CO2 reduction technologies in Japan up to 2030. *Technological Forecasting and Social Change*, *72*(7), 779–797.

Mikler, J. (2005). Institutional reasons for the effect of environmental regulations: Passenger car CO 2 emissions in the European Union, United States and Japan. *Global Society*, *19*(4), 409–444.

Mikler, J. (2010). Apocalypse now or business as usual? Reducing the carbon emissions of the global car industry. *Cambridge Journal of Regions, Economy and Society*, *3*(3), 407–426.

Moriarty, P., & Honnery, D. (2008a). Low-mobility: The future of transport. *Futures*, *40*(10), 865–872.

Moriarty, P., & Honnery, D. (2008b). The prospects for global green car mobility. *Journal of Cleaner Production*, *16*(16), 1717–1726.

Pilkington, A. (1998). The fit and misfit of technological capability: Responses to vehicle emission regulation in the US. *Technology Analysis & Strategic Management*, *10*(2), 211–224.

Rajashekara, K. (1994). History of electric vehicles in General Motors. *IEEE Transactions on Industry Applications*, *30*(4), 897–904.

Romm, J. (2006). The car and fuel of the future. *Energy Policy*, *34*(17), 2609–2614.

Samet, J., Dominici, F., Curriero, F., Coursac, I., & Zeger, S. (2000). Fine particulate air pollution and mortality in 20 US cities, 1987–1994. *The New England Journal of Medicine*, *343*(24), 1742–1749.

Sedgwick, D. (1998). Wallace: Ford chargers better safer than GM's. *Automotive News*, *71*(5748), 26.

Serra, J. (2012). *Electric vehicles: technology, policy, and commercial development*. New York: Earthscan.

Sheller, M. (2004). Automotive Emotions: Feeling the Car. *Theory, Culture & Society*, *21*(4-5), 221–242.

Shiau, C., Michalek, J., & Hendrickson, C. (2009). A structural analysis of vehicle design responses to Corporate Average Fuel Economy policy. *Transportation Research Part A: Policy and Practice*, *43*(9-10), 814–828.

Vilhelmson, B. (1999). Daily mobility and the use of time for different activities. The case of Sweden. *GeoJournal*, *48*(3), 177–185.

Wells, P. (1991). East-West partnerships in automobiles. *Long Range Planning*, *24*(2), 75–81.

Wells, P. (2004). Business Models : The Case of the Automotive Industry. *IIMB Management Review*, *16*(4), 15–24.

Wells, P., & Nieuwenhuis, P. (2004). Business models for relocalisation to deliver sustainability. *Greener Management International*, *47*(Autumn), 89.

Wesseling, J. H., Faber, J., & Hekkert, M. P. (2013). How competitive forces sustain electric vehicle development. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2013.02.005

Williams, A. (2006). Product-service systems in the automotive industry: the case of micro-factory retailing. *Journal of Cleaner Production*, *14*(2), 172–184.

Part I

Introductory chapters

2 Developments in the car industry: Main trends in production approaches, product development and innovation

Around 1900, many companies entered the car industry and developed radical technologies. For instance, different propulsion technologies such as the first hybrids, cars propelled by steam and also electric cars were introduced. Yet, after an initial period of technological variation, the internal combustion engine using petrol emerged as the dominant design and a much smaller number of large companies remained in the industry.

Today, car manufacturers face increasing competition in an industry which is based on economies of scale (Orsato & Wells, 2007). Central to the competitiveness of car manufacturers have been their production approaches and product development. This chapter summarizes literature on these topics and serves as background information for the following chapters. Therefore, this chapter will describe the main trends in the industry, paying particular attention to production approaches (2.1), product development (2.2) and product innovation (2.3).

2.1 The evolution of production approaches

Manufacturing one car requires the production and assemblage of thousands of parts (Ro, Liker, & Fixson, 2007). Therefore, the competitiveness of car manufacturers is, to a large extent, determined by their internal efficiency (Turnbull et al., 1989). A central feature of this efficiency is the continuous improvement of production. Hence, this section provides an overview of the evolution of manufacturing approaches in the car industry.

2.1.1 From craft production to mass production

At the beginning of the twentieth century, cars were produced through *craft production*; that is, vehicles were custom made, one piece at a time and, therefore, were very expensive (Womack, Jones, & Roos, 1990). At the time, car manufacturers' strategy was to build few cars—ones that warranted high profit margins—and to guarantee that all products were sold, as demand exceeded supply (Rubenstein, 2001). What is more, as a car was a luxury product, manufacturers reinforced the exclusivity by breaking speed records or long-distance records.

This period lasted until 1914 (Nieuwenhuis & Wells, 2007), when *mass production*—later also known as Fordism, after Henry Ford—took over. One reason for this change was

that Ford, himself a 'daredevil' on racing circuits, had been pressured by shareholders to build more cars for the public (Rubenstein, 2001). In addition, Ford recognized that—contrary to widespread belief—cars were not just recreational vehicles for rich people; there was also a demand among poorer people for inexpensive cars. Subsequently, at the now famous Highland Park plant close to Detroit, Ford introduced the moving assembly line to the car industry and inaugurated the era of mass production, which became the standard for most of the 20th century. This major innovation changed the industry. Cars were now standardized and produced on a large scale and, therefore, were relatively cheap. The motivation behind the strategy was to reduce the costs of production and to increase demand (Rubenstein, 2001).

However, mass production had its pitfalls. First, because of the extremely high costs of the assembly line and the tools themselves, car manufacturers needed high utilization of their plants and could not afford a production stop. A halt anywhere in the line would stop the entire production process. Therefore, various buffers were built into the system, such as more workers, more space, more supplies and redundant machines. Second, employees were often responsible for only one task, causing repetitive and boring work conditions. Third, because of the large investments in car-specific manufacturing tools, manufacturers postponed introductions of new car designs as long as possible. As Rubenstein (2001: 34) observed, "Mass production used narrowly skilled professionals to design products made by unskilled workers tending expensive single-purpose machines that churned out high volumes of standardized products, which then piled up in inventory until they were needed."

In 1950, Eiji Toyoda, the founder of Toyota, visited Ford to learn about U.S. production methods. However, the Japanese car industry was just emerging, and the demand was insufficient to warrant investment in redundant machines, specialist workers and vast spaces, all necessary for mass production. Hence, Toyota chose to adapt its production system to suit its circumstances. It installed machines that could be retooled more easily and used flexibly. Workers were trained to use multiple machines to increase flexibility and to improve the job conditions. Space and resources were used carefully to reduce waste (Rubenstein, 2001). In short, Japanese car manufacturers in general, and Toyota in particular, were pioneering new production approaches.

2.1.2 The emergence of lean production

Japanese car manufacturers gained a significant cost advantage over their U.S. and European competitors in the 1970s due to their idiosyncratic manufacturing approach (Richardson,

1993). U.S. and European car manufacturers became concerned about Japan's manufacturing competitiveness and ordered researchers to analyse the Japanese method, which resulted in the book *The Machine that Changed the World* (Womack et al., 1990). This study had a significant impact on U.S. and European car production (Rubenstein, 2001), as it illustrated Japanese car manufacturers'—especially Toyota's—competitive advantage. Japanese manufacturers turned out to be superior in both productivity and quality measurements.

Productivity in the car industry was measured in hours per vehicle, for activities including welding, painting and assembly. With regard to productivity, the study showed that Japanese manufacturers needed 16.8 hours in Japan to produce a car; Japanese manufacturers producing in the U.S. (in so-called transplants) needed 21.2 hours; U.S. manufacturers needed 25.1 hours; and European manufacturers 36.2 hours, which was more than double the time for an equivalent car in Japan. With respect to quality, which is measured in defects per hundred cars, Japanese car manufacturers showed the lowest rate of defects (60) and European cars the highest (97). The study found that Japanese car manufacturers used less space, that workers were more flexible (and also less absent) and that they used less inventory. This resulted in costs advantages of almost USD 1,926 per vehicle by Japanese manufacturers (Rubenstein, 2001), which constituted USD 821 in labour costs, including additional wages and health care costs, USD 985 in capital costs, including additional machinery and excess capacity, and organisational deficiencies of USD 120, due to repetitive tasks.

The period of Fordist mass production lasted until 1970 and was (slowly) replaced by what is now known as *lean production*, a term for the Japanese production system coined by Womack et al. (1990) (also often called the Toyota Production System). In addition to the factors mentioned above, lean production was also an attractive production approach because it allowed for customization at competitive prices. Therefore, Western manufacturers sought to introduce the Japanese production methods, which led to several new concepts, including '*Just in time'* (JIT) and '*Total Quality Control'* (TQC, also known as Total Quality Management). JIT is a manufacturing technique that, as the name suggests, produces goods just in time for the next production step, thus integrating suppliers and customers and aligning demand and supply (Turnbull et al., 1989). JIT includes the reduction of waste (anything that is not creating value) at every stage of the production process (Turnbull et al., 1989). This reduces the inventory and increases the return on investment. Furthermore, it improves the responsiveness to the market and increase labour productivity. Demand in the JIT system is signalled through a so-called *kanban* concept. Kanban links the production processes together, signalling demand backwards from the customer (Pilkington, 1998). In addition, JIT requires

the introduction of TQC, which aims to improve product quality and, ultimately, increase customer satisfaction. TQC means that quality control is built into the production system rather than inspecting the car for quality after production (Turnbull et al., 1989). The concept implies that the 'the next in line' is always regarded as a customer. Hence, internally, TQC would consider each subsequent production step within the plant as 'customer' to be satisfied; TQC would not consider quality only in terms of a car that is delivered to the dealer or to the final customer.

2.1.3 From lean production to optimum lean production

The introduction of lean production in Western companies has been studied widely, as it was proclaimed to be something that could save the industry (Rubenstein, 2001; Womack et al., 1990). However, views with regard to its benefits have varied widely. Some scholars have found methods such as 'Just in time' and 'Total Quality Management' to be a valuable alternative to Western approaches (Bertodo, 1991; Hyun, 1994; Womack et al., 1990), while others have been wary of their benefits in a Western context (Pilkington, 1998; Turnbull et al., 1989; Turnbull et al., 1992). Several aspects have emerged from this scholarly work.

First, lean manufacturing is often communicated as a concept that was practiced by all Japanese car manufacturers. However, when comparing Japanese car manufacturers in more detail, different strategies have been found (Pilkington, 1998). By and large, the most notable Japanese representative for lean manufacturing is Toyota. Assuming that all Japanese car manufacturers produce in a similar way boosted the concept of best practice, assuming that there is one optimal way to produce. Pilkington (1998) criticises this notion, arguing that there is no single strategy and revealing different production approaches among Japanese car manufacturers. For instance, Toyota focused on cost and production efficiency (i.e., the Toyota Production System) and Honda on engineering excellence, while Nissan tried to emulate Toyota in order to regain its leading position. Thus, it was misleading to believe that there is one single strategy, as best practice suggests, but production methods were contingent on overall business strategy (Pilkington, 1998).

Second, despite the advantages of JIT, the context of the established Western industry structure was neglected. Turnbull et al. (1992: 167) state that the "imposition of a particular manufacturing strategy which is, in many respects, incompatible with the existing structure of the industry" creates major problems. For instance, the U.K. was characterized by low-volume car manufacturers and large-scale suppliers, which supplied multiple car

manufacturers. This provided sufficient economies of scale for suppliers and resulted in lower costs for car manufacturers. And, in fact, suppliers were the source of major innovations and provided a competitive edge for the U.K. car industry (Turnbull et al., 1992). What is more, it seemed that the fit between JIT and the Western business culture was suboptimal. Western business culture was characterized by decades of 'close but adversarial' relationships (Mudambi & Helper, 1998). The lack of trust between buyers and suppliers was, according to Turnbull et al. (1992: 167), a result of "10 years of price freezes, volume cuts, multiple sourcing and the like, many suppliers view the latest moves to JIT as another means by which the vehicle assemblers intend to put the squeeze on." Consequently, when introducing lean manufacturing, Western car manufacturers were not able to emulate the Japanese buyer-supplier relationships due to a lack of trust.

Third, JIT practices were not emulated throughout the value chain. Eliminating 'waste' resulted in car manufacturers immediately delivering produced cars to dealers. Thus, dealers would increase their stock, which reduced the intended efficiency of the approach (Pilkington, 1998).

In addition to issues of fit between JIT practices and the Western business context, two developments in the car industry prompted car manufacturers to eventually move 'beyond' lean production. First, problems idiosyncratic to lean production became apparent and, second, lean production no longer guaranteed a competitive advantage (Collins et al., 1997). With regard to the first point, lean production suffered from what has been coined the 'Lexus effect' (Rubenstein, 2001). The 'Lexus effect' refers to lean manufacturing's relentless pursuit of continuous improvement, which led engineers to overcomplicate matters.[1] With regard to the second point, Western car companies improved their production and caught up with their Japanese competitors. As a consequence, production excellence was no longer a source of competitive advantage.

Hence, the concept of *optimum lean production* emerged. Optimum lean production rests upon two notions: commonality and co-location (Rubenstein, 2001). Commonality means that car manufacturers 'reused' as many parts as possible from old models in newly developed cars. This saved development time and costs. Co-location refers to the ability to work on the development of a model at different locations by means of ICT. In addition, a new concept, coined 'modularity,' was introduced (Ro et al., 2007). The success of modular production in the computer industry, pioneered by Dell, inspired car manufacturers such as

[1] In the case of Lexus, engineers decided against building a convertible, as tests showed that the roof could not be opened a thousand times at -30 degrees Celsius (Rubenstein, 2001).

Ford (Ro et al., 2007) and Volkswagen (Collins et al., 1997) to implement this approach. Modules combine parts to a self-contained whole, such as a car seat or a cockpit (Ro et al., 2007), which increases efficiency in the supply chain and enables companies to outsource production and, thus, responsibility to suppliers.

In summary, innovations in manufacturing have played a crucial role in the competition among car manufacturers. New manufacturing techniques provided advantages such as increased efficiency or higher quality but also had shortcomings, such as a lack of product diversity or complicated processes.

2.2 Trends in the product development process

Besides the production approach, another source of competitive advantage in the car industry is the product development process (Ibusuki & Kaminski, 2007). According to Clark et al. (1987: 733), it rests on the organisation's capabilities and "occurs through problem-solving cycles carried out by engineers who attempt to optimize a number of different performance parameters." Consequently, this section summarizes the most important trends in the product development process, exploring product development approaches (2.2.1), the role of the organisational setup (2.2.2) and the role of suppliers (2.2.3).

2.2.1 Product development approaches

Production approaches and the product development approaches are closely linked. Therefore, the evolution of production approaches influenced the way manufacturers developed cars. For instance, in mass production, the high costs of model-specific machinery caused a reluctance to develop new cars. In lean production, more flexible machinery stimulated increasing product development, and the outsourcing of production to suppliers shifted part of the responsibility of product development away from car manufacturers. In optimum lean production, new information and communication technologies enabled car companies and suppliers to collaborate in product development virtually, and parts could be used across models. Consequently, the product-development process has evolved over time towards product variety and decentralized development (Ibusuki & Kaminski, 2007).

However, for a long time, product development approaches differed across countries. These differences were a result of markets that were largely unconnected until the 1970s. For instance, prior to the internationalisation of the industry, Japanese companies faced fierce

competition in their home market. The result was a shortage of specialized engineers, which led to the more efficient use of human resources and accelerated development times.

Clark et al. (1987) studied performance differences in product development among global car-producing areas: the U.S., Europe and Japan. An analysis of 29 product-development projects in the U.S., Europe and Japan between 1980 and 1987 revealed that Japanese car manufacturers performed significantly better. For instance, the average project time in Japan was 1,155 hours, compared to 3,478 hours in the U.S. and 3,636 hours in Europe.[2] Another significant measure for product-development capabilities is the lead-time, which refers to the time span between the start of the project and the final market introduction. On average, Japanese projects took 42.6 months, compared to 61.9 months in the U.S. and 62.6 months in Europe (Clark et al., 1987).

Confirming the importance of context and competition, Thomas and Weigelt (2000) compared product-development processes in Japan, the U.S. and Europe and illustrated that the product-development capabilities of car manufacturers were largely driven by the features of the respective home country's rivalry. Japanese firms, due to high competition, would concentrate more on new features (e.g., electronic devices in the car) and less on design, but they remained profitable through capabilities that were favourable for economies of scale. U.S. manufacturers, which faced less competition, were more focused on body styling and engines. Finally, in Europe, because of competition on the basis of brand loyalty, car companies focused on engineering and performance, which were not as salient in the U.S. or Japan (Thomas & Weigelt, 2000). The international differences led to competition in product development and spurred new development strategies.

A major innovation in product-development strategy was to share so-called 'platforms' among multiple brands and models. Until this innovation, cars were largely stand-alone developments. Platform strategies changed this by building on one platform that can accommodate various body designs. The strategy became popular in the car industry, as it allowed car companies to be more cost-efficient, yet responsive to increasing demand for design variety, thus saving development resources as well as reducing time-consuming and expensive changes of machinery (Wells, 2010).

One drawback of the platform strategy was that cars looked similar. Consumers easily recognized that cars with different brand names looked alike and therefore, found some

[2] On average, Japanese cars were less complex, and, therefore, one might argue that the difference in hours can be explained by the difference in complexity. However, when the authors adjusted for that effect, the hours were 2,701 (Japan), 4,892 (U.S.) and 6,426 (EU), respectively.

models less attractive. Thus, more recently, companies have advanced the platform strategy to an ‘architecture strategy.’ This means that cars share the same components but look different from each other. By doing this, car manufacturers can sell apparently different cars resting on similar architectures, which saves development resources, decreases development times, and allows manufacturers to bring more models to the market (Wells, 2010).

In addition to the product development approach, two factors significantly influence the performance in product development: the organisational setup and supplier relationships, which will be described in the next two sections.

2.2.2 Organisational setup and management of product development

In order to reach efficiency and superior performance, a car manufacturer’s organisational setup needs to be aligned with its product-development strategy (Ro et al., 2007). Particularly important is the way in which development projects are managed. At the time of their study, Clark et al. (1987) found that car companies adopted different approaches. In Japanese companies, managers high up in the organisation’s hierarchy would coordinate projects and take responsibility as project managers. U.S. firms also engaged project managers, but they were usually not high up in the organisation’s hierarchy and not directly responsible for managing projects. In contrast, European companies often operated without dedicated project managers and relied largely on collaboration across departments.

However, concomitant with the adoption of new product-development strategies such as platform strategies, car manufacturers began organizing development projects in matrix structures instead of in traditional functional structures. Matrix structures overcame the shortcomings of the functional structure, as it allowed representatives to fulfil their functional role while participating in different projects. What is more, representatives could be part of different projects of different platforms or architectures. Yet, matrix structures also caused tensions due to a “lack of strong demarcation between functional dependence (tasks and targets) and hierarchic dependence (direction and control)” (Calabrese, 1997: 240), leading to communication problems. Calabrese (1997) studied communication and co-operation—such as meetings and direct contacts—in product development. Based on the results of a case study of a single car firm, Calabrese confirmed that the challenge in the development process stemmed less from technological issues, and more from individuals working together within a project. To overcome this challenge, continuous learning, sufficient data-transfer processes and the proper motivation are required to enable efficient matrix structures (Calabrese, 1997).

However, the issue becomes more complicated when considering that car manufacturers develop a variety of cars at the same time. Thus, how do car manufacturers simultaneously manage the development of different projects? Is it wise to focus resources on one development project at a time to ensure that the product becomes a success? Or is it more beneficial to work on several new projects at the same time and see which one succeeds? Nobeoka and Cusumano (1997) analyzed the 17 largest car manufacturers worldwide over a 12-year period (1980 through 1991) to understand which development strategy had a positive effect on sales. They looked at new cars brought to the market and studied the multi-project strategies of these car manufacturers. The authors distilled four different development strategies: 'New Design,' 'Rapid Design Transfer,' 'Sequential Design Transfer' and 'Design Modification.' Under 'New Design,' manufacturers developed new products from scratch. 'Rapid Design Transfer' was applicable if car manufacturers transferred knowledge or technology from one model that was in the development phase to another that was just launched. In 'Sequential Design Transfer,' firms could also integrate available technology from previously finished projects into new projects, a concept close to optimum lean production. 'Design Modification' implied that new projects were built largely on a predecessor model—also referred to as a facelift.

Their results showed that 'Rapid Design Transfer'—transferring knowledge and components from one project to another at an early stage—had a significant positive correlation with sales growth and that firms increasingly applied this strategy. From 1980 until 1982, only nine percent of the sample (n=47) applied the Rapid Design Transfer strategy. From 1989 until 1991, 20 percent of the projects (n=61) were already using this approach, thus providing evidence for the increasing establishment of optimum lean production. In essence, firms leveraged existing technologies more often and faster and, thus, increased sales (Nobeoka & Cusumano, 1997).

More recently, car manufacturers have adopted new concepts to gain cost efficiency. They now combine the concepts of value engineering and target costing (Ibusuki & Kaminski, 2007). Value engineering refers to identifying areas where costs can be saved, while target costing sets the limits of costs, for instance, for a specific part that warrants the profitability of the product in the long run.

2.2.3 Supplier strategies and relationships

As mentioned above, because product-development projects of Japanese companies took significantly less time, they had a competitive advantage in product development (Clark et al., 1987). One reason for this advantage was that Japanese manufacturers sourced more parts from suppliers. These so-called 'Black Box parts' were components that were largely developed by suppliers. Japanese companies sourced 62 percent as Black Box Parts, compared to 16 percent by U.S. companies and 39 percent by European companies (Clark et al., 1987). Outsourcing of whole modules and handing over of responsibility to suppliers increased their significance. Wynstra, von Corswant, and Wetzels (2010: 625) state that through "supplier involvement firms can achieve better product quality, shorter development lead time, and reduced product and development cost."

The degree of a car manufacturer's vertical integration was influenced by the choice of the production approach. As pointed out earlier, in mass production, the timely and uninterrupted supply of goods was essential to the smooth assembly of cars. Hence, a high degree of vertical integration reduced the risk in the supply chain. Lean production, in contrast, relied on the production of smaller, customized numbers of cars at a time and the outsourcing of components and systems. Thus, this approach lent itself to vertical disintegration and more responsibility for suppliers. As a result of the popularization of lean production and optimum lean production, the car industry witnessed a shift to vertical disintegration. Yet, disintegration increased the dependence of car manufacturers on suppliers and, in turn, created risks. For instance, if a supplier froze the development of a certain module, the performance of a car manufacturer was directly at risk (Wells, 2010). Thus, new buyer-supplier relationships and vertical disintegration created opportunities in product development, but also posed a new source of risks for car manufacturers.

But is a close collaboration with suppliers efficient? In a comparative study, Bertodo (1991) analysed the role of suppliers in the global car industry in the 1980s. The study found that Japanese manufacturers were the least integrated and sourced almost 80 percent from suppliers, compared to 62 percent in North America and only 52 percent in Europe. The study showed that Japanese companies cooperated closely with suppliers as part of the '*keiretsu*' network, which generated cost savings of up to 50 percent (Bertodo, 1991). A '*keiretsu*' is a "a network of manufacturers and suppliers that have equity ownership in one another as a means of mutual security [...] characterized by a great deal of parts outsourcing to a small number of closely knit suppliers who are given long-term contracts" (Ro, Liker, & Fixson, 2008: 184). In a *keiretsu*, car manufacturers and suppliers held shares in each other and had

interlocking boards. Through the *keiretsu* concept, suppliers received more responsibility, as they were integrated early into the development process of vehicles (Ro et al., 2008). Moreover, first tier suppliers often had responsibility for whole subsystems.

Western manufacturers tried to emulate the Japanese *keiretsu* concept. Hyun (1994) observed the restructuring of the supplier network by Western companies, which involved a reduction of suppliers, closer cooperation with suppliers in the development process, coordinated activities, focus of car manufacturers on assembling and more open communication (Hyun, 1994). As a result, today, more and more parts are developed by suppliers (Wynstra et al., 2010). Whereas in mass production, a large number of suppliers would sell parts or components to car manufacturers, (optimum) lean production reduced this number to 200 to 300 suppliers that often supplied modules or whole systems (Ro et al., 2008). Also, contracts became more long term, and the involvement of the supplier in development and production increased. While this increased competition among suppliers, it also improved trust between car manufacturers and suppliers.

Trust has been found to be an important element of competitive advantage because it may reduce transaction costs, facilitate information sharing and stimulate investments critical to the buyer-supplier relationship (Dyer & Chu, 2000). Consequently, a concern for car manufacturers is what fosters trust in the buyer-supplier relationship. Dyer and Chu (2000) conducted a comparative study of buyer-supplier relationships in the U.S., Japan and Korea, examining 135 U.S., 101 Japanese and 217 Korean suppliers. They found that there are institutional differences that explain degrees of trust, as well as ways to promote trust (Dyer & Chu, 2000). Japanese buyer-supplier relationships were characterized by higher trust, longer relationships and more face-to-face hours. To stimulate trust, providing support in cost reduction and quality improvement helped considerably. For instance, Japanese car manufacturers in the U.S. assisted local suppliers in implementing JIT techniques and gained higher degrees of trust compared to their U.S. counterparts, despite a shorter overall relationship time (six years vs. 22 years). Wasti and Wasti (2007) studied buyer-supplier relationships in the Turkish car industry. Their analysis of 106 surveys from car-part suppliers also confirmed that the introduction of manufacturing techniques such as JIT or TQM positively influenced trust. Because JIT and TQM required assistance in the setup, frequent contact and close relationships, trust was built. Hence, support by car manufacturers—such as giving assistance—aided in creating trust (Dyer & Chu, 2010).

While production approaches and the product development process have changed over time, product innovation also has evolved. How and why this has occurred will be discussed in the next section.

2.3 Product innovation in the car industry

A final influence on competitiveness in the car industry has been the innovation of cars itself. While the product development process concerns the way cars are developed, product innovation refers to the technologies employed. Although a dominant design emerged—a multipurpose vehicle with an internal combustion engine (Orsato & Wells, 2007)—and the attention of car manufacturers shifted to process innovation (Abernathy & Clark, 1985), product innovation remains influential, particularly considering newly emerging LEVs. Consequently the following two sections examine the timing of product innovation (2.3.1) and product innovation in an international context (2.3.2).

2.3.1 Timing of product innovation vis-à-vis competitors

A topic that has been widely discussed in the literature with regard to product innovation in the car industry is whether to be a first mover or a follower (Frynas et al., 2006; Klepper, 1996). Being a first mover allows manufacturers to increase switching costs for consumers, pre-empt assets such as a marketing channel (Frynas et al., 2006), and to develop technological leadership (Lieberman & Montgomery, 1988). On the contrary, being a follower avoids the risks of not appropriating the value of an innovation and might save a firm large investments.

Mueller (1993) analyzed the effect of technological leadership from a first-mover perspective and found that car manufacturers could benefit from first-mover advantages. The example of the luxury-car manufacturer Mercedes showed that their technological leadership stems from being a first mover. Honda, too, enjoyed a leadership position due to its significant innovation efforts. This created a favourable reputation, which attracted, retained and motivated talented employees, and, in turn, reinforced the firm's product-innovation capabilities (Mueller, 1993). However, a first-mover strategy needs to fit the firm's capabilities. For instance, Rover tried to become a technological leader but lacked the necessary capabilities—the technological know-how, among others (Mueller, 1993). Hence, a

firm cannot easily shift its product-innovation strategy and timing due to organisational inertia and path dependence (Mueller, 1993).

Inertia significantly slows product innovation. Sources of inertia reside in product managers' and firms' resources, such as accumulated expertise of employees or patents. Thomas and Weigelt (2000) describe how the available resources and capabilities of car manufacturers influence managers' decisions regarding product-innovation strategy. In a study of new product launches in the U.S. car industry from 1980 until 1993, they revealed that product managers positioned new cars close to existing models of their portfolio and far from the products of competitors; this was particularly true for domestic incumbents. Conversely, new entrants or foreign incumbents entering a country are likely to position newly developed cars closer to existing products of competitors in the market to gain a foothold. Consequently, entering a foreign market influences product innovation, with car manufacturers' product innovation being driven by considerations regarding competitors and timing but also new international markets. The international context of product innovation is addressed in the next section.

2.3.2 Product innovation in the international context

Being able to sell one car in various markets, potentially globally, could provide a competitive advantage for car companies. Scholars argue that with increasing globalization, international markets converge and industries become more integrated (Levitt, 1983). Put differently, it has been argued that the world faces "global markets for standardized consumer products on a previously unimagined scale" (Levitt, 1983: 92). This suggests that companies could standardize cars globally and, indeed, for many years, companies have tried to develop a 'world car'. For the car industry, this raises the question of how product-innovation strategies should be designed: Should they offer products adapted to local markets or standardize globally (Schlie & Yip, 2000)?

Based on a survey of the thirteen largest global car manufacturers, Schlie and Yip (2000) found that national markets differ and require differentiated cars. They suggested a more eclectic approach, which involves the clustering of similar markets rather than treating all markets as the same (Schlie & Yip, 2000). In a similar vein, the consultancy Booz & Company noted, with regard to product innovation, that despite convergence of markets, different areas in the world have different needs. For instance, with reference to small cars, the following has been asserted (Dehoff et al., 2008: 4):

> ‘[T]he small-car revolution is taking place within the context of the very different needs and desires of the new consumer in emerging markets. Consumers buying cars that cost $8,000 differ greatly from those buying $15,000 cars. Those low-cost cars are typically their first, and they will be used as family cars, but not for long-distance trips—instead, they will be predominantly driven around town. For this and other reasons—people in developing countries shop for food much more frequently than Americans, for instance—cargo capacity is less important than people-carrying capacity. You can’t, however, impress these consumers with $15,000 cars from which critical features have been removed to save money. Cars for this market must be built from the ground up, frugally but not cheaply.’

That is to say, consumers for cars are not all alike in different areas of the world, largely due to economic wealth and location-specific factors such as distance to drive or available fuels. Indeed, Ghemawat and Ghadar (2006) showed that despite a general consolidation process in the industry, product variation increased instead of decreased.

A related issue is that global car manufacturers face the challenge of deciding under which brand they should commercialize their models. Product innovation in the car industry is attached to brands. For example, General Motors sells the same car in different countries of the world under different brands. Brands are decisive for the success in national markets, as research has shown that brands are less likely to perform well in markets that are economically distant and differ in population size from the home market (Townsend et al., 2008). For instance, Chinese car manufacturers are more likely to enter countries in Asia or Africa first. Moreover, Townsend et al. (2008) showed that the most successful strategy to globalize a brand is to simultaneously enter one country on each of the three main car-manufacturing continents (North America, Europe, Asia) and then enter new markets from those bases. This allows learning about local or ‘continental’ market characteristics and gaining the ability to create a global presence. For instance, BMW established its presence in selected countries in Europe, North America and Asia/Australia early and subsequently entered nearby markets. Hence, the “evolution from an international to a regional to a multi-regional to a global brand is clearly observable in the nature of the progression of BMW’s international expansion pattern” (Townsend et al., 2008: 541).

However, companies’ drivers for product innovation not only comprise industry and market forces, but also non-market factors—i.e., government pressure. Although, the “principal focus of the strategy formulation process is on the market environment and competitive strategy, […] for many firms the nonmarket component can be just as crucial” (Baron, 1995: 63). One factor of particular importance with regard to product innovation is

government safety and environmental guidelines, such as increasing safety and decreasing negative impacts on the natural environment. However, most government guidelines require technological change, and this change often increases costs and has an immediate impact on companies' profitability. In addition, regulation often affects the design of cars (Uduma, 2000). For instance, when seatbelts became mandatory, the design of some convertibles had to change to accommodate the new safety guidelines. In short, governments have a significant influence on the car industry, but effects often differ between and sometimes even within countries.

2.4 Summary

In summary, car manufacturers have continuously innovated production approaches, the product development process and products since the inception of the industry. Manufacturing approaches have advanced considerably, characterized by increasing efficiency and standardization. This has had an effect on the way cars are developed. Today, product development is characterized by 'architecture strategies' and modularization approaches, developed in matrix structures with a close link to suppliers. However, in contrast to the advances in product development, product innovations occurred only incrementally after the emergence of the dominant design. While the emergence of LEVs as a potential breakthrough innovation is also embedded in these characteristics of the industry, there are also more idiosyncratic factors that have been driving this development. These factors will be discussed in the next chapter.

References

Abernathy, W. J., & Clark, K. B. (1985). Innovation: Mapping the winds of creative destruction. *Research Policy*, *14*(1), 3–22.

Baron, D. P. (1995). Integrated strategy: Market and nonmarket components. *California Management Review*, *37*(2), 47–65.

Bertodo, R. (1991). The role of suppliers in implementing a strategic vision. *Long Range Planning*, *24*(3), 40–48.

Calabrese, G. (1997). Communication and co-operation in product development: A case study of a European car producer. *R&D Management*, *27*(3), 239–252.

Clark, K. B., Chew, W. B., Fujimoto, T., Meyer, J., & Scherer, F. (1987). Product development in the world auto industry. *Brookings Papers on Economic Activity*, *1987*(3), 729–781.

Collins, R., Bechler, K., & Pires, S. (1997). Outsourcing in the automotive industry: From JIT to Modular Consortia. *European Management Journal*, *15*(5), 498–508.

Dehoff, K., Sehgal, V., Loehr, J., & Tominaga, K. (2008). Cars for India, Cars for the World. Booz & Company Inc.

Dyer, J., & Chu, W. (2010). The determinants of trust in supplier–automaker relations in the US, Japan, and Korea: A retrospective. *Journal of International Business Studies*, *42*(1), 28–34.

Dyer, J. H., & Chu, W. (2000). The determinants of trust in supplier-automaker relationships in the US, Japan and Korea. *Journal of International Business Studies*, *31*(2), 259–285.

Frynas, J. G., Mellahi, K., & Pigman, G. A. (2006). First mover advantages in international business and firm-specific political resources. *Strategic Management Journal*, *27*(4), 321–345.

Ghemawat, P., & Ghadar, F. (2006). Global integration ≠ global concentration. *Industrial & Corporate Change*, *15*(4), 595–623.

Hyun, J.-H. (1994). Buyer-supplier relations in the European automobile component industry. *Long Range Planning*, *27*(2), 66–75.

Ibusuki, U., & Kaminski, P. C. (2007). Product development process with focus on value engineering and target-costing: A case study in an automotive company. *International Journal of Production Economics*, *105*(2), 459–474.

Klepper, S. (1996). Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review*, *86*(3), 562–583.

Levitt, T. (1983). The Globalization of Markets. *Harvard Business Review*, *61*(3), 92–102.

Lieberman, M. B., & Montgomery, D. B. (1988). First-mover (dis)advantages: retrospective and link with the resource-based view. *Strategic Management Journal*, *19*(12), 1111–1125.

Mudambi, R., & Helper, S. (1998). The close but adversarial model of supplier relations in the US auto industry. *Strategic Management Journal*, *19*, 775–792.

Mueller, F. (1993). Understanding technological leadership: observations from the automobile industry. *Technology Analysis & Strategic Management*, *5*(1), 15–26.

Nieuwenhuis, P., & Wells, P. (2007). The all-steel body as a cornerstone to the foundations of the mass production car industry. *Industrial and Corporate Change*, *16*(2), 183–211.

Nobeoka, K., & Cusumano, M. a. (1997). Multiproject Strategy and Sales Growth: the Benefits of Rapid Design Transfer in New Product Development. *Strategic Management Journal*, *18*(3), 169–186.

Orsato, R. J., & Wells, P. (2007). U-turn: the rise and demise of the automobile industry. *Journal of Cleaner Production*, *15*(11-12), 994–1006.

Pilkington, A. (1998). Manufacturing strategy regained: evidence for the demise of best practice. *California Management Review*, *41*(1), 31–42.

Richardson, J. (1993). Parallel sourcing and supplier performance in the Japanese automobile industry. *Strategic Management Journal*, *14*(5), 339–350.

Ro, Y. K., Liker, J. K., & Fixson, S. K. (2007). Modularity as a Strategy for Supply Chain Coordination: The Case of U.S. Auto. *IEEE Transactions on Engineering Management*, *54*(1), 172–189.

Ro, Y. K., Liker, J. K., & Fixson, S. K. (2008). Evolving Models of Supplier Involvement in Design: The Deterioration of the Japanese Model in U.S. Auto. *IEEE Transactions on Engineering Management*, *55*(2), 359–377.

Rubenstein, J. M. (2001). *Making and selling cars: innovation and change in the US automotive industry*. Baltimore: The Johns Hopkins University Press.

Schlie, E., & Yip, G. (2000). Regional follows global: strategy mixes in the world automotive industry. *European Management Journal*, *18*(4), 343–354.

Thomas, L., & Weigelt, K. (2000). Product location choice and firm capabilities: Evidence from the US automobile industry. *Strategic Management Journal*, *21*(9), 897–909.

Townsend, J. D., Yeniyurt, S., & Talay, M. B. (2008). Getting to global: An evolutionary perspective of brand expansion in international markets. *Journal of International Business Studies*, *40*(4), 539–558.

Turnbull, P., Oliver, N., & Wilkinson, B. (1989). Recent developments in the UK automotive industry: JIT/TQC and information systems. *Technology Analysis & Strategic Management*, *1*(4), 409–422.

Turnbull, Peter, Oliver, N., & Wilkinson, B. (1992). Buyer-supplier relations in the UK-automotive industry: Strategic implications of the Japanese manufacturing model. *Strategic Management Journal*, *13*(2), 159–168.

Uduma, K. (2000). Innovations in Auto Safety Design, a Key to Quality Improvement. *Technological Forecasting and Social Change*, *64*(2-3), 197–208.

Wasti, S. N., & Wasti, S. A. (2007). Trust in buyer–supplier relations: the case of the Turkish automotive industry. *Journal of International Business Studies*, *39*(1), 118–131.

Wells, P. E. (2010). *The Automotive Industry in an Era of Eco-Austerity: Creating an Industry As If the Planet Mattered*. Cheltenham, UK: Edward Elgar Publishing.

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The machine that changed the world*. New York: Macmillan.

Wynstra, F., Von Corswant, F., & Wetzels, M. (2010). In Chains? An Empirical Study of Antecedents of Supplier Product Development Activity in the Automotive Industry•. *Journal of Product Innovation Management*, *27*(5), 625–639.

3 Low-emission vehicles (LEVs): Introducing technologies and firm/government perspectives

3.1 Introduction

Despite the increasing sophistication of production systems and product development, the car industry has been much less innovative regarding the dominant propulsion technology, which has remained the internal combustion engine (ICE) for the past century. However, in recent years, there has been more attention to changes to the current 'automobility paradigm' (Nieuwenhuis et al., 2006). As Carson and Vaitheeswaran put it optimistically (2007: 6): "A powerful grassroots movement—call it the Great Awakening—is clearly under way that is sparking a great global race to fuel the car of the future." Various factors have played a role in the emergent discussion about alternatives to the ICE. Increasing energy prices and the depletion of resources point to the need for more efficient alternatives (Steen et al., 2011). Moreover, increased air pollution and the contribution of transport-related CO_2 emissions to climate change underline the need for low-emission alternatives (European Commission, 2012). Finally, customers' environmental awareness has increased, with 'green consumers' demanding more sustainable cars.

However, although various technologies are available, low-emission vehicles (LEVs) still account for only a fraction of total vehicle sales and are, thus, a niche product. And although there seem to be good reasons for a change of the 'automobility paradigm' towards more sustainable technologies, there is strong inertia amongst the salient actors in the development of LEVs—namely, car manufacturers and governments. This chapter will briefly introduce perspectives of car companies and governments on LEVs, covering aspects that are examined in much more detail in the subsequent chapters. First, however, to set the stage and explain the challenges that the respective LEV technologies pose, the next section will discuss the most prevalent LEV technologies.

3.2 LEV Technologies

At the inception of the car, technologies that caused little to no tailpipe emissions, such as electric vehicles, were available. Since then, there has been a proliferation of alternative technologies to the ICE, including extreme ideas such as a nuclear car (by Ford) or air-compressed propulsion. Today, two main streams of alternatives have emerged: options that

use alternative fuels in the ICE and technologies that employ alternative powertrains (Zapata & Nieuwenhuis, 2010). The former—alternative fuels—entails the use of different energy sources (e.g., biodiesel, gas, bioethanol) within an ICE and, thus, represents an incremental improvement (Zapata & Nieuwenhuis, 2010). The latter, more radical alternative— different types of powertrains—refers to an entirely different system that propels the car without the ICE, through, for example, the use of a battery or fuel cells (see Table 3.1).

Table 3.1: Alternative fuels vs. powertrain: incremental vs. radical innovation

Technology	Incremental innovation	Radical innovation
Liquefied petroleum gas	*	
Compressed natural gas	*	
Biodiesel	*	
Bioethanol	*	
Hydrogen internal combustion	*	
Internal combustion-electric hybrid	*	
Battery-electric		*
Fuel cell		*

Adapted from Zapata and Nieuwenhuis (2010)

Despite the various options available, only a few technologies are competitive enough to challenge the ICE. The three most prevalent technologies that compete to be the dominant LEV design and replace the ICE are hybrid-electric vehicles (HVs), electric vehicles (EVs), and fuel-cell vehicles (FCs) (Frenken, Hekkert, & Godfroij, 2004). Consequently, this dissertation will pay attention to these three technologies. The sections below will introduce them briefly, discussing their functionality, advantages and disadvantages, costs and the type of knowledge required for the technology.

3.2.1 Hybrid technologies

Hybrid vehicles combine two power sources: an ICE and an electric motor with a battery. Consequently, they build on the incumbent technology and partially on knowledge gained in electric vehicles (see 3.2.2). While most major car manufacturers are able to build HVs, integrating two propulsion technologies in one car requires considerable engineering skills, which—besides the high costs of the battery—adds costs to production. Toyota was the first car manufacturer to employ the technology in a mass-produced car, the Prius (Hasegawa, 2008). The Prius 1 used NiMH batteries supplied by a joint venture with Matsushita, Panasonic EV.

HVs combine an internal combustion engine and one or more electric motors. Several HV variations are possible; for instance, the ICE could be fuelled by petrol or diesel, and the electric motors may just support the car's appliances and/or support the energy or even allow driving only on electricity. A plug-in option offers the possibility to recharge the battery, which enables longer electric-only rides (see Table 3.2).

Table 3.2: Various hybrid technologies and their features (compiled by author)

Functioning	Explanation	Example	Fuel efficiency
Mild hybrid	The ICE is the primary propulsion source; the electric motor runs the accessories and can give a boost at hard acceleration	GM Silverado	~21 miles per gallon
Parallel hybrid	The car is able to run on electric power alone without the ICE running; the two engines are connected to each other	Toyota Prius	~50 miles per gallon
Plug-in hybrid	Like a series hybrid, but the batteries are chargeable with a plug, allowing longer electric-only rides	Toyota Prius Plug-In	~95 miles per gallon
Range-extender	An electric motor is driving the car, and an ICE is producing the electricity	GM Volt	~93 miles per gallon

Hybrids can be distinguished by their degree of hybridization—that is, the extent to which the electric engine supports the ICE. As shown in Table 3.2, four options are available: mild hybrids, full hybrids, plug-ins and range-extenders. Mild hybrids only marginally utilize the electric engine, whereas full hybrids fully exploit the electric potential. Both propulsion technologies have in common that they are solely fuelled by petrol. The battery of the car is charged while driving, either by the ICE or through regenerative braking. The third option is a plug-in hybrid that offers the possibility of charging the battery by connecting the car with a wire to the electric grid. Finally, range-extenders, such as the Chevy Volt, are propelled mainly by the electric engine, and the internal combustion engine charges the battery when it is depleted. However, in the remainder of this dissertation plug-in vehicles or range-extender will be included in the analysis of EVs given that they can drive more than 20 km on battery power.

Most modern hybrids that are currently being introduced to the market rely on lithium ion batteries. However, the majority of hybrids on the road, such as the Prius 2 and 3, use

Nickel-Metal Hydride (NiMH) batteries with 1.3kWh. Replacement costs of these batteries for car owners range from USD 2,000 (for the first generation) to USD 4,000.[1]

3.2.2 Battery-electric vehicle technologies

Battery-electric vehicles are equipped with an electric motor that sources its energy from a battery. The challenge with electric cars is not the electric motor, but the battery. Electric motors are omnipresent in our lives and have been proven to function in items ranging from electric toothbrushes to refrigerators. They are superior to the ICE with regard to maintenance and failure rates (Serra, 2012). However, the low range of the battery, its weight, and its long recharging time are disadvantages compared to the ICE.

Most of the first electric cars, introduced at the end of the 1990s, were equipped with lead-acid batteries, which were most suitable at the time due to low costs and low maintenance requirements (see Table 3.3). What is more, the industry had vast experience with these batteries, as they were already employed in ICE-propelled cars as electricity storage. However, the disadvantage of lead-acid batteries is their low energy density: in order to reach a sufficient range, an average-sized car requires so many batteries that the resulting weight would be too high. Another battery type, Nickel Cadmium (NiCd), has the advantages of a long life cycle of 1,500 recharges and cost-effectiveness. Moreover, its energy density is higher in comparison to lead-acid. However, the disadvantage of NiCd is its high self-discharging propensity, its required maintenance, and the inherent memory effect—that is, if the battery is not fully depleted and gets recharged, the device appears to 'remember' the now smaller capacity, thus leading to lasting capacity deficits. Yet another battery type is Nickel Metal Hydride (NiMH). This type eliminates some of the problems of lead-acid and NiCd, as it has a higher energy density, can be recharged relatively fast and does not require as much maintenance as NiCd batteries. Toyota used NiMH in its RAV4-EV, as did Honda in the EV Plus. Yet, NiMH has similar disadvantages as NiCd, namely the memory effect, self-discharge propensity and the need for maintenance.

[1] Estimates vary considerably for the cost of replacement since the information is not publicly available. Based on information from chats with Prius owners, this is a rough estimate. See, for instance, http://priuschat.com/forums/toyota-prius-plug-in/102539-prius-plug-in-lithium-ion-battery-replacement-costs.html accessed 31-3-2012.

Table 3.3: Characteristics of commonly used rechargeable batteries

	NiCd	**Lead- Acid**	**NiMH**	**Li-Ion**
Commercial use since	1950	1970	1990	1991
Typical battery costs for a 6-7 Volt unit	USD 50	USD 25	USD 60	USD 100
Average number of recharges until battery capacity drops below 80% of initial capacity	1500	200 - 300	300 - 500	500 - 1000
Required time for fast charge	1h typical	8-16h	2-4h	2-4h
Self-discharge per month	20%	5%	30%	10%
Maintenance requirements	30 to 60 days	3 to 6 months	60 to 90 days	not required

Adapted from Buchmann (2001)

A more promising technology is Lithium-Ion (Li-Ion), which is used in most EVs currently entering the market. For example, Nissan integrated this battery, produced by Sony, into its Prairie Joy EV. Li-Ion batteries have the advantage of providing full power until the battery is depleted. While it is not prone to the 'memory effect,' its high energy density is still not comparable to that of gasoline. What is more, a current downside of the battery is its high cost, which, according to estimates, ranges from USD 600 and USD 1,000 per Kilowatt-hour (kWh). The Nissan Leaf is equipped with a 24 kWh battery, so in the best case scenario, the battery pack costs USD 14,400 (Serra, 2012: 134).

3.2.3 Fuel-cell technologies

The third LEV technology is fuel cells. This technology propels a car like an electric vehicle, but the energy source is not a battery, but a fuel cell that produces energy by combining hydrogen with oxygen. The process produces pure water and is, thus, a clean propulsion source. Both elements, hydrogen and oxygen, are abundantly available. Each fuel cell consists of an anode and a cathode, and an electrolyte that separates the two. In practice, multiple fuel cells are combined in stacks to provide sufficient energy. The most often-used membrane is Proton Exchange Membrane Fuel Cells (PEMFC) (Harborne et al., 2007).

Generally speaking, there are two ways to provide the fuel cell with hydrogen. First, hydrogen can be stored onboard the car, either compressed or cooled to a liquid in a tank, as

in the F-Cell by Daimler. Second, the vehicle can have an onboard transformer that extracts hydrogen from another source, such as methanol or gasoline. Gasoline has the advantage that the required infrastructure is readily available, whereas a methanol infrastructure would need to be developed. Thus, fuel-cell technologies—except if propelled by petrol—would require a new infrastructure, which would involve large, long-term investments. In addition, fuel cells are currently expensive, and customers have considerable anxiety about the technology due to the explosive nature of hydrogen.

3.2.4 Comparison of LEV technologies

The three main technologies are in different stages of development and commercialization (see Table 3.4 for an overview). Hybrid technology is the most advanced, due to three main factors: the efforts undertaken by Toyota; the less radical technology; and the considerable learning with the technology in the industry since its commercialization in 1997. While electric vehicles were also first commercialized in 1997, this did not occur on the same scale, although a renaissance has taken place since 2006 (see Chapter 4). Nonetheless, batteries are expensive and not yet developed sufficiently to serve as a substitute for the ICE. Fuel-cell vehicles are too expensive for production and the required hydrogen infrastructure is not available.

Table 3.4: An overview of low-emission vehicle technologies

	Hybrid Vehicles	**Electric Vehicles**	**Fuel-Cell Vehicles**
Propulsion technology	Combination of an internal combustion engine with an electric motor	Electric motor, powered by a battery	Electric motor, powered by fuel cells using hydrogen
Advantages	Can rely on current infrastructure	No direct emissions—i.e., no smog	No direct emissions—i.e., no smog
Disadvantages	Efficiency Battery costs	Low range Recharging time Battery costs No charging infrastructure	No refuelling infrastructure Safety issues Production of hydrogen
Climate Change Mitigation Potential	Still emits CO_2 emissions	More efficient, but still dependent on electricity, which might be produced with CO_2 emitting technologies	Depending on which fuel is used (hydrogen, methanol, electricity, petrol) there are still CO_2 emissions, but to varying extents

Adapted from Frenken et al. (2004)

The technologies also differ with regard to their green credentials. Hybrids are the least sustainable since they continue to rely on petrol and, thus, emit CO_2. Electric vehicles and fuel-cell vehicles may emit no CO_2, but that depends on how the electricity or the hydrogen is produced. For instance, although the EV itself emits no CO_2, the electricity might be produced in a coal power plant. Therefore, depending on the way that the electricity or hydrogen is produced, electric cars or fuel-cell cars could be considerably more sustainable than hybrids.

However, this comparison is taking a tank-to-wheel (T2W) perspective—i.e., excluding life-cycle costs. Overall sustainability does not merely refer to the use of alternatives to the internal combustion engine, but to the whole life cycle of a vehicle. Orsato & Wells (2007a) delineate four stages in the life cycle of a car: (1) pre-assembly (e.g., gaining the raw resources); (2) assembly (e.g., energy used in the assembly plant); (3) use (energy used through driving, mostly petrol; and (4) post-use (dealing with the end-of-life dismantling, etc.).

Hence, the proliferation of emerging LEV technologies has created a state of ferment and a search for the dominant design (Hekkert & Van den Hoed, 2004), the outcome of which is still unclear. In comparing the most radical technology, fuel cells, with hybrids, Hekkert and Van den Hoed (2004) conclude that the hybrid technology has an advantage. Employing Rogers' (1984) concept of relative advantage of a technology, the authors juxtapose the two technologies based on petrol use. They conclude that if the hybrid technology becomes dominant before fuel cells, there is little chance for the FC technology to succeed in the long run (Hekkert & Van den Hoed, 2004). Similarly, Bento (2010) warns that the early success of hybrids in the form of plug-in hybrids can, indeed, decrease the likelihood that fuel-cell vehicles will succeed. With EVs emerging as the new focus of technological development, the race to the dominant design is becoming even fiercer (Bakker, Van Lente, & Engels, 2012; Dijk, Orsato, & Kemp, 2012; Wesseling, Faber, & Hekkert, 2013). In fact, Serra (2012) asserts that the only viable option for future transportation is the electric vehicle.

However, this dissertation does not seek to understand which technology will eventually win, but, rather, tries to shed light on how and why car manufacturers have so far engaged in LEV technologies; what the role of governments has been; and what the interplay is between these two types of actors. To this end, the following sections briefly describe the perspectives of car companies and governments on LEVs, based on insights from the literature, thus touching upon aspects that will be studied in much more detail in Chapters 4-7.

3.3 The perspective of car companies

Despite the uncertainty over whether LEVs will move outside the niche and, if so, when, and which technology will be dominant, car companies pay increasing attention to LEVs. At the same time, that incumbents are averse to technological change has been observed widely in the car industry (Bento, 2010; McGrath, 2010). In particular, three factors have been mentioned in relation to car companies' resistance towards LEV technologies: the inertia in the industry, the vested interests of car manufacturers and the uncertainty revolving around LEV technologies.

First, since the 1920s, following a number of contingent social and technological events, the ICE has been the dominant engine design, powering approximately 99 percent of all cars. This dominance of the ICE has led to a significant degree of inertia in the industry and has created several sources of lock-in (Unruh, 2000). On a technological level, standard architectures emerged that created scale and learning economies, thereby reducing unit production costs and improving performance through specialized skills and knowledge. Consequently, organisations have developed routines, production facilities, and strong supplier and customer networks in order to sustain these scale and learning economies. Simultaneously, on a societal level, consumer preferences and expectations, support structures, and institutional frameworks have developed around the dominant design, providing further sources of lock-in (Dyerson & Pilkington, 2005; Geels, 2002; Orsato & Wells, 2007a; Unruh, 2000).

Orsato and Wells (2007) examine more detailed sources of inertia in the car industry. Interestingly, they conclude that the dominance of the current technological regime is largely an effect of three characteristics of cars: the all-steel body, the internal combustion engine and the multi-purpose character of the vehicles. The all-steel body made production more efficient and cars safer. Also, because the ICE uses petrol, which has very high energy density, it is able to drive long distances, which is not possible, for instance, with electric batteries (so far). Last, the fact that today's vehicles are multi-purpose vehicles—i.e., drive around 500 km or more, at a speed of 160 km/h and carrying five passengers—allows people to fulfil multiple purposes. Taken together, these elements make the industry resistant to change (Orsato & Wells, 2007a).

A second factor that impedes technological change is that car manufacturers have a vested interest in the incumbent technology, as LEVs would be largely competence-destroying (Henderson & Clark, 1990). The "mass production industry is a highly capital

intensive sector and decisions are made largely on their capital intensity. . . . [E]xisting cost consequences and amortization of sunk costs are key elements in any decision regarding future technology choices" (Zapata & Nieuwenhuis, 2010: 16). In the words of Amory Lovins (1993: 17): "They [car manufacturers] are prisoners of enormous sunk costs which they treat as unamortized assets, substituting accounting for economic principles". What is more, the legitimacy that car manufacturers possess supports them in resisting the change to LEVs (McGrath, 1999). That is, despite the availability of a potentially more environmentally-friendly technology, incumbents have been said to protect their position by using their incumbency to create high public awareness of their less environmentally friendly technologies. McGrath (1999) argues that incumbents may shift public awareness away from new technologies to competence-enhancing incremental improvements and lay the path for inferior technologies. This may only be overcome by an outside shock to the industry.

Third, car manufacturers face uncertainty revolving around LEV technologies. After a new technology has been introduced, there is the danger of a new lock-in having been created. Lock-ins often occur due to small events in history, such as a marketing event or a political problem that needs to be solved immediately (Cowan & Hulten, 1996). And a small advantage can lead to a snowball effect, i.e. initiate a process comparable to a chain reaction in which the popularity of a technology suddenly increases (Cowan & Hulten, 1996). It has been argued that this needs to be avoided because it might result in settling on an inferior technology in this early stage of LEV development. However, Frenken et al. (2004), in a study analyzing incumbents' LEV patents, show that the R&D portfolios are not converging to one technology.

Considering the various sources of inertia and the uncertainty surrounding LEVs, three strategic options for car companies come to the fore (Howells, 2002): to exit the market; to improve the existing technology; or to switch to the new technology (Harborne et al., 2007; Howells, 2002; Pistorius & Utterback, 1997). The first strategy—exiting—has not occurred, mainly because LEVs are still in their infancy. However, what has been witnessed is that the existing technology has improved and that car companies are slowly switching to LEVs. According to Howells (2002: 889), this is "an extraordinary case of economically 'irrational' behaviour." Yet, McGrath (1999: 248) provides an explanation for this phenomenon in the car industry, arguing that "[i]n light of the large moneys invested in human and physical capital made by incumbents, they resist any real overhaul of the industry and its dominant design". Consequently, incumbents keep investing primarily in the development of traditional engine

types due to high competition and higher expected returns in the short run with incremental innovations.

However, for industry incumbents, it is clear that sooner or later cars with ICEs will be extinct because oil will run out, although no one knows exactly when (Steen et al., 2011). Indeed, views on the timing and extent of market penetration of LEVs diverge significantly. Consequently, some car companies are slowly switching to LEVs. According to Volkswagen, it "is going to be an engineering marathon. It's not going to be a sprint. . . . Electric powertrains . . . will be "a supplement" to internal combustion engines. . . . [B]y 2020 EVs will have a global share of 1.5 to 2 percent" (Guilford & Ciferri, 2009: 3). On the contrary, for Nissan, LEVs such as "[e]lectric vehicles could take 10 percent of the global market by 2020, or roughly 6 million units in annual sales. . . . We see it as mass market" (Greimel, 2009: 14). Similarly, industry specialists have diverging expectations as to how the market will play out (Serra, 2012). Whereas consultancies and banks share a rather optimistic view, the International Energy Agency has a quite bleak outlook (Serra, 2012). Hence, the question for incumbents is when to invest in LEVs (Steen et al., 2011).

Generally, car manufacturers have several options. Introducing a radical technology can result in a first-mover advantage (Lieberman & Montgomery, 1988), while adopting a wait-and-see strategy avoids risks of being too early on the market (Steen et al., 2011). Thus, incumbents have the choice to pioneer a market, to follow a pioneer early on, or to move late into the market. Schneider et al. (2004) argue that being a first-mover—such as Toyota launching the Prius—provides an advantage in terms of image and experience, which it generates while having the monopoly (Schneider et al., 2004). Early movers often also enjoy government support in various forms (Steen et al., 2011). Moreover, investing in LEVs signals (potential) shareholders and may have a positive effect on market value (Ba et al., 2012). Interestingly, Ba et al. (2012: 25) found that the market tended to reward less profitable rather than profitable firms "because investors expect automakers that are doing well with existing business to concentrate on their existing business and less profitable automakers to find a competitive edge through green vehicle innovations". However, the pioneer runs the risk that after the entrance of early followers, it might find itself in second place, largely due to its vast investments in the technology. The chosen strategy—whether to improve old technologies or to slowly switch—depends on the firm's capabilities. For instance, the reason for Toyota's success with the Prius is their superior product-development capabilities (Clark et al., 1987). They were able to combine two propulsion technologies in one car in a way that is economically viable for mass production.

However, the decision for car manufacturers to switch to LEV technologies is not as clear-cut. Rather, the question is to what extent to invest in LEV technologies. “Many parties seek to cope with both sides of the dilemma, even if the cost of this dual strategy is high. They invest, but not at any price. They participate, but not all out” (Steen et al., 2011: 11). Thus, most car manufacturers follow a pre-emptive strategy to avoid surprises from new entrants in the market, such as entrepreneurs or diversifying firms (Hockerts & Wüstenhagen, 2010), to be prepared if the market picks up a technology, or to be ready to react when governments exert pressure.

Thus, incumbents in the car industry—while being averse to technological change due to inertia, vested interests and uncertainty—incrementally switch to LEVs, an approach that appears to be a dual strategy. One actor that reinforces this development is the government (Mikler, 2010). How governments may affect the development of LEVs is explored in the next section.

3.4 The government perspective

Due to the reasons mentioned in the introduction to this chapter, governments have an interest in stimulating the transition to LEVs, and they promote their development and commercialization using various options (Serra, 2012). On the one hand, government policies target the supply side—particularly car companies. On the other hand, governments stimulate demand—particularly targeting customers (Rennings, 2000). The characteristics, advantages and pitfalls of both approaches are briefly discussed below.

With regard to *supply-side* policy measures, governments make an effort to shape market characteristics—through public-private projects, for example—or to craft regulation that enforces certain technologies. Public-private projects such as LEV demonstrations are a means to learn about and shape the markets for novel LEV technologies (Harborne et al., 2007). Harborne et al. (2007) examined fuel-cell bus demonstrations on three continents, in the U.S., Europe and Japan, and found that the major benefit of such projects is the learning possibilities for all stakeholders involved. Challenges remain, however, such as the tendency of governments to pick a winning technology due to resource constraints, instead of testing competing technologies in equally protected spaces (Harborne et al., 2007).

Regulatory frameworks can impose certain technology standards—through voluntary agreements between governments and car manufacturers or through command and control (i.e., through technology-forcing) regulation (Gerard & Lave, 2005; Pilkington, 1998;

Rennings, 2000). Two types of technology regulation with respect to LEVs are noteworthy: improved emission performance regulation and zero-emission vehicle regulation. The two approaches differ in the degree to which the required technologies are familiar to the car manufacturers. Improved emission performance regulation, such as CAFE standards in the U.S., demand measures that firms are familiar with. Car manufacturers can react with incremental changes, such as making the ICE more efficient or integrating devices such as a catalytic converter. However, zero-emission regulation, such as the ZEV programme in California, requires radical actions because the ICE in its current design will, by definition, never be a zero-emission vehicle.

Stringent regulation might impede new business models that are necessary for LEVs (Nieuwenhuis et al., 2006). At the same time, regulation can become the source of a lock-in. Badly designed frameworks stimulate incremental improvements of the ICE instead of radical innovation (Dijk & Yarime, 2010). In addition, regulation could also be aimed at stimulating radical innovation but subsequently modified in favour of less radical innovation, such as what happened with California's ZEV mandate (Dijk & Yarime, 2010).

The "responses of firms [towards regulation] are determined by their capabilities and the availability of technological solutions" (Pilkington, 1998: 213). Car manufacturers might lobby against (parts) of the regulation, for instance, by requesting that light trucks be excluded from CAFE standards (as has been the case), or they might innovate and bring more efficient technologies, such as hybrids, to the market. In either case, "in combination the regulations have had a substantial effect on the product development activities of the car manufacturers, which otherwise would have remained locked into a cycle of incremental development" (Pilkington, 1998: 220).

Another government approach to promote the diffusion of LEVs is to stimulate the *demand-side* by providing incentives for LEVs, such as tax credits, or to increase fuel taxes for ICEs. Tax credits have gained increasing popularity, particularly in the course of the financial crisis. Tax credits allow the buyer of an LEV to deduct the incentive from his or her income tax. Yet, the effectiveness of tax credits is debatable. Some studies assert that incentives are crucial for the successful diffusion (Beresteanu & Li, 2011), while others find that "[s]trong income tax credits for the purchase of new diesel, hybrid, and plug-in hybrid vehicles are very expensive and essentially ineffective at reducing [greenhouse gas] emissions from transportation" (Morrow et al., 2010: 1318). Another government programme is cash-for-clunkers, under which consumers receive a cash amount for trading in an old car for a

new, preferably more fuel-efficient car. However, research shows that the initial demand surge is offset by decreasing demand in subsequent months (Mian & Sufi, 2012).

Opinions also differ with regard to the effectiveness of a fuel tax. According to Mikler (2010), demand for fuel is inelastic, and, thus, higher taxes would not enhance diffusion. Therefore, Mikler (2010: 14) argues that the success of new technologies is not driven as much by prices as it is by consumers' and incumbents' acceptance of the status quo, as reflected in the (unchanged) product portfolios of the incumbents. However, Diamond (2008) shows that the adoption of hybrids is driven by fuel prices; hence, fuel taxes positively stimulate LEV diffusion. This view is supported by Beresteanu and Li (2011). In analyzing the effect of gasoline prices and tax incentives on the demand for hybrid vehicles, the authors found that each explained more than 15 percent of the increased demand for hybrid vehicles in California. More precisely, 27 percent of the increase in hybrid cars is explained by fiscal incentives, compared to a 14 percent increase due to rising oil prices (Beresteanu & Li, 2011).

An example is the diesel introduction in France. The technology was introduced and promoted in France in the 1970s during the time of the oil crises (Bento, 2010). With, on average, 15 percent higher efficiency than the ICE, the diesel engine reduced the dependency on oil significantly. However, production costs for diesels were higher (15 percent more, on average), and there was no infrastructure available. Hence, the government promoted the technology by lowering taxes on diesel fuel as compared to those on gasoline. On average, the price difference was 25 percent between 1980 and 2006 (Bento, 2010: 5). The effectiveness of the policy is reflected in the share of diesel in the market. Today, 50 percent of the cars in France have a diesel engine, and 70 percent of new car sales are diesels (Bento, 2010).

These studies show that policy instruments vary in their effectiveness. Thus, despite governments being a driver for LEVs, their actions also bear risks for car manufacturers. Considering the different policy tools (Serra, 2012), incentives for LEVs, such as tax credits for EVs or cash-for-clunker deals, expose car manufacturers to uncertainty because their availability is finite. What is more, their continuation depends on the political tide (Steen et al., 2011). If sustainability vanishes from government agendas, then investments could be in vain.

Governments stimulating LEV development face a dilemma: they not only must be flexible enough to not hinder LEV technologies from emerging, but also must be certain enough for car manufacturers to have the confidence to invest. This points to the close link between the perspectives of governments and of car companies, which will receive more attention in subsequent chapters based on an identification of several research gaps.

3.5 Research gaps

The previous chapters and this chapter thus far have described the evolution of the car industry at large, the different LEV technologies, and the firm and government perspectives on LEVs. This overview points at the increasing interest in LEVs. Yet, despite the many available insights, some research gaps remain.

First, although there is a considerable literature on the technological aspects of LEVs (Frenken et al., 2004; Rajashekara, 1994), the competition between technologies (Bakker et al., 2012; Wesseling et al., 2013) as well as on the future of mobility (Eggers & Eggers, 2011; Kosugi, Tokimatsu, & Yoshida, 2005; Moriarty & Honnery, 2008a, 2008b), no study, to the author's knowledge, provides a comprehensive overview of the current international evolution of LEVs and of a potential transition towards LEVs adopting a firm perspective. Studies have explained past transitions, such as from horse-drawn carriages to the automobile (Geels, 2005); potential transition scenarios (Lovins & Cramer, 2004); and insights into the transition of specific technologies, such as those for EVs (Cowan & Hulten, 1996; Dijk et al., 2012; Pilkington, Dyerson, & Tissier, 2002) or hybrids (Dijk & Yarime, 2010). Some have also compared multiple technologies (Bakker et al., 2012; Hekkert & Van den Hoed, 2004; Wesseling et al., 2013). Given the potential, it might be worthwhile to obtain more insight into recent international developments with regard to the main LEV technologies, paying attention to the developments in the different regional car markets, the trajectories of the different LEV technologies, and the activities of specific actors, particularly firms and governments. This will be examined in Chapter 4.

Second, although there is research that explains responses of car manufacturers to emission regulation (Pilkington, 1998; Shiau et al., 2009), the effect of demonstration projects (Harborne et al., 2007; Mikler, 2005) and policies in general (Åhman, 2006; Koopman, 2010), studies have not yet addressed the interplay between car manufacturers and governments There is limited insight into how LEVs are brought to the market in a 'protected' way. Considering that LEVs often involve disruptive technologies and, consequently, often fail to fulfil incumbents' profitability requirements (Christensen, 1997), they seem to require protection in the development and initial commercialization stage. Research has provided insight into protection mechanisms, especially the stimulation of LEVs in niches from the government side (Hoogma, 2000; Nykvist & Whitmarsh, 2008; Raven, 2007; Smith & Raven, 2012; Weber, Hoogma, Lane, & Schot, 1999; Windrum & Birchenhall, 1998), but possible forms of protection of LEV development and commercialization by car manufacturers

themselves has received little attention. Moreover, it remains unclear how car manufacturers utilize protection provided by governments and how government and firm protection mechanisms interact. This dissertation aims to help fill this gap through an analysis of the interplay of governments and car manufacturers and the role of protection provided by both types of actors (Chapter 5).

Third, because LEVs are fundamentally different from cars with an ICE on some dimensions, they seem to require changes in the business model such as in pricing, the value chain or the necessary infrastructure (Christensen, 1997). However, incumbents face constraints in changing business practices due to existing resources, capabilities and routines (Ahuja & Lampert, 2001; Bettis & Prahalad, 1995; Bower & Christensen, 1995). Entrepreneurs seem more likely to be the source of new business models (Hockerts & Wüstenhagen, 2010). Scholars have investigated and described new business models that are more sustainable for the car industry in general (Wells, 1991; Wells, 2004; Wells & Nieuwenhuis, 2004; Williams, 2006), yet it remains unclear which business model might be suitable for LEVs and who would be best placed to introduce them. Further, it is unclear how incumbents' path dependence and the influence of government support influence new business models. These topics will be explored further in Chapter 6.

Finally, studies have pointed to various barriers to car manufacturers investing in LEVs (Orsato & Wells, 2007a, 2007b; Pilkington, 1998; Unruh, 2000; Zapata & Nieuwenhuis, 2010). The lack of infrastructure, the different driving experience but also high costs inhibit the large scale introduction of LEVs. As laid out above, LEVs can be sustainable and create social and environmental value but customers are often not willing to pay a higher price (Rennings, 2000). Still, EV development has gained some momentum recently, after initial commercialization attempts in the 1990s failed (Bakker et al., 2012; Dijk et al., 2012; Wesseling et al., 2013). The motivations for incumbents to invest in EVs—next to government policies—remain however unclear. Chapter 7 illuminates possible factors that have not been fully addressed yet.

References

Åhman, M. (2006). Government policy and the development of electric vehicles in Japan. *Energy Policy*, *34*(4), 433–443.

Ahuja, G., & Lampert, C. M. (2001). Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. *Strategic Management Journal*, *22*(6-7), 521–543.

Ba, S., Lisic, L. L., Liu, Q., & Stallaert, J. (2012). Stock Market Reaction to Green Vehicle Innovation. *SSRN Electronic Journal*. doi:10.2139/ssrn.2033413

Bakker, S., Van Lente, H., & Engels, R. (2012). Competition in a technological niche : the cars of the future. *Technology Analysis & Strategic Management*, *24*(5), 421–434.

Bento, N. (2010). Dynamic competition between plug-in hybrid and hydrogen fuel cell vehicles for personal transportation. *International Journal of Hydrogen Energy*, *35*(20), 11271–11283.

Beresteanu, A., & Li, S. (2011). Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles in the U.S. *International Economic Review*, *52*(1), 161–182.

Bettis, R., & Prahalad, C. (1995). The dominant logic: Retrospective and extension. *Strategic Management Journal*, *16*(1), 5–14.

Bower, J., & Christensen, C. (1995). Disruptive technologies: catching the wave. *Harvard Business Review*, (Jan-Feb), 43–53.

Buchmann, I. (2001). What is the perfect battery? Retrieved February 2, 2012, from http://www.buchmann.ca/Article4-Page1.asp

Carson, I., & Vaitheeswaran, V. V. (2007). *Zoom: the global race to fuel the car of the future*. New York: Twelve.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Clark, K. B., Chew, W. B., Fujimoto, T., Meyer, J., & Scherer, F. (1987). Product development in the world auto industry. *Brookings Papers on Economic Activity*, *1987*(3), 729–781.

Cowan, R., & Hulten, S. (1996). Escaping lock-in: the case of the electric vehicle. *Technological Forecasting and Social Change*, *53*(1), 61–80.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy*, *37*(3), 972–983.

Dijk, M., Orsato, R. J., & Kemp, R. (2012). The emergence of an electric mobility trajectory. *Energy Policy*, (in Press).

Dijk, M., & Yarime, M. (2010). The emergence of hybrid-electric cars: Innovation path creation through co-evolution of supply and demand. *Technological Forecasting and Social Change*, *77*(8), 1371–1390.

Dyerson, R., & Pilkington, A. (2005). Gales of creative destruction and the opportunistic incumbent: The case of electric vehicles in California. *Technology Analysis & Strategic Management*, *17*(4), 391.

Eggers, F., & Eggers, F. (2011). Where have all the flowers gone? Forecasting green trends in the automobile industry with a choice-based conjoint adoption model. *Technological Forecasting and Social Change*, *78*(1), 51–62.

European Comission. (2012). CO2 emissions from new cars down by 3% in 2011. Retrieved May 27, 2013, from http://ec.europa.eu/clima/news/articles/news_2012062002_en.htm

Frenken, K., Hekkert, M., & Godfroij, P. (2004). R&D portfolios in environmentally friendly automotive propulsion: Variety, competition and policy implications. *Technological Forecasting and Social Change*, *71*(5), 485–507.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274.

Geels, F. W. (2005). The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technology Analysis & Strategic Management*, *17*(4), 445–476.

Gerard, D., & Lave, L. B. (2005). Implementing technology-forcing policies: The 1970 Clean Air Act Amendments and the introduction of advanced automotive emissions controls in the United States. *Technological Forecasting and Social Change*, *72*(7), 761–778.

Greimel, H. (2009). Ghosn: Electric cras are worth the billions that will be invested. *Automotive News*, *83*(6372), 14.

Guilford, D., & Ciferri, L. (2009). EV debate: Bit players or mainstream? *Automotive News*, *84*(6378), 3.

Harborne, P., Hendry, C., & Brown, J. (2007). The Development and Diffusion of Radical Technological Innovation: The Role of Bus Demonstration Projects in Commercializing Fuel Cell Technology. *Technology Analysis & Strategic Management*, *19*(2), 167–188.

Hasegawa, Y. (2008). *Clean Car Wars: How Honda and Toyota are Winning the Battle of the Eco-Friendly Autos*. Singapore: Wiley.

Hekkert, M., & Van den Hoed, R. (2004). Competing technologies and the struggle towards a new dominant design. *Greener Management International*, *47*(Autumn), 29–44.

Henderson, R., & Clark, K. (1990). Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms. *Administrative Science Quarterly*, *35*(1), 9–30.

Hockerts, K., & Wüstenhagen, R. (2010). Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. *Journal of Business Venturing*, *25*(5), 481–492.

Hoogma, R. (2000). Exploiting Technological Niches: Strategies for Experimental Introduction of Electric Vehicles. *PhD thesis, Twente University Press, Enschede.*

Howells, J. (2002). The Response of Old Technology Incumbents to Technological Competition - Does the Sailing Ship Effect Exist? *Journal of Management Studies*, *39*(7), 887–906.

Koopman, G. J. (2010). Policies to Reduce C02 Emissions from Cars in Europe. *Transport Economics*, *29*(1), 53–70.

Kosugi, T., Tokimatsu, K., & Yoshida, H. (2005). Evaluating new CO2 reduction technologies in Japan up to 2030. *Technological Forecasting and Social Change*, *72*(7), 779–797.

Lieberman, M. B., & Montgomery, D. B. (1988). First-mover (dis)advantages: retrospective and link with the resource-based view. *Strategic Management Journal*, *19*(12), 1111–1125.

Lovins, A. B., & Cramer, D. R. (2004). Hypercars, hydrogen, and the automotive transition. *International Journal of Vehicle Design*, *35*(1/2), 50.

McGrath, R. G. (2010). Business Models: A Discovery Driven Approach. *Long Range Planning*, *43*(2-3), 247–261.

McGrath, R. N. (1999). Effects of incumbency and R&D affiliation on the legitimation of electric vehicle technologies. *Technological Forecasting and Social Change*, *60*(3), 247–262.

Mian, A., & Sufi, A. (2012). The Effects of Fiscal Stimulus: Evidence from the 2009 Cash for Clunkers Program. *The Quarterly Journal of Economics*, 1107–1142.

Mikler, J. (2005). Institutional reasons for the effect of environmental regulations: Passenger car CO 2 emissions in the European Union, United States and Japan. *Global Society*, *19*(4), 409–444.

Mikler, J. (2010). Apocalypse now or business as usual? Reducing the carbon emissions of the global car industry. *Cambridge Journal of Regions, Economy and Society*, *3*(3), 407–426.

Moriarty, P., & Honnery, D. (2008a). The prospects for global green car mobility. *Journal of Cleaner Production*, *16*(16), 1717–1726.

Moriarty, P., & Honnery, D. (2008b). Low-mobility: The future of transport. *Futures*, *40*(10), 865–872.

Nieuwenhuis, P., Wells, P., & Vergragt, P. J. (2004). Technological Change and Regulation in the Car Industry Introduction. *Greener Management International*, *47*(Autumn), 5–11.

Nykvist, B., & Whitmarsh, L. (2008). A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting and Social Change*, *75*(9), 1373–1387.

Orsato, R. J., & Wells, P. (2007a). U-turn: the rise and demise of the automobile industry. *Journal of Cleaner Production*, *15*(11-12), 994–1006.

Orsato, R. J., & Wells, P. (2007b). The Automobile Industry & Sustainability. *Journal of Cleaner Production*, *15*(11-12), 989–993.

Pilkington, A. (1998). The fit and misfit of technological capability: Responses to vehicle emission regulation in the US. *Technology Analysis & Strategic Management*, *10*(2), 211–224.

Pilkington, A., Dyerson, R., & Tissier, O. (2002). The electric vehicle: Patent data as indicators of technological development. *World Patent Information*, *24*(1), 5–12.

Pistorius, C., & Utterback, J. (1997). Multi-mode interaction among technologies. *Research Policy*, *26*(1), 67–84.

Rajashekara, K. (1994). History of electric vehicles in General Motors. *IEEE Transactions on Industry Applications*, *30*(4), 897–904.

Raven, R. (2007). Niche accumulation and hybridisation strategies in transition processes towards a sustainable energy system: An assessment of differences and pitfalls. *Energy Policy*, *35*(4), 2390–2400.

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332.

Ross Morrow, W., Gallagher, K. S., Collantes, G., & Lee, H. (2010). Analysis of policies to reduce oil consumption and greenhouse-gas emissions from the US transportation sector. *Energy Policy*, *38*(3), 1305–1320.

Schneider, M., Schade, B., & Grupp, H. (2004). Innovation Process “Fuel Cell Vehicle”: What Strategy Promises to be Most Successful? *Technology Analysis & Strategic Management*, *16*(2), 147–172.

Serra, J. (2012). *Electric vehicles: technology, policy, and commercial development*. New York: Earthscan.

Shiau, C., Michalek, J., & Hendrickson, C. (2009). A structural analysis of vehicle design responses to Corporate Average Fuel Economy policy. *Transportation Research Part A: Policy and Practice*, *43*(9-10), 814–828.

Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, *41*(6), 1025–1036.

Steen, M., Deventer, P., Bruijn, H., Twist, M., Ten Heuvelhof, E., Haynes, K., & Chen, Z. (2011). Governing and Innovation: The Transition to E-Mobility-A Dutch Perspective. *GMU School of Public Policy*. Retrieved from http://ssrn.com/abstract=1943207 or http://dx.doi.org/10.2139/ssrn.1943207

Unruh, G. (2000). Understanding carbon lock-in. *Energy Policy*, *28*(12), 817–830.

Weber, M., Hoogma, R., Lane, B., & Schot, J. (1999). *Experimenting with sustainable transport innovations: a workbook for strategic niche management*. Seville: Institute for Prospective Technological Studies.

Wells, P. (1991). East-West partnerships in automobiles. *Long Range Planning*, *24*(2), 75–81.

Wells, P. (2004). Business Models : The Case of the Automotive Industry. *IIMB Management Review*, *16*(4), 15–24.

Wells, P., & Nieuwenhuis, P. (2004). Business models for relocalisation to deliver sustainability. *Greener Management International*, *47*(Autumn), 89.

Wesseling, J. H., Faber, J., & Hekkert, M. P. (2013). How competitive forces sustain electric vehicle development. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2013.02.005

Williams, A. (2006). Product-service systems in the automotive industry: the case of micro-factory retailing. *Journal of Cleaner Production*, *14*(2), 172–184.

Windrum, P., & Birchenhall, C. (1998). Is product life cycle theory a special case? Dominant designs and the emergence of market niches through coevolutionary-learning. *Structural change and economic dynamics*, *9*(97), 109–134.

Zapata, C., & Nieuwenhuis, P. (2010). Exploring innovation in the automotive industry: new technologies for cleaner cars. *Journal of Cleaner Production*, *18*(1), 14–20.

Part II

Empirical chapters

4 The evolution of low-emission vehicles: Car manufacturers and policy interventions

Abstract

An extensive literature on low-emission vehicles (LEVs) has described the emergence of LEVs and the influence of policy interventions. Thus far the literature has explored the link between policies, firm innovation and the LEV trajectory on a regional level—with the U.S. and specifically California as most popular geographical areas. This does not reflect how most car manufactures operate, however. Car manufacturers operate internationally and are exposed to and respond to different policy interventions in different geographical areas. Based on archival data from 1997 to 2010, this chapter explores how government policies at local, national and international levels interact with car manufacturers' innovation strategies and, in turn shape the international LEV trajectory. In doing so, it provides a comprehensive perspective on the international LEV trajectory and shows that LEVs have carved out a significant niche in the market. In addition, this chapter proposes a framework that explains the co-evolution between government policies and car manufacturers, and how this interaction influences the LEV trajectory, heeding the call for a better geographical conceptualization of technological trajectories. The findings suggest that three mechanisms shape the global LEV trajectory: (1) policy diffusion and international policies, (2) international operations of firms, and (3) the fit between policy demands and firm capabilities.

4.1 Introduction

Global challenges such as climate change, resource depletion and energy security, as well as local challenges including air pollution and congestion, have led governments around the world to require the car industry to become more sustainable. Since 1990, increasingly local, national and international government policies have prompted incumbents in the car industry to invest in more environmentally-friendly products, especially low-emission vehicles (LEVs) (Oltra & Saint Jean, 2009a; Pilkington & Dyerson, 2006). As a result, car manufacturers have engaged in sustainable technologies, launched concept cars, and tested other new technologies, but so far few LEVs have been commercially marketed. Three LEV technologies have emerged as most promising to become sustainable alternatives for the internal combustion engine (ICE): hybrid vehicles (HVs), electric vehicles (EVs) and fuel-cell vehicles (FCs) (Frenken, Hekkert, & Godfroij, 2004). Over time, the car industry went through different periods in which either EVs, HVs or FCs were considered to be the most likely technology substitute for the ICE (Bakker, Van Lente, & Engels, 2012; Dijk, Orsato, & Kemp, 2012; Wesseling, Faber, & Hekkert, 2013).

A growing body of literature in innovation studies documents the emergence of LEVs (Dijk et al., 2012; Dyerson & Pilkington, 2005; Wesseling et al., 2013). The literature explores both the technological developments regarding ways to escape the lock-in of the ICE (Christensen, 2011; Cowan & Hulten, 1996; Zapata & Nieuwenhuis, 2010) and the competition among alternative LEV technologies (Bakker et al., 2012; Bento, 2010; Berggren, Magnusson, & Sushandoyo, 2009; Frenken et al., 2004; Wesseling et al., 2013). The majority of studies focus on a single country and accordingly regard government policies as the driving force for car manufacturers to engage in LEVs (e.g. Pilkington & Dyerson, 2006; Zapata & Nieuwenhuis, 2010; Van Bree, Verbong, & Kramer, 2010). Policies are necessary to provide a supportive environment, through subsidies and tax incentives for instance (Bento, 2010; Struben & Sterman, 2008), which is why governments are considered central to the facilitation of a transition towards more sustainable mobility (Van Bree et al., 2010).

So far the literature has explored the link between policies, firm innovation and the LEV trajectory on a country level. However, scholars have paid little attention to the fact that car manufacturers operate internationally and are exposed to, and deal with, different policy interventions in various geographical areas. In view of the important role of government policies and considering the international nature of the car industry, the question arises how the totality of government policies at local, national and international levels interact with car

manufacturers' innovation strategies and, in turn, shape the international LEV trajectory. To analyze this interaction, this chapter draws on a co-evolution perspective as it has developed in the socio-technical systems literature (Dijk & Yarime, 2010; Geels, 2002, 2006; Van Bree et al., 2010), and explores how various local, co-evolutionary developments between government policy and firm innovation together shape an international LEV trajectory. In doing so, this research heeds the call for adding a spatial dimension to the perspective on sustainability transitions in the socio-technical systems literature (Coenen, Benneworth, & Truffer, 2012). This chapter examines the international development of LEVs from 1997—the year in which the first LEVs were commercialized—to 2010, paying particular attention to the different levels of policy contexts that have influenced firm innovation as well as the LEV trajectory.

In the following section, the stage will be set by briefly exploring the literature on the evolution of LEVs and introducing literature on the influence of governments on firm innovation. Subsequently, the methods used for collecting, coding, and analyzing the data will be presented. Next, the results analyze different phases of the LEV trajectory and distil three mechanisms that influence the international LEV trajectory with the aim to propose a framework that explains the co-evolution between government policies and car manufacturers' strategies and this mutual evolution's influence on the LEV trajectory. The findings regarding the LEV trajectory, policy context and firm innovation strategy will be discussed, explaining how the discovered mechanisms contribute to an enhanced understanding of the international development of LEVs. Finally, areas for further research will be discussed.

4.2 The evolution of LEV technologies

The evolution of alternatives to the internal combustion engine has received increasing attention from innovation scholars. The literature has focused on the evolution of the most promising technologies namely hybrid vehicles, electric vehicles and fuel-cell vehicles. Initially, the innovation diffusion literature (e.g. Bento, 2010; Chanaron & Teske, 2007; Frenken, Hekkert, & Godfroij, 2004) and the socio-technical system literature (e.g. Bakker, van Lente, & Engels, 2012; Hekkert & Van den Hoed, 2004; Van Bree, Verbong, & Kramer, 2010), were mainly concerned with three questions: how did LEVs emerge (Dijk et al., 2012; Oltra & Saint Jean, 2009a; Serra, 2012; Van Bree et al., 2010), how do LEVs escape the lock-in situation of the ICE (e.g. Christensen, 2011; Cowan & Hulten, 1996; Zapata &

Nieuwenhuis, 2010), and which LEV technology will become the dominant LEV technology (e.g. Bakker et al., 2012; Bento, 2010; Berggren, Magnusson, & Sushandoyo, 2009; Frenken et al., 2004).

One stream of literature explored the emergence of LEVs. Many studies point to the Zero Emission Vehicle Mandate in California in 1990 as the trigger for the LEV trajectory (Dijk et al., 2012; Dyerson & Pilkington, 2005; Pilkington & Dyerson, 2006; Van den Hoed, 2007). At the time, California suffered from severe pollution problems. The mandate required the seven car manufacturers with the largest share of the Californian market that they replace 2 percent of their total sales with zero-emission vehicles beginning in 1998 and 10 percent in 2003 (Pilkington, 1998). Later also governments in other countries put policies in place that stimulated LEV development. According to a patent study by Oltra and Saint Jean (2009a), car manufacturers initially focused on EVs, but unsatisfactory performance led car manufacturers to also develop other technologies, mainly HVs and FCs. Since then, these three technologies have been competing for the dominant design (Frenken et al., 2004; Oltra & Saint Jean, 2009a).

Another stream of literature investigated how to escape the lock-in of the ICE. The lock-in of the ICE revealed itself in routines, economies of scale and customer-supplier relationships as well as in customer preferences and established legal frameworks (Cowan & Hulten, 1996; Unruh, 2002). An early study by Cowan and Hulten (1996) reviewed the history of EVs and predicted that the lock-in of the ICE will remain for an extended period because of EV's technological inferiority and the lack of development of a required support infrastructure. These disadvantages held true for other technologies as well. In a later study investigating the concept of innovation in the car industry, Zapata and Nieuwenhuis (2010) pointed to the large investments in plants and development of the ICE as a source of lock-in. These sunk costs could only be recouped with the sales of large numbers of cars. To escape the lock-in of the ICE, scholars asserted that different conditions would need to come together: favourable regulation, a technological breakthrough, change of customer behaviour and the development of niche markets (Cowan & Hulten, 1996; Zapata & Nieuwenhuis, 2010). The concurrent occurrence of this combination is rare, however. Christensen (2011) suggested an alternative: the lock-in could be bypassed by employing the production approach of modular production and design, and integrating alternative powertrains in existing conventional cars as modules. Nevertheless, high costs and low functionality remained barriers to the large-scale introduction of any LEV technology, according to a study that modelled transition challenges (Struben & Sterman, 2008).

Researchers also studied the competition between the emerging alternatives to the ICE. Three technologies have been competing for the dominant LEV design, namely fuel cell vehicles, electric vehicles including plug-in EVs, and hybrid vehicles (Frenken et al., 2004; Hekkert & Van den Hoed, 2004; Oltra & Saint Jean, 2009a; Wesseling et al., 2013). Fuel-cell vehicles are regarded as the 'greenest' technology because they run on hydrogen—which is abundant on earth—and they have the most efficient technology (Bento, 2010). Fuel cell vehicles are, for example, more efficient than electric vehicles. Indeed, from a total life cycle perspective, if electricity were to be generated in coal plants, EVs emit even more greenhouse gases than ICE cars (Hawkins, Singh, Majeau-Bettez, & Strømman, 2012). More recently, a new variety of EVs emerged: the plug-in EV (Dijk et al., 2012). Plug-in EVs (PIs) are equipped with a small internal combustion engine as a back-up for longer trips. It alleviates the short range and refuelling problem of EVs (Bento, 2010). In comparison, hybrid vehicles combine an ICE with an electric motor that supports the ICE. HVs are the least radical technology and were popularized by Toyota's Prius (Chanaron & Teske, 2007).

In a study on the competition between HVs and FCs with a gasoline converter, Hekkert and Van den Hoed (2004) found that if HVs become dominant it will be difficult for FCs to become popular, as HVs are more efficient and require fewer investments. Chanaron and Teske (2007) explored whether HVs would become an industry standard. They concluded that HVs will become mainstream in the U.S. and Japan, but remain a niche in Europe because diesel technology is stimulated by governments and favoured by customers there. With the rising popularity of HVs, concerns about a premature lock-in of an inferior technology arose. The risk was that car firms would focus on a potentially suboptimal LEV technology because HVs still commonly burn fossil fuels (Bento, 2010; Frenken et al., 2004; Oltra & Saint Jean, 2009a). In a patent study, Frenken et al. (2004) illustrated that this risk was low because the variety of the car manufacturers' technological R&D portfolio was still increasing rather than decreasing. Interestingly, a patent data analysis from 1990 until 2005 by Oltra and Saint Jean (2009a) showed that most innovation efforts by car manufacturers still focus on conventional technologies, i.e. ICE and diesel, with more than 50 percent of all registered patents.

4.3 Underlying dynamics of the LEV trajectory: Government-firm interactions

The majority of studies on the LEV evolution agree that car manufacturers and policymakers are the key actors in LEV development (e.g. Hekkert & Van den Hoed, 2004; Pilkington & Dyerson, 2006; Zapata & Nieuwenhuis, 2010). Understanding the dynamics between the two groups of actors therefore enables a better understanding of LEV trajectory. Governments' environmental policies are widely regarded as the trigger for car manufacturers to engage in LEVs (Hekkert & Van den Hoed, 2004; Pilkington, Dyerson, & Tissier, 2002; Van den Hoed, 2007; Zapata & Nieuwenhuis, 2010). Some scholars claim that next to technological breakthroughs, government policy is the most important driver for the evolution of LEVs (Åhman, 2006; Frenken et al., 2004; Oltra & Saint Jean, 2009a).

Several studies have explored the impact of government policies on LEV evolution. One way in which governments intervene is through voluntary instruments, such as public-private partnerships (Cowan & Hulten, 1996; Harborne, Hendry, & Brown, 2007; Nykvist & Whitmarsh, 2008). Further, scholars have evaluated market-based instruments such as tax credits (Diamond, 2009; Gallagher & Muehlegger, 2011; Ross Morrow, Gallagher, Collantes, & Lee, 2010), and examined the impact of command-and-control instruments, such as emission or fuel-efficiency regulation, which require car firms to develop LEV technologies (Pilkington & Dyerson, 2006; Pilkington, 1998; Zapata & Nieuwenhuis, 2010). Scholars studying the impact of environmental policies on car manufacturers' LEV engagement have mostly focused on single-country contexts—with the U.S. and specifically California being the most popular geographical areas due to the critical role of the ZEV programme (Pilkington et al., 2002).

What has remained underexplored in these studies, however, is that car manufacturers operate internationally and are exposed to a variety of government policies at different levels. This raises the question of how the interplay between government policies at the local, national and international levels and car manufacturers' innovation strategies influences the international LEV trajectory. A perspective that helps to analyze the influence of multiple actors in multiple areas on the LEV trajectory is the co-evolution framework as it has been developed in the socio-technical systems literature (Geels, 2002).[1] The main function of a

[1] Also management scholars draw on the notion of co-evolution (Lewin & Volberda, 1999). The management perspective examines "how organizations systematically influence their environments and how organizational environments (comprised of other organizations and populations) influence those organizations in turn" (Lewin

socio-technical system is to align social and technological developments. Within a social-technical system, the linkages between actors such as consumers, car manufacturers and governments form a socio-technical regime (Geels, 2004). Although the relative stability of a socio-technical system over time is one of the main assumptions underlying this perspective, it is possible for a new socio-technical system such as LEVs to emerge, albeit gradually (Schot & Geels, 2007). Several factors can also potentially destabilize the established system and initiate more radical/fundamental changes, including technological breakthroughs (Mitchell, 1989), new regulations, and shifts in customer preferences and/or environmental conditions (Geels, 2002). The process is accelerated when such dynamics move in parallel (Schot & Geels, 2007). Promising breakthrough technologies often occur in niches, which are protected spaces that shield these technologies from mainstream development and market selection mechanisms (Schot & Geels, 2007). Protection occurs, for instance, through public-private partnerships between governments and car manufacturers.

The co-evolution perspective has been a popular lens for exploring LEV developments (Whitmarsh, 2012). Van Bree et al. (2010) utilized the perspective to develop transition scenarios for FCs and EVs. Oltra and Saint Jean (2009b) studied the co-evolution between car manufacturer's innovation strategies and the competition amongst different LEV technologies. To understand the emergence of EVs, Dijk and Yarime (2010) examined the co-evolution of supply (i.e. car manufacturers) and demand (i.e. consumers). They derived four key co-evolutionary mechanisms that shape the LEV trajectory: scale economies, learning about the market, social construction of LEV connotation, and network effects. Yet, the study regarded policymakers as an external force to co-evolution, rather than as co-evolving itself (Dijk & Yarime, 2010).

These studies pay little attention to the international nature of the LEV trajectory. One of the few that acknowledged the international dimension was Bakker et al. (2012: 431), explaining that LEV "trajectories are developed in local contexts and outcomes aggregate on a global level." Many governments around the world have designed policy measures to foster LEV development which shape local dynamics (Mikler, 2005). This has created various local co-evolutionary developments that together form an international LEV trajectory. While studies on LEVs in particular have neglected the international perspective, studies in the socio-technical systems literature have, in general, paid little attention to the spatial dimension. Coenen et al. (2012: 968) asserted that "analyses have often neglected where

& Volberda, 1999: 520). Yet, this chapter looks not so much at the intra-organizational level but rather 'higher' levels of analysis for which the socio-technical systems literature is more suitable (Geels, 2006).

transitions take place, and the spatial configurations and dynamics of the networks within which transitions evolve." In other words, the international transition of systemic innovations—such as LEVs—has been underrepresented (Carlsson, 2006).

In order to obtain insights in how government policies at the local, national and international level interact with car manufacturers' innovation strategies and, in turn, shape the international LEV trajectory, this chapter will first take stock of the firms that engaged in LEV technologies. Next, it will illustrate the various local, national and international interplays between car manufacturers and government policies which shape the international LEV trajectory. The next section describes the methodology adopted in this study.

4.4 Methodology and sample

This study analyzes the international LEV trajectory using a longitudinal approach. Since the main objective is to understand how multiple policy interventions affect innovation strategies of internationally operating car manufacturers, I collected qualitative process data, which "consist largely of stories about what happened and who did what when—that is, events, activities, and choices ordered over time" (Langley, 1999: 692). Using process data, I aimed to identify patterns in the way in which firms engage in innovation. In addition this would help to provide a more comprehensive account of the LEV trajectory from an international perspective.

As concrete illustration of, and background for, this international focus, Table 4.1 provides an overview of the sales of the largest 20 car manufacturers from Europe, Japan and the U.S., representing 95 percent of the sales in these areas in 2000 and 89 percent of the world's car production in that year. These three hubs were the main areas of the car industry in which almost 89 percent of new vehicles were sold (Mikler, 2005). The table illustrates that, generally, car manufacturers dominated their home markets. Domestic car manufacturers in Europe contributed 77 percent of all sold cars in their home area, while this amounted to 68 percent in the U.S. and up to 95 percent in Japan. Interestingly, Japanese car manufacturers also had a 26 percent share of the U.S. market (equivalent to 4.4 million cars). In fact, the majority of the Japanese manufacturers sold in absolute terms even more cars in the U.S. than in their home country (e.g. Honda, Mazda, Mitsubishi, Nissan, Toyota), highlighting the importance of U.S. regulation for Japanese car manufacturers. Japanese car manufacturers also held a 13 percent share of the European market, but overall sold more cars in Japan.

Table 4.1: Sales in the three lead markets of the largest car manufacturers in 2000

Car manufacturers sorted by origin	**Sales in Western Europe**	*% of combined Sales*	**Sales in Japan***	*% of combined Sales*	**Sales in the U.S.**	*% of combined Sales*	**Combined sales in 2000**
Europe							
BMW	499,000	*69%*	36,000	*5%*	188,000	*26%*	723,000
Daimler (Mercedes, Smart)	811,000	*68%*	51,000	*4%*	336,000	*28%*	1,198,000
Opel	1,508,000	*100%*	-	*0%*	-	*0%*	1,508,000
Fiat (all)	1,475,000	*100%*	1,800	*0%*	-	*0%*	1,476,800
Peugeot (Peugeot, Citroen)	1,929,000	*99%*	11,000	*1%*	-	*0%*	1,940,000
Renault	1,559,000	*100%*	2,000	*0%*	-	*0%*	1,561,000
Saab	79,000	*65%*	2,800	*2%*	39,000	*32%*	120,800
Volvo	230,000	*63%*	15,500	*4%*	122,000	*33%*	367,500
VW	2,756,000	*85%*	58,000	*2%*	436,000	*13%*	3,250,000
Sub-Total	**10,846,000**	*77%**	**178,125**	*4%**	**1,121,000**	*7%**	
U.S.							
Chrysler	97,000	*4%*	7,500	*0%*	2,522,000	*96%*	2,626,500
Ford	1,247,000	*24%*	7,600	*0%*	4,021,000	*76%*	5,275,600
GM	6,600	*0%*	4,900	*0%*	4,981,000	*100%*	4,992,500
Sub-Total	**1,350,658**	*10%**	**20,000**	*1%**	**11,524,000**	*68%**	
Japan							
Daihatsu	-	*0%*	385,000	*100%*	-	*0%*	385,000
Honda	182,000	*9%*	691,000	*34%*	1,159,000	*57%*	2,032,000
Hyundai	227,000	*48%*	-	*0%*	244,000	*52%*	471,000
Mazda	181,000	*26%*	253,000	*37%*	254,000	*37%*	688,000
Mitsubishi	160,000	*21%*	296,000	*38%*	315,000	*41%*	771,000
Nissan	393,000	*24%*	502,000	*30%*	751,000	*46%*	1,646,000
Suzuki	131,000	*21%*	424,000	*69%*	60,000	*10%*	615,000
Toyota	542,000	*16%*	1,216,000	*36%*	1,620,000	*48%*	3,378,000
Sub-Total	**1,816,000**	*13%**	**3,767,000**	*95%**	**4,403,000**	*26%**	
Total	14,012,600	*40%*	3,965,100	*11%*	17,048,000	*49%*	35,025,700
Total Area Sales in 2000	14,746,571	*40%*	4,259,872	*12%*	17,811,673	*48%*	36,818,116
Sample % or area sales	95%		93%		96%		95%
World production							41,215,653
% of World production							**89%**

* % of area sales

Sources:

European Data: ACEA, New vehicle registrations by manufacturer, Historical series: 1990-2012 http://www.acea.be/images/uploads/files/20120806_06_PC_90- 12_By_Manufacturer_W_Europe.xls (accessed 24-10-2012)
Japanese Data: Japan Automobile Manufacturers Association Inc., Motor vehicle Statistics of Japan (2012) http://www.jama-english.jp/publications/MVS2012.pdf (accessed 23/10/2012)
U.S. Data: Based on WardsAuto Data: www.wardsauto.com/keydata/historical/UsaSa28summary.xls www.wardsauto.com/keydata/historical/UsaSa01summary.xls (accessed 23/10/2012)
World Data: http://www.worldometers.info/cars/ (accessed 23/10/2012)

The European car manufacturers, on the other hand, had smaller shares in the U.S. and only the luxury car manufacturers BMW and Daimler (Mercedes, Smart) had considerable shares, but sold less than in their home area. Volkswagen, Volvo and Saab also had lower shares in the U.S. market. Sales by foreign car manufacturers in Japan were negligible (less than 6 percent). Consequently, Japanese regulation was less central for U.S. and European car manufacturers. U.S. manufacturers operated mainly in their home country. Only Ford and GM—through its European subsidiary Opel—also had a large share in Europe. While this indicates that the home country was most important for most car manufacturers, it also shows that the industry was internationally connected. The varying degrees of importance of home and host markets for car manufacturers make this study an interesting case to see how particular countries and firms affected the international LEV trajectory.

I collected data from two trade magazines—*Automotive News* and *WardsAuto World*—and a car magazine—*Autoweek*—as they focus on the car industry and can provide insight into industry and corporate perceptions by offering rich descriptions of technologies, developments within incumbents, and the relevant policies. Furthermore, I chose the *Financial Times* because of its focus on business strategies and attention to environmental issues in the broader political and economic context. Both newspaper and magazine articles are seen as a stable source, given that they existed prior to the start of the case study and provide good insight into the main themes of interest for this chapter and allows gaining robust data for triangulation (Yin, 2009). I performed a keyword search for the period 1997-2010, using search terms from the different LEV technologies—i.e., hybrid, electric vehicle and fuel cell. In this way, I generated a dataset of 9,908 articles over a 14-year period. The year 1997 was used because in that year the first LEVs were brought to the market. Moreover, 1997 saw the adoption of the Kyoto protocol which formalized international action against global warming. It added to the uncertainty of car manufacturers because their products contribute significantly to greenhouse gas emissions

To analyze the articles, I used the qualitative data-analysis software Atlas.ti 6.2, which can manage large datasets and enables users to define the length of selected quotations and fully capture the richness of the information. I followed a three-step approach for the data analysis. In the first stage, I analyzed which technologies car firms engaged in (i.e. hybrid vehicles, electric vehicles or fuel cell vehicles) and examined up to which stage the cars were developed (i.e. concept car including prototype, test car or mass produced car). This generated a list of 320 LEVs that were announced between 1997 and 2010 (see Table 4.3, included in the next section). In the second stage, I tracked all relevant policy interventions found in the

dataset (e.g. public-private partnerships, tax incentives, regulation) in different geographical areas—i.e. countries and regions—at different policy levels—i.e. local, national and international. In the third stage, I tracked how policy interventions affected firm innovation by linking policy interventions with car manufacturers' LEV engagement, analyzing the effects of policy interventions over time. I then combined all interactions into a matrix and identified patterns. Based on the matrix, I generated narrative descriptions of the effects over time and across areas (Bourgeois & Eisenhardt, 1988). Finally, the narrative was juxtaposed with the relevant literature, and refined accordingly.

4.5 Evolution of the LEV trajectory

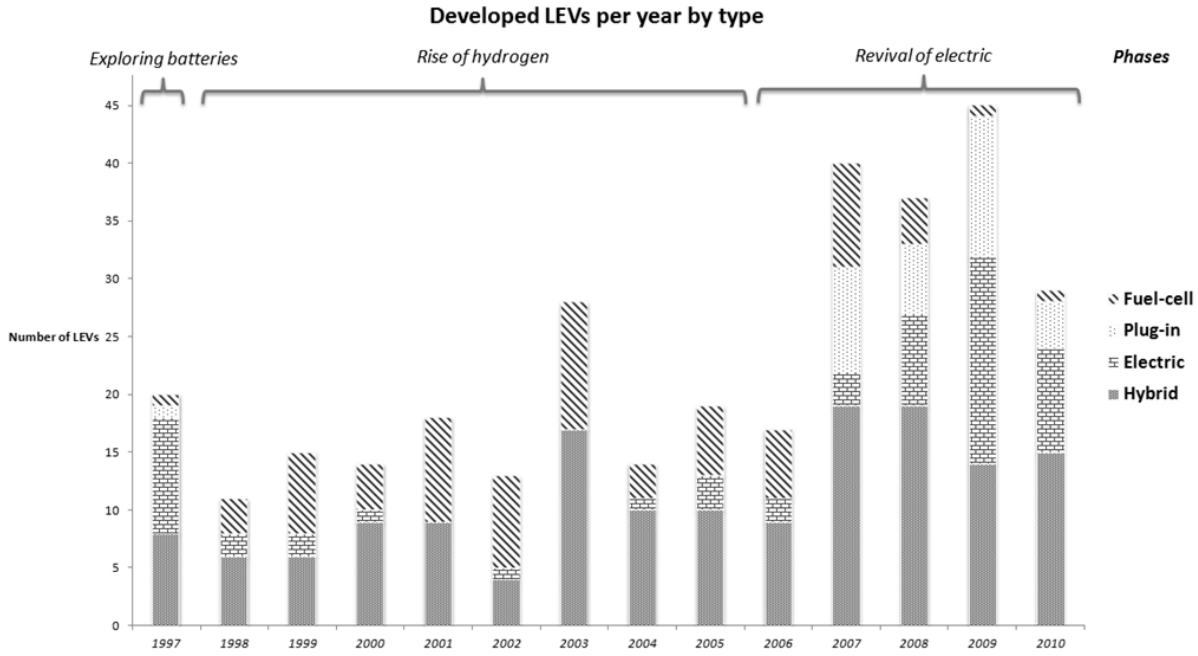
In the following, the evolution of the LEV trajectory is depicted. In particular I explore the interplay between government policies and car manufacturers' innovation strategies. In discussing the findings, I follow the phases distinguished by Bakker et al. (2012) based on their analysis of a Dutch weekly car magazine. On the basis of article counts of battery electric and hydrogen vehicles, they labelled the period until 1998 as 'exploring batteries'; the period 1998-2005 as 'the rise of hydrogen' and 2006-2009 as 'the revival of electric'. Different from their two-fold distinction, this study further differentiates battery electric vehicles (see Figure 4.1), also showing developments in hybrid and plug-in vehicles. Moreover, it is based on actual LEVs launched, not on the number of articles on specific technologies.

Based on the coding for this study, a list of LEVs developed by car manufacturers was compiled, distinguishing concept cars, test cars and mass-produced cars. Although triangulating the data against corporate websites showed no inconsistencies, the results may not be complete as it is based on secondary sources. From 1997 to 2010, 29 car manufacturers that engaged in LEVs emerged from the analysis and were found to have launched in total 320 different LEV models; most were concept cars or prototypes (221), some were test cars (39) and others were mass produced (60).[2] In the studied period, the engagement of car manufacturers in LEVs increased over the years (see Figure 4.1), with about 23 LEVs, on average, developed per year. The lowest number of LEVs was developed in 1998 (11) and the highest in 2009 (45). Most LEVs were HVs (155), followed by EVs (92) and FCs (73),

[2] Concept cars refer to vehicles that have been shown for instance at car shows, or built as prototypes to test technologies. Test cars are vehicles that are used in a controlled environment to learn about the technology. Commercialized cars refer to those that were made available to mainstream customers.

indicating a general dominance of HVs, which is likely due to their less radical character compared to EVs and FCs.

Figure 4.1: Announced LEVs per year by type



(Labelling of phases taken from Bakker et al. 2012; data collected by author)

Until 1998, car manufacturers focused on batteries in various forms (electric, hybrid, plug-in vehicles). In that sense, this study's findings for 1997 confirmed those by Bakker et al. (2012) who compared electric to hydrogen (FCs) on the basis of article counts. Car manufacturers for the first time launched LEVs on a larger scale and experimented with the technologies. Table 4.2 indicates that more than half (55 percent) of all presented LEVs in this phase were EVs (including PIs); HVs, which also rely on batteries, represented 40 percent. The share of FCs was negligible (5 percent). Table 4.3 shows that the majority of LEVs were developed by Japanese (12) and U.S. (5) manufacturers. European car manufacturers only developed 3 LEVs.

Table 4.2: Share of announced LEVs developed in the phases of the LEV trajectory

Period	***1997***	***1998-2005***	***2006-2010***
Hybrid	40%	54%	45%
Electric (incl. PI)	55%	7%	42%
Fuel cell	5%	39%	13%

The second phase, the "Rise of hydrogen," as Bakker et al. (2012) labelled it, began in 1998. Between 1998 and 2005, EV development almost halted and car manufacturers focused more on FCs and HVs. Only 7 percent of all LEVs were EVs, the remaining 94 percent were shared between HVs (54 percent) and FCs (39 percent). The large difference between EV and HV engagement of firms in this period emphasizes the value of distinguishing between EVs and HVs rather than aggregating them as battery electric cars, as in Bakker et al.'s (2012) study. The distinction provides a more nuanced picture of the technological development. For instance, it shows that HVs had a solid share in this period. In this phase, HVs and FCs competed for the dominant LEV design position (Hekkert & Van den Hoed, 2004). Table 4.3 illustrates that although firms from all areas increased their LEV activity, EU manufacturers developed the least LEVs (19) compared to those from the U.S. (50) and Japan (63).

Table 4.3: Announced LEV activities by manufacturers' area/country of origin, types and phases

Period	***1997***				***1998 – 2005***				***2006 – 2010***				**Grand total**
Type	**US**	**EU**	**JP**	**Total**	**US**	**EU**	**JP**	**Total**	**US**	**EU**	**JP**	**Total**	
HV	2	2	4	**8**	29	9	33	**71**	15	22	39	**76**	**155**
EV (incl. PI)	3	-	8	**11**	3	1	6	**10**	24	22	25	**71**	**92**
FC	-	1	-	**1**	18	9	24	**51**	6	5	10	**21**	**73**
Total	**5**	**3**	**12**	**20**	**50**	**19**	**63**	**132**	**45**	**49**	**74**	**168**	**320**

The last phase, the "Revival of electric," began in 2006. In this phase, the LEV trajectory shifted towards EVs. Figure 4.1 illustrates not only the overall increase in LEV development, but also the sudden increase in EV development (including PIs). In fact, between 2006 and 2010, 42 percent of all LEVs were EVs (including PIs), a sharp increase from the small share in the previous phase. At the same time, FCs lost 26 percent and HVs 9 percent of the overall market share (see Table 4.2). FCs lost momentum with the introduction of PIs and the renewed interest in EVs, confirming the fear that PIs could close the market for FCs (Bento, 2010). Therefore, in this phase, while hybrids established their position, EVs competed to claim the dominant position.

Generally, LEV activity increased over time, with the three phases of the LEV trajectory being characterized by their foci on different LEV technologies. Activity differed considerably between manufacturers from different areas, as explained above, and within areas, sometimes per individual firm as well (see overview in Table 4.4). This suggests that

the international LEV trajectory is not only a result of technological developments but is also significantly shaped by the co-evolution between policy interventions and car manufacturers' strategies. In the following I will shed light on the interplay between different policies and firm innovation and its impact on the LEV trajectory over each period, paying attention to international, national and local developments and specific manufacturers where applicable.

Table 4.4: LEVs developed per firm and technology from 1997 until 2010

Car manufacturer	HV	PI	EV	FC	Total
U.S.					
Chrysler	10	3	4	5	**22**
Fisker	-	1	-	-	**1**
Ford	12	3	4	6	**25**
GM	24	8	4	13	**49**
Tesla	-	-	3	-	**3**
Total	*46*	*15*	*15*	*24*	***100***
EU					
BMW	4	1	3	3	**11**
Daimler	9	3	4	7	**23**
Ferrari	1	-	-	-	**1**
Fiat	1	-	1	-	**2**
Peugeot	4	-	2	3	**9**
Porsche	3	-	-	-	**3**
Volvo	1	1	1	-	**3**
VW	6	1	2	2	**11**
Total	*29*	*6*	*13*	*15*	***63***
Asia					
BYD	-	2	2	-	**4**
Daihatsu	-	-	-	1	**1**
Great Wall Motors	1	-	1	-	**2**
Honda	17	-	2	9	**28**
Hyundai	9	1	-	4	**14**
Kia	2	-	1	1	**4**
Mazda	3	-	-	4	**7**
Mitsubishi	2	1	4	2	**9**
Nissan	9	2	10	3	**24**
Renault	3	-	4	-	**7**
Saab	1	-	-	-	**1**
SAIC	1	-	-	-	**1**
Subaru	4	1	-	-	**5**
Suzuki	1	1	3	2	**7**
Tata	-	-	1	-	**1**
Toyota	27	3	4	8	**42**
Total	*80*	*11*	*32*	*34*	***157***
Grand total	**155**	**32**	**60**	**73**	**320**

(Data collected by author)

The situation in 1997

A landmark event at an international level with significant effects on the car industry was the Kyoto protocol, concluded in 1997. As part of a longer process involving the United Nations Framework of Convention on Climate Change (UNFCCC), aimed at reducing greenhouse gas (GHG) emissions, the Kyoto protocol updated the non-binding UNFCCC, which implemented mandatory reduction targets. This transnational framework included binding, measureable objectives to reduce six GHGs, including CO_2, and had an effect on many countries' regulatory frameworks for CO_2 emissions. For instance, the European Union committed to reduce its GHG emissions by at least 8 percent below 1990 levels between 2008 and 2012. The framework suggested to its Member States various means to tackle GHG emissions, including the reduction of CO_2 emissions through transportation. Most countries, including EU Member States and Japan, but not the U.S., ratified the protocol. As a result, many countries tightened their fuel-efficiency regulation because CO_2 emissions are correlated with the usage of fuel. That is to say, while the Kyoto protocol had little direct effect on car manufacturers, the targets affected the implementation of car-related policy measures in many regions and countries, and also raised general environmental awareness. Consequently, it affected firms indirectly. As the protocol translated into GHG reducing measures in various countries, it stimulated the LEV trajectory towards more incremental innovations by car manufacturers.

At a national level, and in response to the development of Toyota's HV Prius, the Japanese government altered its third Battery-powered electric vehicle (BPEV) expansion plan to support the diffusion of hybrids that Toyota initially sold below production costs. The Ministry of International Trade and Industry (MITI) integrated HVs for the first time. Japan's first expansion plan was established in 1976 with the goal to commercialize EVs. It was a concerted effort between both public actors (e.g. government agencies) and commercial actors (e.g. car manufacturers) to reduce the barriers for EVs and bring them to the market (Åhman, 2006). A Purchasing Incentive Programme was installed in 1996 for which only EVs were initially eligible. As part of the adaptation of the expansion plan in 1997 HVs also qualified for these funds. Japanese car manufacturers developed 8 EVs and 4 HVs in this phase (see Table 4.5). Most engaged were the three largest Japanese car manufacturers in 2000: Toyota (2 EVs and 1 HV), Nissan (3 EVs) and Honda (1 EV and 1 HV) (see Table 4.1).

Table 4.5: Announced LEVs by development stage in 1997

	1997			
Area/type	**Concept**	**Test**	**Mass produced**	***Total***
US				
HV	2	0	0	*2*
EV (incl.PI)	0	2	1	*3*
FC	0	0	0	*0*
Total	*2*	*2*	*1*	*5*
EU				
HV	2	0	0	*2*
EV (incl.PI)	0	0	0	*0*
FC	1	0	0	*1*
Total	*3*	*0*	*0*	*3*
JP				
HV	3	0	1	*4*
EV (incl.PI)	4	4	0	*8*
FC	0	0	0	*0*
Total	*7*	*4*	*1*	*12*
Grand total	**12**	**6**	**2**	**20**

At a local level, California—one of the largest car markets in the world—was a frontrunner in LEV development. The California Air Resource Board (CARB) adopted the Zero Emission Vehicle (ZEV) programme in 1990, which required car manufacturers to have 2 percent of their sales to be ZEVs beginning in 1998, growing to 10 percent by 2003. Despite initial support for the programme, car manufacturers were unable to make ZEVs commercially viable, as batteries remained expensive and their driving range was too limited. Consequently, the firms engaged in intensive lobbying to stop the programme. This resulted in a memorandum of understanding, which obliged car manufacturers to put up to 3,750 EVs on Californian roads between 1998 and 2000 (Shaheen, Wright, & Sperling, 2001).

Only the largest car manufacturers in terms of sales in California—General Motors, Ford and Chrysler from the U.S., and Toyota, Honda, Nissan and Mazda from Japan—had to bring ZEVs to the market, and one of them—Mazda—even managed to avoid the memorandum of understanding by purchasing credits for 138 cars from Ford. Car manufacturers began launching EVs in California to comply with the memorandum but also for tests in a few other states such as Arizona. The EVs were mainly leased or sold to corporate customers, not commercialized to individual consumers. General Motors' EV1, one of the notable exceptions and the only mass-produced EV, was also leased to individual consumers. After the agreed-upon 3,750 EVs were on the road, all car manufacturers stopped producing more. An anonymous official of Honda provided the answer why: "The real question, if we were to keep selling the EV Plus, would be, 'Are we moving forward? Are we

advancing the technology?' And the answer would be, 'I think not.'" (Automotive News, 73(5817), 1999, p. 12).

California's ZEV programme was not very successful in making LEVs mainstream. In fact, after the CARB relaxed its demands, many car firms (including General Motors) reclaimed all EVs and scrapped them. EVs were too expensive; the batteries were not powerful enough to provide a sufficient driving range; and the recharging infrastructure was not available. Ford subsequently raised concerns about whether government-imposed goals are beneficial: "What the electric Ranger experience did teach us is when we just do something either because regulators have asked us to do it or just to say we are there, there is really not much value to that" (Automotive News, 75(5918), 2001, p. 26). While the ZEV programme was too ambitious for car manufacturers, it was successful in that it raised awareness of LEVs. In fact, many other states, such as New York, initially adopted the ZEV regulation, but they were stopped by court injunctions. The programme also influenced the BPEV (Battery Powered Electric Vehicle) expansion plan in Japan and triggered a large-scale EV test in Germany, on the island of Rugen.

Table 4.5 illustrates the impact of the ZEV programme on the LEV trajectory; 11 EVs were presented in 1997, 3 from U.S. car manufacturers (2 by GM and 1 by Ford) and 8 from Japanese car manufacturers (4 by Nissan, 2 by Toyota, 1 by Honda and 1 by Suzuki). Therefore, in this battery exploration phase, U.S. and Japanese car manufacturers engaged mainly in LEV technologies that use batteries, i.e. EVs and HVs, triggered by policy interventions in California and Japan. While Californian policies seem to have influenced both U.S. and Japanese car manufacturers, Japanese policies only appeared to affect Japanese car manufacturers.

Thus, this phase was characterized by car manufacturers' exploration of batteries. The results showed that EVs were not yet ready for commercialization. This left HVs competing for the dominant position against the now rising FC (i.e. hydrogen) technology.

1998 – 2005: Rise of hydrogen

At an international level, rising oil prices, caused in part by the Iraq war and later by the impact of Hurricane Katrina, had a significant influence. In the U.S., petrol prices crossed the three USD mark, and manufacturers could not meet the demand for HVs. Prius sales rose by 130 percent, and Toyota suspected that they could have sold even more, but production could not keep up with demand. Irv Miller, group vice president of corporate communications for

Toyota Motor Sales U.S. commented: “Our belief is that we can sell significantly more than what our current sales volume is” (Automotive News, 78(6104), 2004, pp. 4-42).

At a national level, various countries implemented stricter fuel-efficiency standards in this period. One of the first countries after the U.S. to implement new measures was Japan. In 1999, it implemented fuel-consumption standards under its ‘Top-Runner’ programme. Dividing their cars into weight classes, car manufacturers needed to meet the fuel-economy standards by the target year 2010. On average, the consumption per fleet was supposed to be 16.8 km/l (125 gCO_2/km). Subsequently, Japanese car manufacturers lobbied for government support for LEVs, such as a lower tax rate. The government, in turn, reduced the sales tax for LEVs. Along with Toyota, which launched the Prius, Honda also benefited from these incentives when it launched the Impact HV. Yet, not all car manufacturers invested in HVs. Nissan’s CEO Carlos Ghosn argued, for instance: “We have the technology […] But when I have seen the cost of the car I say, no way" (Autoweek, 51(46), 2001, p. 4). Nevertheless, the incentives supported the diffusion of LEVs, and by 2000, Toyota had sold more than 70,000 Prius cars. Furthermore, the incentives stimulated sales and provided Japanese car manufacturers with a competitive edge that later also influenced other countries, such as the U.S., to introduce similar incentives.

In contrast to Japan’s mandatory regulations, the European Union agreed with the European Car Manufacturing Association (ACEA) to set a voluntary target in 1998. The targets aimed to reduce the car firms’ fleet average CO_2 emissions per kilometre driven from the 1995 fleet average of 186 gCO_2/km to 140 gCO_2/km by 2008. Since the agreement was voluntary, it had little effect on European car manufacturers. Just 19 LEVs were developed (see Table 4.6) to which Daimler had already contributed 9. Besides the voluntary character, another reason for the low numbers of LEVs developed was that diesel technology was prevalent in Europe. The large European firms had developed very efficient diesel engines that were regarded as more promising ways to comply with fuel-efficiency regulations than EVs, HVs or FCs. This situation was idiosyncratic to Europe. Leading European car manufacturers such as Volkswagen and PSA Peugeot were not able to capitalize on their diesel technology in the U.S. or Japan because these countries’ pollution standards for particulate matter and NO_x were too strict, and diesel cars were not popular amongst customers in these markets. Moreover, most European car manufacturers had small to negligible market shares in the U.S. and Japan. Daimler was the one notable exception to the European manufacturers’ lack of engagement, as it introduced both FC and HV concepts. This was not unexpected since the U.S. market became more important to the firm after Daimler’s

merger with Chrysler and because it wanted to maintain its image of being a technological leader.

Table 4.6: Announced LEVs by development stage from 1998 to 2005

	1998 – 2005			
Area/type	**Concept**	**Test**	**Mass produced**	***Total***
US				
HV	24	1	4	*29*
EV (incl. PI)	1	1	1	*3*
FC	16	2	0	*18*
Total	*41*	*4*	*5*	*50*
EU				
HV	9	0	0	*9*
EV (incl. PI)	1	0	0	*1*
FC	8	1	0	*9*
Total	*18*	*1*	*0*	*19*
JP				
HV	20	1	12	*33*
EV (incl. PI)	6	0	0	*6*
FC	19	5	0	*24*
Total	*45*	*6*	*12*	*63*
Grand total	**104**	**11**	**17**	**132**

Various other countries also implemented stricter fuel-efficiency standards in this period. South Korea—which ratified the Kyoto protocol—replaced a voluntary agreement by mandatory standards in 2004. Beginning in 2006, cars were required to achieve 34.4 mpg (for 1,500cc) and 26.6 mpg (for >1,500cc), respectively. Contrary to its intention, this engine size based standard resulted in larger cars rather than higher fuel efficiency. China also began to regulate cars' fuel economy in 2005. Adopting a weight-based system, the framework was implemented in two steps. Phase 1 targeted cars sold between 2005 and 2007, and phase 2 those sold after 2007. In phase 1, fuel efficiency achieved an increase of 9 percent over the 2002 level, from 26 mpg to 28.4 mpg. What is more, the tax rate was reduced for small engines and increased for larger engines (from 5 to 3 percent and from 8 to 20 percent, respectively).

In the U.S., beginning in 2004, the Corporate Average Fuel Economy standards (CAFE) for light trucks were tightened. CAFE standards, which were first implemented in the 1970s in reaction to the oil crisis, required car manufacturers' fleets to meet fuel-efficiency standards. In order not to penalize small-business owners, in its original setup CAFE had distinguished between cars and light trucks. In 1996, cars had to meet 27.5mpg and light trucks 20.7mpg. Yet, because light trucks (e.g., SUVs) became increasingly popular as family cars, regulators now also targeted them, increasing the standard for light trucks to 21.0 mpg.

Furthermore, the government passed new CAFE standards intended to gradually increase the light-truck fuel-efficiency target from 21 mpg to 24 mpg in 2011.

Consequently, U.S. car manufacturers sought to implement the hybrid technology in light trucks to improve their fuel efficiency. GM argued that "[t]he strategy here is to go after the highest fuel-consuming vehicles first" (Automotive News, 77(6051), 2003, p. 26). This strategy was also adopted by Ford, which integrated the hybrid technology into the Ford Escape HV, the first SUV with hybrid technology. Toyota, on the other hand, found itself endowed with an innovative and green image following the successful launch of the Prius Two in 2003. U.S. and European car manufacturers were subsequently criticized for the lack of hybrids in their line-ups. In order to catch up with Toyota's lead in HV technology, Daimler, GM and BMW even decided to jointly develop their own full hybrid technology. Table 4.6 indicates the increasing interest in HVs by U.S. and Japanese car manufacturers which developed 29 and 33 HVs respectively.

The Big 3 (GM, Chrysler and Ford) lobbied the federal government for tax incentives for hybrids. Chrysler announced that it wanted to make some profits on the technology and therefore needed tax incentives. "We think the price premium will be $3,000. We think the cost is under that. But we have to make a little profit on it. Our strategy is to get the component set numbers up higher, drive the costs down and perhaps someday take the price premium below $3,000. We are also hoping and we're actually campaigning to get this $3,000 tax credit that was talked about last year" (Automotive News, 75(5918), 2001, p. 26). Not surprisingly, Toyota also lobbied for incentives in the U.S. Toyota's vice-president for its U.S. operations and chairman of the U.S. Alliance of Automobile Manufacturers, agreed: "There is a consensus that we need incentives for advanced technology" (Automotive News, 75(5927), 2001, p. 3). Following industry pressure and the positive results of incentives on LEV diffusion in Japan in 2005, tax credits for HVs of up to USD 3,400 were put in place by the Bush administration.

Hybrids increasingly appeared in the portfolios of manufacturers selling cars in the U.S., but not necessarily because the firms saw a market for them. The disadvantage of hybrids remained: the technology was expensive to develop and difficult to integrate into cars. Many car manufacturers, such as Nissan, invested in hybrids only to comply with government requirements: "In 2006, we will have a hybrid model for sale, purely to meet government requirements" (WardsAuto World, 39(12), 2003, pp. 40-41). Daimler argued that the commercialization was a matter of costs. "It's a question of cost and whether you are prepared to subsidize customer sales" (Autoweek, 55(39), 2005, p. 5). Ford's CEO Bill Ford declared:

“If (hybrids) don’t get customer acceptance, I really don’t know what we do next. [...] What our entire industry needs is government help. Hybrids are more costly. We know consumers have a very limited appetite for paying more for these vehicles” (Automotive News, 77(6021), 2003, p. 16).

As a result of national regulation and incentives, the diffusion of HVs increased in Japan and the U.S. In Europe, hybrids were not picked up by the market, in part due to the popularity of (more) fuel-efficient diesels, but also because no tax incentives were provided. Toyota was concerned about the lack of incentives and pleaded for a unified tax (incentive) system: “Europe has 17 different tax systems. [...] If the European Union is serious about lowering greenhouse gas emissions, why not support that with a standard, pan-European tax incentive? [...] We will take the initiative and talk with the EU on these matters” (Automotive News, 77(6036), 2003, p. 58).

At the local level, governments increased the popularization of LEVs with both market-based measures and command-and-control initiatives. California, for instance, allowed HVs to be driven in the carpool lane. Other states, such as Virginia, subsequently emulated this practice. In London, HVs were exempted from the newly introduced congestion charge. This practice—already in place in Singapore—inspired other urban areas to limit access to city centres through measures like the ‘environmental zones’ in large German cities (‘Umweltzonen’).

At the same time, GM and DaimlerChrysler filed suits against the CARB to stop the ZEV programme. GM’s concern was that the mandate could be implemented by more U.S. states, which would have affected more than 20 percent of the U.S. car market. The programme was eventually considerably modified, and car manufacturers were allowed to comply with credits that they could earn, for instance, with small golf-cart-like EVs or hybrids. Subsequently, many car manufacturers, including Daimler and General Motors, offered so-called Neighbourhood electric vehicles (NEVs), and some dropped out of EV projects, such as Ford, which divested its Think EV manufacturer, that it bought earlier, and invested in hybrids. In 1999, as an alternative to EVs, CARB began stimulating the development of FCs through the California Fuel Cell Partnership (CaFCP). Refuelling infrastructure was provided, and manufacturers could test FC technologies and their practicality. CaFCP also inspired other public-private partnerships which were subsequently initiated, most prominently the Japan Hydrogen & Fuel Cell (JHFC) demonstration project and the Clean Energy Partnership (CEP) in Germany.

FCs have an electric engine but do not need a battery. Instead, they generate energy from a fuel cell that runs, for example, on hydrogen or even methanol. Consequently, the cost and range challenges of EVs could be overcome. Various firms engaged in FCs and participated in the CaFCP. In Europe, Daimler introduced the NECAR 3—the first fuel-cell car with an on-board hydrogen generator. Daimler even announced its intention to bring FCs commercially to the market in 2003. Subsequently, many other car manufacturers, including Toyota, Honda and GM, announced their engagement in FCs. GM aimed to become the leader in fuel-cell vehicles, wanting to be the first to bring one million FCs to the market. GM was convinced to be able to commercialize FCs by the end of the decade. “The fact that we developed Hy-wire as a drivable concept vehicle in just eight months (from its Detroit debut) shows our commitment to this technology and the speed at which we are progressing” (WardsAuto World, 38(9), 2002, p. 34).

Tables 4.3 and 4.6 illustrate the impact of policies at the local and national levels on the LEV trajectory. In this phase, 51 out of the total 73 FCs were developed. European car manufacturers developed 9 FCs, U.S. manufacturers 18 FCs and Japanese car manufacturers 24 FCs. Car manufacturers mainly refitted standard cars with fuel-cell technology. Daimler, for instance, based its cars on the A and B Classes. Most active were GM (9 concept vehicles, e.g. the AUTOnomy concept), Toyota (7 concept vehicles, e.g. the Fine-X), and Daimler (3 concept vehicles, e.g. the F-Cell). Other car manufacturers also engaged, however. For example, Ford refitted its Focus model with an FC engine, BMW its 750hLs with an engine that was able to run on petrol or hydrogen, and Honda developed the FCX Clarity. The largest number of FCs was built by DaimlerChrylser, which had a test fleet of more than 100 cars.

While FCs were regarded as an alternative to EVs, they were also a means to reduce the pressure from national fuel-efficiency regulation. In the U.S., car manufacturers lobbied against the CAFE standards, using their involvement in FCs as an argument. GM claimed that CAFE did not support the transition towards sustainable mobility: “CAFE is actually an obstacle to the realization of this vision of hydrogen-based, clean, efficient, personal mobility” (Automotive News, 76(5967), 2002, p. 3).

In 2003, doubts were mounting regarding costs and technological problems. Car manufacturers had not lived up to their promises of commercializing FCs. Also, the U.S. National Academy of Engineering doubted the initially optimistic outlooks of car manufacturers and argued vehemently that the over-optimistic commercialization dates be reviewed. Honda also pointed to another factor: "A marketable fuel-cell vehicle will be realizable in 10 years. [...] But the car cannot run alone. Getting the overall infrastructure

needed to support these cars in place will take 20 to 30 years" (WardsAuto World, 39(12), 2003, pp. 34-35). To overcome the infrastructure problem, some car manufacturers experimented with on-board converters of gasoline to hydrogen. In 2004, the U.S. Department of Transportation offered a new—but still rather positive—outlook: "We can develop a marketable technology by about 2015 and achieve widespread commercial availability by the year 2020" (Automotive News, 78(6080), 2004, p. 6). Nevertheless, although public-private partnerships continued, the popularity of FCs lost momentum at the end of this period. The public-private partnerships enabled car manufacturers to test radical technologies for very few cars only and thus had a rather small immediate effect on LEV diffusion.

2006 – 2010: Revival of electric

After it seemed that HVs would become the dominant design, the 'revival of electric' cars began again in 2006. A new wave of EV interest started. The financial crisis, tightening fuel-efficiency standards, reduced battery prices due to increasing production capacity, and urban interest in pollution free alternatives triggered a new search for alternative technologies reflected in increasing launches of EVs and plug-ins. In this period 71 of the 92 EVs (including PIs) were developed (see Table 4.7).

Table 4.7: Announced LEVs by development stage from 2006 to 2010

	2006 – 2010			
Area/type	**Concept**	**Test**	**Mass produced**	***Total***
US				
HV	3	0	12	*15*
EV (incl. PI)	17	4	3	*24*
FC	4	2	0	*6*
Total	*24*	*6*	*15*	*45*
EU				
HV	16	1	5	*22*
EV (incl. PI)	18	4	0	*22*
FC	4	1	0	*5*
Total	*38*	*6*	*5*	*49*
JP				
HV	21	2	16	*39*
EV (incl. PI)	16	5	4	*25*
FC	6	2	2	*10*
Total	*43*	*9*	*22*	*74*
Grand total	**105**	**21**	**42**	**168**

At an international level, the financial crisis was most influential and had a significant impact on EV popularity. Beginning in 2008, the financial crisis put various manufacturers in

financial distress due to decreasing demand and changing preferences towards smaller, fuel-efficient cars. Governments supported car manufacturers with stimuli to develop green technologies, for example, by giving loans pegged to developing green technologies or market-based incentives for EVs, such as tax credits, rebates or subsidies. The provision of incentives for EVs fostered the engagement of car manufacturers in EVs.

At a national level—besides incentives for EVs triggered by the financial crisis—fuel economy standards were tightened. In the U.S., the new Energy Act in 2007 required 35.5 mpg (equivalent to 6.6 l/100 km) by 2020 (from an average of 24.7 mpg in 2004), measures which were introduced stepwise. In Japan, the Top Runner period ended in 2010. In these two markets, HVs were now fully established and integrated in the portfolios of car manufacturers. U.S. car manufacturers commercialized 12 HVs in this phase and Japanese car manufacturers 16 (see Table 4.7). GM integrated the HV technology as an option in selected models such as the Tahoe, Malibu and Saturn Vue. Toyota also added the HV option to various models such as the Camry and models of its luxury brand Lexus (e.g. LS460h), in addition to bringing the third version of the purpose-built Prius to the market.

In Europe, ACEA member firms continuously failed to achieve the voluntary targets despite the voluntary agreement. Additional local pressures such as the UK's change of its car-tax system to a system based on CO_2 emissions did not seem to have much effect either. This is indicated by the continually low number of LEVs developed in the previous phases by European manufacturers compared to their Japanese and U.S. counterparts (see Table 4.3). In fact not a single LEV was commercialized by European car manufacturers in the previous periods; the largest share of LEVs was taken by FCs that were further developed and tested by Daimler and Peugeot (each 3). Nonetheless, in 2006, the CO_2 emissions fleet average of European car manufacturers was 160 gCO_2/km (reduced from 186 gCO_2/km), which meant that only 43.5 percent of the total reduction of 46 gCO_2/km from 1995 to 2008 had been achieved. It became evident that car manufacturers would not be able to reach the targeted reduction goals in 2008.

Because the ACEA members failed to meet the voluntary targets, mandatory CO_2 emission targets were finally adopted in 2009. The regulation demanded that by 2015, European car manufacturers' fleet average had to be 130 gCO_2/km. In order to ease the burden on car manufacturers, it was agreed that only 120 gCO_2/km needed to be achieved with vehicle technology while the remaining 10 gCO_2/km could be realized through additional measures such as low-resistance tires, an easier and cheaper fix for car manufacturers. The targets were phased in starting in 2012, when 65 percent of the fleet

needed to comply. In order to incentivize the introduction, the EU implemented a stick and a carrot. The 'stick' was in the form of penalties for non-compliance per vehicle. For each gram exceeding the target (after the 4th gram), car manufacturers were charged EUR 95, which could have severe financial consequences. The 'carrot' was given in the form of credits that could be earned with vehicles that emitted less than 50 gCO_2/km. Every so-called 'supercredit' was equivalent to 3.5 cars in 2012/13 (2.5 in 2014 and 1.5 in 2015, respectively). As a consequence, European car manufacturers also contributed significantly to LEV development for the first time (see Table 4.7). They especially developed EVs with integrated HV technology in their portfolios, five of which were commercialized. Daimler, Volkswagen, and Renault particularly pursued EV development in the form of four EV concepts. Renault also invested significant amounts in EV development together with Nissan, with which it has an equity alliance.

Japan, in contrast to Europe's slow development, met the Top Runner programme's 2010 targets in 2002. Therefore, in 2006, the targets were increased. Despite low penalties, car manufacturers complied even before the deadline due to tax incentives and pride, because firms that failed to comply would be made public (Mikler, 2005).

At the local level, various initiatives fostered EV commercialization. Particularly for urban areas, EVs were increasingly regarded as a solution to congestion and pollution. California's regulations in particular were influential because they stimulated PI development, regarded by car manufacturers as the cheapest way to comply. Toyota argued that the "way California has set up the rules, plug-in hybrids would likely appear to be one of the lowest-cost ways to meet the requirements" (Automotive News, 84(6378), 2009, p. 3). GM unveiled the Volt plug-in and announced its upcoming production, declaring that "[t]his is not a science project and not a public relations ploy" (Reed, 2007: 25). Shortly afterwards, Toyota also announced that it would work on a plug-in version of the Prius, while Nissan and Mitsubishi announced the mass production of fully electric vehicles, namely the Nissan Leaf and the Mitsubishi iMiev. Also, for the first time in a long while, new entrants were attracted to the car industry. The EV start-up Tesla built a sports car, the Tesla Roadster; Fisker developed a PI luxury sports car; and Better Place introduced mobile payment methods and battery swapping for EVs in various test projects in Israel and Japan.

The 'revival of electric' was characterized by challenges of price versus range. On the one hand, the limited range of EVs could be increased by bigger and better batteries, but that would increase the costs, that were already high, even more. To try to overcome these challenges, car manufacturers engaged in various EV tests. BMW conducted a large-scale test

in 2009: “We are learning a heck of a lot just about the sheer infrastructure,” said Jim O’Donnell, CEO of BMW North America. “When we bring out another electric car, we will be in a great position because we know all the wrinkles” (Automotive News, 84(6378), 2009, p. 27). Learning was also crucial for Toyota’s test of PIs, particularly in terms of energy use. Introducing lithium-ion batteries, Toyota stated: “We want to know if people pay attention to their energy use” (Automotive News, 84(6408), 2010, p. 6). GM found its ideal battery range, 40 miles. After a test, Toyota chose a smaller battery: “We decided to go with a smaller battery that needs more charges […] That’s a decision we made. That’s part of the test” (Automotive News, 84(6408), 2010, p. 6).

Subsequently, car manufacturers sought ways to commercialize EVs, but they faced high costs, as well as infrastructure and standardization challenges. Due to high development and production costs and different recharging technologies, car manufacturers aimed to produce LEVs that could be marketed internationally. Subaru met the challenge by focusing on PIs: “We are concentrating on the development of the electric vehicle system through the plug-in Stella. We need to equip [the] vehicle with an EV system that can be marketed globally” (Automotive News, 84(6382), 2009, p. 22). Manufacturers of EVs were especially affected by the cost challenge. Ford intended to commercialize the Focus as an EV in 2011, but considered the high price to be an impediment. “We are going to make it as affordable as we can, but clearly it will be more expensive than a regular gas car […] So that will limit its appeal at least initially” (Automotive News, 84(6359), 2009, p. 21). Other firms, such as VW, decided not to invest in EVs due to the high costs. “To do something like this anytime soon, there would have to be a big breakthrough in costs, the likelihood of which is rather remote” (Autoweek, 59(20), 2009, p. 9). As a result, in 2010, only four EVs, the Mitsubishi iMiev, the Nissan Leaf, the Think and the PI GM Volt, were commercialized.

At the same time, car manufacturers continued to engage in the other two LEV technologies, hybrids and fuel cells. Car manufacturers invested further in fuel-cell tests to be prepared for future developments. For instance, Daimler sent 70 FC test cars based on the B Class to the U.S. in 2010. Hybrids became mainstream in this period (see Figure 4.1) and almost all car manufacturers integrated HVs into their product portfolios. For instance, Nissan decided to sell more than 50,000 HVs in 2006. In 2008, Daimler decided to invest in HVs and to integrate hybrids into their whole line-up. Daimler’s CEO Dieter Zetsche commented: “We have decided on hybridization on all of our cars in the future and so far we have had a lot of questions and excitement, but I don’t know how that will translate into a take rate” (Automotive News, 83(6328), 2008, p. 8). Even luxury car manufacturers such as Porsche and

Ferrari started to develop HVs, also to counter urban penalties for high emissions and to adapt to mandatory fuel-efficiency targets in Europe.

In summary, after years of LEV development, which began with the introduction of EVs, car manufacturers again sought to commercialize EVs. In between, FCs were briefly regarded as the solution to more sustainable transportation, but cost challenges and the lack of refuelling infrastructure impeded their introduction, and only a few hundred cars were built. The hybrid technology pioneered by Toyota gained most popularity. Initially belittled, hybrids were eventually an important part of car manufacturers' product portfolios, with more than a million cars sold. HVs also paved the way for the renewed interest in EVs. Increasing battery-production capacity improved the technology, reduced costs, and led to the sale of a few thousand EVs.

4.6 Mechanisms in the international LEV policy context

From the description of the three phases through which the LEV trajectory evolved, it emerged that in addition to technological developments, these phases were shaped by a co-evolution between government policies and car manufacturers' strategies. Policies affected car manufacturers and vice versa. The previous section demonstrated how the co-evolution of LEVs came to pass internationally. For instance, policies in the U.S. influenced car manufacturers in and from Japan. This raises the question of what connects the various local and national co-evolutionary trajectories. Understanding the links between several local co-evolutionary trajectories may enable a better understanding of how the national, and then international LEV trajectory is shaped. Also, it addresses the need for a better understanding of the spatial dimension of sustainability transitions (Coenen et al., 2012).

Three mechanisms seem to influence the interaction between local and national co-evolutionary trajectories. 'Mechanisms' have been used before to depict the interaction between actors (Dijk & Yarime, 2010), as they allow for depicting causal relations or feedback links. The first proposed mechanism that emerged from the analysis is *policy diffusion and international policies*. An extensive stream of literature has described policy diffusion, defined as "one government's choices being influenced by the choices of other governments" (Moynihan, Shipan, & Volden, 2012: 1). Local or national policies can influence policy developments in other areas through policy diffusion. At the local level, an example of policy diffusion was the Californian ZEV programme. The ZEV programme influenced policy measures in other countries, such as Germany and Japan, and is widely

regarded as the general trigger for LEV development (see Table 4.8). At the national level, policy interventions stimulated policies internationally. In particular, the Japanese Top Runner programme and the purchasing incentive programme for LEVs were successes. Other countries emulated the Japanese approach of fostering LEVs, such as the U.S. implementing tax incentives. Also during the financial crisis many countries implemented similar support programmes for LEVs (e.g. tax incentives).

In addition international policies can provide guidelines for national policies. At the international level, the Kyoto protocol has had a strong effect, particularly on national greenhouse gas emission regulation (Kolk & Pinkse, 2008). The Kyoto protocol influenced countries to stimulate LEV development—to implement or increase fuel-efficiency standards, for example. Also, the Kyoto protocol ultimately led to the ACEA agreement, and they jointly affected the ACEA members. In addition, it raised general environmental awareness. Hence, international policy diffusion as well as international policies resulted in a multi-faceted international policy context, which added to the complexity of the co-evolution of the LEV trajectory.

Table 4.8: Policy interventions and their impact on firm innovation and policy

Policy intervention	Content	Impact on firm innovation	Effect on subsequent policy interventions
International level			
Public-Private Partnerships			
2001: Clean Urban Transport for Europe	• Supported various urban areas (e.g., Amsterdam, Barcelona, London) in testing FC technology	• Various manufacturers tested hydrogen technology—e.g., Shell, BP, DaimlerChrysler	• Triggered UK participation in FC test
Regulation			
1997: Kyoto conference	• Protocol of the UNFCCC targeted at fighting climate change • Member countries agreed to reduce greenhouse gas emissions • Included binding targets	• Little direct effect	• Stimulated voluntary EU ACEA agreement • Stimulated UK to change car tax to be based on CO_2 • Internationally raised awareness for the environment and to reduce CO_2 emissions
1998: Voluntary CO_2 regulation (EU)	• Voluntary agreement of European car manufacturers to reduce emissions by 25 percent—i.e., 140 gCO_2/km by 2008	• Voluntary targets did not trigger direct LEV commercialization • Toyota lacked diesel technology and hence was complying slow which	• Influenced countries such as the UK to alter their car tax to be based on CO_2 emissions

	• Would reduce overall EU CO_2 emissions by 8 percent	raised criticism, therefore Toyota build a small vehicle plant in collaboration with Peugeot • Daimler bought small car firm "Smart" to support compliance	
2009: CO_2 regulation (EU)	• The voluntary agreement was revised in 2005 • Car manufacturers failed to meet targets • EU crafted mandatory CO_2 emission targets	• Regulation achieved that incumbents engaged more in LEV technologies, but outcomes were not clear at the time of analysis. • Incumbents tried to comply partially with non-technology-related means, e.g., weight reduction	• n/a
National level			
Public-Private Partnerships			
2002: FreedomCAR (U.S.)	• Replaced PNGV • In total, USD 1.7 bn were supposed to be spent • In 2004, car manufacturers received USD 350 million to develop fuel cells • In 2005, funds were further increased	• Resulted in no directly related cars	• Started discussion about the hydrogen economy • Stimulated other FC programmes—e.g. CEP, JHFC
2002: Clean Energy Partnership (Germany)	• Facilitated testing of FC technology in daily driving • Provided infrastructure • Intended to refine technology and reduce costs	• Car manufacturers tested FCs extensively in Berlin • Various manufacturers participate—BMW, DaimlerChrysler, Ford, General Motors, Honda, Toyota, Volkswagen	• n/a
2002: Japan Hydrogen & Fuel Cell Demonstration Project (Japan)	• The Japanese Hydrogen and Fuel Cell Demonstration project was targeted at testing FC technology • Initial target of 5m FCVs by 2020 was abandoned in 2006 • Clarify well to wheel efficiency • Studies on mass production	• Participating manufacturers (Toyota, Honda, Nissan, DaimlerChrysler, General Motors, Mazda, Suzuki, Mitsubishi, and BMW) tested their FC technologies in test cars and obtained real-world driving information • Incumbents provided cars—e.g., GM gave car free of charge for one year to FedEx	• n/a
Regulation			
1998: Top Runner programme (Japan)	• 'Top runner' approach sets the most fuel efficient product as the benchmark for all other products • The target for passenger cars was 15.1km/l by 2010	• Japanese car manufacturers improved fuel efficiency and complied before the target year 2010	• Served as a blueprint for other governments
2001: UK car tax	• UK changed car tax to be based on CO_2 emissions	• No direct firm innovation response • Sales of diesels rose from	• Stimulated manufacturers to rethink their strategy

	• LEVs received tax reduction	34 percent in 2001 to 70 percent in 2005	and implement more environmentally friendly strategies, such as low emission fleets or video conferencing
2004: CAFE increase for light-trucks (U.S.)	• More-stringent standards for light-trucks were implemented • From 21 mpg to 24 mpg	• Car manufacturers integrated HVs to meet CAFE standards • Manufacturers made no profit on LEV technology, but cross-subsidized with profits from light-trucks • GM collaborated with Daimler and BMW to develop full hybrids	• U.S. sought to stop its 'addiction to oil' which created an atmosphere of change in the industry towards more fuel efficient technologies
Incentive programmes			
1996: BPEV Purchasing Incentive Programme (Japan)	*1st stage* • Japanese government made USD 68 million available for subsidies to cover half of the additional costs of LEVs	• Was targeted at EVs initially, but only 400 EV cars benefited, and programme had little influence.	• Was one of the first large-scale incentive programmes
1997	*2nd stage* • The third electric vehicle expansion plan (BPEV) was altered and included hybrids and fuel cells • Was integrated into the Clean-Energy Vehicles Introduction Programme (CEV)	• Various car manufacturers (e.g., Honda, Mitsubishi, Toyota) engage in environmentally friendly technologies • Toyota sold more than 70,000 hybrids until 2000	• Provided Japanese car manufacturers with a competitive edge • Influenced U.S. incentives as it gave Toyota a competitive edge
2005: U.S. tax credits	• Up to USD 3,400 for hybrids • Supported 60,000 new cars per manufacturer	• Stimulated increasing engagement in HVs by almost all car manufacturers	• Partially informed later tax incentives for EVs
2000: PowerShift grant scheme (UK)	• Supported LEVs with up to GBP 1,000 • Stalled in 2004 due to insufficient funds and stopped in 2006 as funds seemed insufficient to kick-start LEV mass commercialization	• Had little direct impact on firm innovation	• n/a
Local level			
Public-Private Partnerships			
1999: California Fuel-Cell Partnership	• Planed to test 50 fuel-cell vehicles • Intended to demonstrate efficiency of FCs, prove commercial viability and prepare commercialization, e.g. build infrastructure	• Various manufacturers participated to test FCs (DaimlerChrysler, General Motors, Hyundai, Honda, Nissan, Toyota, Volkswagen)	• Informed JHFC and CEP as well as FreedomCAR

Regulation			
1990: ZEV programme	*1st stage*		
	• Beginning in 1998, 2 percent of cars sold in California need to be ZEVs • Beginning in 2003, 10 percent need to be ZEVs	• The largest 6 car manufacturers brought a limited number of EVs to the market, mainly converted mainstream vehicles • The ZEV programme was too ambitious; car manufacturers lobbied against it until the mandatory commercialization of ZEVs was abolished. • GM and DaimlerChrysler obtained court injunction and were able to freeze the regulation	• ZEV mandate was adopted by various other States (e.g. New York) and also to EV tests elsewhere, e.g. Rügen, Germany • The adoption of other states (e.g., New York) was overturned by the federal court after lobbying of the car industry • Stimulated BPEV expansion plan in Japan
2004: ZEV programme	*2nd stage*		
	• Average vehicle sold in 2016 needs to emit 30 percent less GHG emissions • Car manufacturers were allowed to use credits to comply, SULEV, PLEV technologies such as hybrids earned credits • Car manufacturers were required to put hybrids on the market	• Stimulated hybrid development and more efficient ICEs • Create scale for hybrids and fostered their international diffusion • Car manufacturers stopped their engagement in ZEVs	• Various states (>10) adopted the regulation
Incentives			
2003: London congestion charge	• The city of London implemented a GBP 5 congestion charge for driving in the city • LEVs were excluded	• Car manufacturers started small LEV projects, such as Daimler tested 100 EVs in the city centre	• Other cities such as Singapore had similar programmes in place • Created concern as some diesel cars were as fuel efficient as the Prius but were not exempted
2004: Carpool- Lane Usage in California	• LEVs were allowed to use the carpool lane even with one occupant • Limited amount of licenses was available	• Stimulated HV sales in California	• Stimulated the overall LEV development, particularly HV diffusion

The second mechanism that emerged is the *international operations of firms*. Different local co-evolutionary trajectories interacted because car manufacturers operated in different international markets. Although Table 4.1 indicates that car manufacturers have traditionally tended to focus on their home market, most were present in various markets and connected the different geographical areas. Areas that have had LEV policies in place and in which

many foreign car manufacturers operated (e.g. California) affected car manufacturers beyond national borders and therefore had a larger influence on the international LEV trajectory than areas in which few foreign players operated (e.g. Japan). Equally, car manufacturers that operated in various areas such as Toyota were affected by several policies, shaped home and host markets, and therefore appeared to be more influential on the international LEV trajectory than firms that focused largely on their home market (e.g. Peugeot). Considering that firms are resource constrained, car manufacturers had an interest to reach sufficient economies of scale. Thus, car manufacturers that operated internationally may have first developed technologies that met requirements in one country and then sought to offer these technologies in various other markets where they might enhance profitability.

The following example illustrates how internationally active car manufacturers interacted with national LEV trajectories and in turn affected the international LEV trajectory. Toyota, like many Japanese car manufacturers, had large market shares in Japan and in the U.S. Therefore, they were exposed to Japanese and U.S. policies equally. When California allowed complying with the ZEV regulation through credits from HVs, Toyota and Honda also began selling HVs in California, which were until then only available in Japan. This is supported by Åhman (2006: 439) who reported that Japanese car manufacturers were not only affected by their domestic policies to develop LEVs but also by Californian policies: "Toyota, Nissan and Honda were all affected by the Californian ZEV mandate and now entered the BPEV development race more seriously than before and began investing heavily in BPEV technology." The car manufacturers might have sold the HVs in California or the U.S. also without the stimulating policy, yet this is unlikely as the cars were initially sold at a loss.

Not only U.S. and Japanese car manufacturers were affected by the Californian ZEV programme but also European car manufacturers. Pilkington et al. (2002: 7) put forward that "European [...] automobile manufacturers faced the same restrictions from the CARB ZEV mandate, and so had also been developing EVs for both indigenous and export use." The empirical results showed that the European car manufacturers Daimler and, at a later stage, BMW were especially engaged in developing LEVs as more than 25 percent of their sales were generated in the U.S. (see Table 4.1). Likewise, car manufacturers from the U.S., Japan and Korea had larger shares in the (Western) European market. However, as there was no unified policy that stimulated LEVs until 2009, this market was less influential on the LEV trajectory than the U.S. Only with the implementation of incentives for LEVs in various EU Member States in the wake of the financial crisis and the mandatory European fuel efficiency targets implemented in 2009 (which gave super-credits for LEVs), did European policy begin

to influence the international LEV trajectory. While it is too early to speculate about the effects, this may have offered an opportunity for U.S. and Japanese car manufacturers to promote their technologies and in turn shape the LEV trajectory in Europe, where they were already active and where they might leverage their home-market experience with LEV technologies. General Motors (Volt), Nissan (Leaf) and Mitsubishi (iMiev) were the only incumbents from outside of Europe to sell EVs in the European market, perhaps as forerunners of such a trend.

The two previous mechanisms explain how markets are linked. However, whether internationally operating car manufacturers transfer technologies from home to host countries (and vice versa) and whether local/national policies stimulate policymakers abroad depends on a third mechanism: the *fit between policy requirements and firm capabilities*. This mechanism acts in a sense as a moderator of the two previous mechanisms on the evolution of LEVs.

Policies often required car manufacturers to develop new technologies. If these technologies could be developed with capabilities that car manufacturers already possessed, there was a good fit. If policies required car manufacturers to develop technologies for which they lacked the capabilities there would be a misfit. Pilkington (1998) addressed this mechanism on a national level, stating that the fit between regulatory demands and the capabilities of car manufacturers determines the response of car manufacturers. When less strict policy demands (e.g. to reduce emissions) were made, car manufacturers could exploit existing capabilities—a case of good fit between policy and capability (Pilkington, 1998). When policies required radical developments (e.g. zero emissions), car manufacturers needed to develop new capabilities first, so (initially) there was a misfit between policies and car manufacturers' capabilities (Pilkington, 1998). A fit between policies and car manufacturers' capabilities was likely to result in positive outcomes, whereas a misfit was likely to impair the successful implementation of the policy.

Building on this concept, Pilkington (1998) analyzed car manufacturer's responses to U.S. emission regulations and confirmed that more radical regulatory demands triggered resistance while less strict regulatory demands led to compliance. The results of this chapter support these findings. What is more, this chapter suggests that a poor fit between regulation and capability would reduce international diffusion. Thus, this mechanism not only shaped the national co-evolution between policies and car manufacturers, but also extended to international car manufacturers and policymakers.

The effect of the relative fit between government policy and firm capability also depended on the type of policy. Governments implemented different measures: command-and-control type regulations, market-based incentives and public-private partnerships (see Tables 4.8 and 4.9). Partnerships, mostly in the form of public-private partnerships targeted radical technologies in this industry—mainly focusing on FCs. Partnerships were not only intended to provide a platform for car manufacturers for testing and learning (Harborne et al., 2007), but also to mitigate the investment risks involved (Link & Scott, 2001). Car manufacturers had to develop new capabilities and some participated in a small series of tests using conventional cars modified to implement the expensive but emission-free fuel-cell technology. The tests showed that while the technology was efficient, it was not practical in terms of costs and infrastructure. Only few car manufacturers participated in these tests. Further, they refrained from making the technology available internationally. Nonetheless, although the direct effect on the international diffusion of LEVs was marginal, it did stimulate research and it provided an important learning platform for the technology (Link & Scott, 2001).

Table 4.9: Comparison of policy instruments

Instrument	Target technology	Example	Required capabilities	Result
Partnerships	(Largely) radical technologies	California Fuel Cell Partnership	New capabilities (e.g. zero-emission fuel cell technology)	Stimulated experimentation; LEVs were tested in controlled environment; no commercialized LEVs; no international diffusion
Command-and-control	(Largely) radical technologies	ZEV programme	New capabilities	"Carrot and stick" stimulated car manufacturers to engage; radical requirements were not successful in (international) mass diffusion of LEVs
	Largely incremental technologies	Top Runner U.S. CAFE standards	Combination of existing and new capabilities	"Carrot and stick" stimulated car manufacturers to engage; based on incremental requirements LEVs were commercialized and internationally transferred
Market-based incentives	Incremental and radical technologies	U.S. tax credits, Car pool lane usage	Combination of existing and new capabilities	Were successful in promoting incremental technologies; often entirely depleted; manufacturers of radical technologies would internationalize to countries with generous incentives

Command-and-control type policy interventions, such as emission regulation, appeared to have a more profound effect on the diffusion of LEVs. Yet, the design of the

regulation was crucial. Regulation that required radical technologies, such as the ZEV programme, affected the industry as a whole and triggered experimentation with various technologies, yet it had little direct effect on the international diffusion of ZEVs. In contrast, less strict fuel-efficiency regulation, such as tightened CAFE standards, mandatory fuel economy standards in Japan and Europe, and the modified Californian emission regulations, allowed car manufacturers to react with technologies that were both cost-effective and suitable for the mass-market: hybrids. Firms could build on existing capabilities (e.g. ICE engine technology) and incrementally integrate new capabilities (e.g. adding an electric support engine), which they could commercially exploit and transfer to other markets. Therefore, while less strict fuel-efficiency regulation stimulated less radical technologies, it compelled many car manufacturers to engage, stimulated the international diffusion of hybrid technology and resulted in a larger number of LEVs sold.

Finally, market-based policy interventions, such as tax credits and carpool-lane usage licenses, were provided for LEV technologies in many countries, and were often regarded as the most effective in stimulating sustainable technologies (Ambec & Lanoie, 2008). Generally, the more radical the technology was, the more generous the incentives were. Nevertheless, the majority of the incentives were used for less radical technologies, i.e. hybrids. In the U.S., tax credits of up to USD 8,000 were available for FCs, but the overwhelming majority of the credits were used for HVs. Some car manufacturers, such as Toyota, used all their allotted hybrid incentives (60,000). In California, all licenses for carpool-lane usage were given out, and used by HVs with a license later traded at a USD 4,000 premium. In Japan, incentives for LEVs stimulated the sales of 70,000 cars within three years.

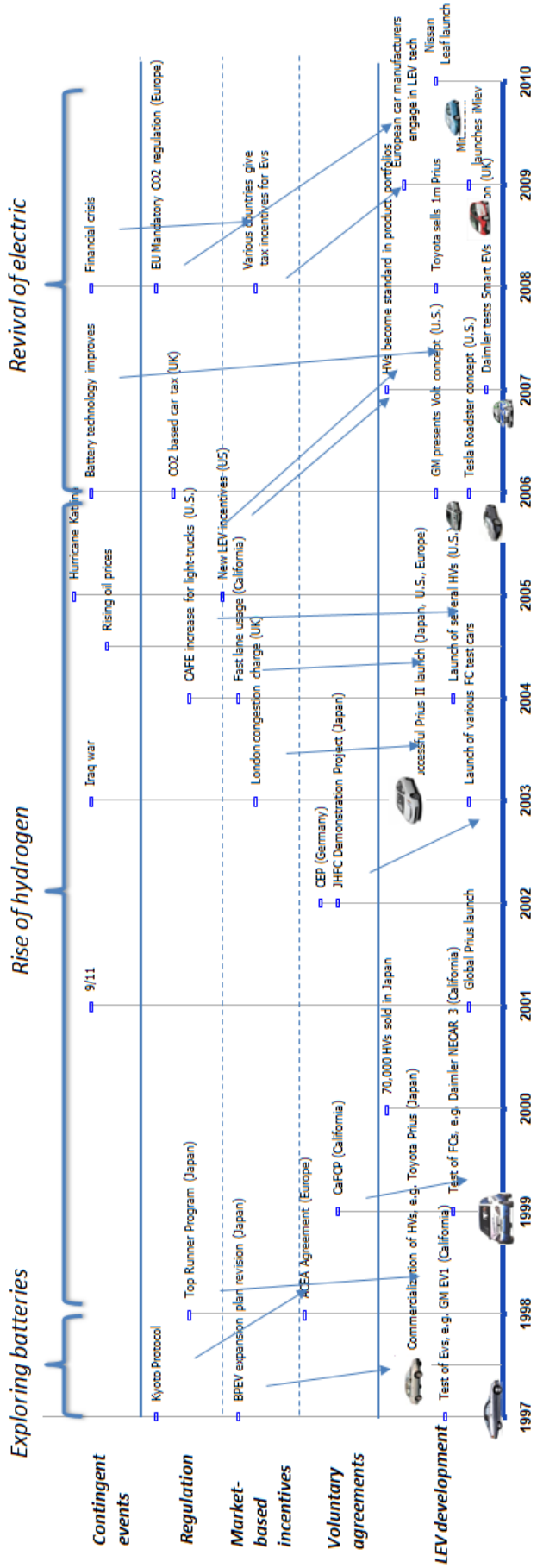
Hence, market-based instruments were successful in diffusing LEVs, but only for the less radical HV technology. Although incentives for EVs and FCs were more generous, car manufacturers would generally not commercialize more technologically radical cars, and consumers would not purchase the available EVs or FCs. As with the less strict command-and-control regulation, car manufacturers could build on existing capabilities and incrementally add new capabilities that were both applicable to a wider market and commercially viable. Yet, it should be noted that the few car manufacturers that mass-produced more radical technologies (mainly EVs) would sell EVs internationally provided there were generous incentives. Car manufacturers such as Nissan and Mitsubishi began commercializing their EVs internationally to countries that offered generous incentives soon after their products launched.

In summary, strict regulation and public-private partnerships that targeted radical technologies (e.g. the ZEV programme or CaFCP) required firms to develop new capabilities. These policies were less successful in internationally commercializing LEVs (see Table 4.9). In contrast, less strict regulation that stimulated incremental technologies (e.g. fuel efficiency standards) allowed firms to build on existing capabilities and more freely develop new capabilities. These stimulated international commercialization. Market incentives stimulated the development and commercialization of incremental technologies.

The three mechanisms—policy diffusion and international policies, international operations of firms, and fit between policy requirements and firm capabilities—have been important in the LEV trajectory. Figure 4.2 presents the evolution in the three phases, including key events embodied in the mechanisms. The first 'Exploring batteries' phase of LEVs was triggered largely by the ZEV programme, which was subsequently emulated in other car markets through policy diffusion. As these policies required new capabilities, there was a misfit with car manufacturers' capabilities in all markets and few cars were launched. The 'Exploring batteries' phase was therefore short-lived. Concomitantly, the Kyoto protocol affected fuel-efficiency regulation and tax incentives in many countries. In Japan, it stimulated the Top Runner programme. The requirements could be met with existing capabilities and stimulated the diffusion of hybrids. Subsequently, car firms from Japan diffused the hybrid technology to the U.S. due to their international operations and because the U.S. implemented incentives for HVs.

In the 'Rise of hydrogen' phase, these HVs competed against FCs. FCs were stimulated by the CaFCP and the idea of a hydrogen economy. Yet, car manufacturers lacked the necessary capabilities and FC technology was too nascent for commercial viability. HV technology, on the other hand, was picked up, and the LEV trajectory witnessed an increase in HV activities. This was also driven by market incentives and contingent events, such as the Iraq war and hurricane Katrina, which led to raising fuel prices. After the diffusion of hybrids, battery technology improved and paved the way for a renewed interest in EVs, which led to the 'Revival of electric' phase. The global financial crisis in 2008 triggered governments to support advanced green technologies, largely EVs. Table 4.3 shows that only in the 'Revival of electric' phase European car manufacturers also increased their engagement in LEVs due to the newly implemented mandatory CO_2 emission regulation and the incentives emerging in the wake of the global financial crisis.

Figure 4.2: Timeline of selected events in the LEV trajectory



4.7 Discussion and conclusion

The basic argument emerging from this longitudinal case study is that the LEV trajectory—besides technological developments—was shaped by the international co-evolution between policies in different geographical areas at different policy levels and car manufacturers' innovation strategies. This provides a new perspective on the LEV development since thus far scholars have largely focused on technological aspects (Bakker et al., 2012; Bento, 2010; Magnusson & Berggren, 2011; Wesseling et al., 2013). While some studies pointed to the relevance of government policies and firm innovation, they focused either on single countries or one specific technology only (Dyerson & Pilkington, 2005; Van Bree et al., 2010; Zapata & Nieuwenhuis, 2010). Moreover, this chapter has attempted to identify the mechanisms that underlie the international co-evolution between government policies and car manufacturers to shed light on the emergence of the international LEV trajectory, thereby responding to calls for more attention to such a spatial dimension (Coenen et al., 2012).

Accordingly, this chapter makes two contributions. First, it provides a more comprehensive perspective on the LEV trajectory. While drawing on the three phases identified by Bakker et al. (2012) based on a Dutch weekly car magazine, this chapter enhances their findings by building on an expansive database compiled from four international sources. Moreover, rather than relying on article counts for specific technologies, this study is based on actual LEV launches. It extends Bakker et al.'s (2012) findings in that it considers all three LEV technologies rather than combining EVs and HVs into battery electric vehicles, thus presenting a more nuanced understanding of the three phases.

The chapter also pays attention to the policy-firm interplay in different geographical areas and at different policy levels which illustrates the international interactions of car manufacturers and policymakers. In addition, it illustrates the competition between the different LEV technologies for substituting the ICE as a dominant design. The results show that none of the LEV technologies have significantly challenged the dominant ICE design due to unresolved high costs and low functionality, confirming earlier studies (Oltra & Saint Jean, 2009a; Struben & Sterman, 2008). However, LEVs have carved out a significant niche in the market and gradually found ways to escape the lock-in of the ICE, particularly through hybrids or plug-in EVs, facilitated by favourable regulation, development of niches and changes in consumer preferences (Cowan & Hulten, 1996; Zapata & Nieuwenhuis, 2010). Concurrently, this chapter shows that the focus of car manufacturers on HVs and EVs locked

out FCs as an alternative LEV technology, confirming earlier concerns of a pre-mature lock-in of a suboptimal technology (Hekkert & Van den Hoed, 2004).

The second contribution of this chapter is that it heeds the call for a spatial conceptualization in the socio-technical systems literature (Carlsson, 2006; Coenen et al., 2012). So far, scholars have paid limited attention to the geography of technological trajectories and tended to treat different geographical areas in which trajectories occur as one space (Coenen et al., 2012). Trajectories have been conceptualized as emerging in local niches that evolve into a global level (Geels & Raven, 2006); however, this conceptualisation does not necessarily refer to geographical areas but rather to the wider community of actors that are either directly (locally) or indirectly (globally) related to projects (Coenen et al., 2012). In short, the literature so far has insufficiently shown where technological trajectories are shaped and which mechanisms influence the trajectory across geographical areas. This chapter proposes three mechanisms—policy diffusion and international policies, international operations of firms, and fit between policy requirements and firm capabilities—that conceptualize how several local technological trajectories may shape an international trajectory.

These mechanisms may enable a better understanding of the international co-evolution of technological trajectories and enrich the socio-technical systems literature by explaining co-evolution internationally between policies and firms. In doing so, the mechanisms fill the gap of insufficient spatial conceptualization in the socio-technical systems literature (Coenen et al., 2012). The mechanisms increase the understanding of the role of different geographical areas, account for the diversity of transitions, and link the transition literature to existing research that investigates different spatial dimensions (Coenen et al., 2012). The mechanisms also answer a call of Whitmarsh (2012) to enhance the explanatory power of socio-technical systems frameworks in international contexts. Whitmarsh criticizes the socio-technical systems perspective for being less conceptualized at the macro level, such as the integration of climate change policies and points to the necessity to investigate mechanisms that link international with local developments, since “the two are inextricably linked and causality is bi-directional” (Whitmarsh, 2012: 485). In summary, the international perspective of the mechanisms applied in this study adds to our understanding of the interplay of various international policies and firms in shaping transitions of sustainable technologies.

This chapter also raises a number of interesting paths for future research. First, this chapter revealed that governments as well as firms protected LEV technologies from market selection mechanisms through tax incentives and through selling cars at a loss. Yet, what

influence did this protection have on the LEV trajectory? Further, which types of protection are more effective? Second, it became evident that LEVs and, in particular, EVs have fundamentally different characteristics than cars with an ICE. They need a new recharging infrastructure, they have different driving experience and the equipment is more expensive. This raises the question how incumbents have altered their business models for LEVs—bearing in mind that government incentives influence their managerial discretion and that their choices are path dependent. Last, it remains a puzzle why some car manufacturers engaged heavily in the development and commercialization of LEVs (e.g. GM, Toyota, Nissan)—despite LEVs being loss-making—while others remained hesitant and refrained from engaging in LEVs (e.g. VW). These questions present fruitful areas for further research that serves as input for subsequent chapters.

Obviously, the study reported in this chapter also has limitations. The analysis has focused mainly on the policy-firm interplay, thereby underexposing other factors such as demand conditions. Also, inferring car manufacturers' reactions from policy measures and vice versa requires caution. Reactions of actors often bear a time lag and are also influenced by a multitude of other internal and external factors. A further limitation is the reliance on secondary sources. Yet, ,"given the often highly secretive nature of new product development activities in the car industry and the highly emotive political atmosphere of these initiatives", as Pilkington and Dyerson (2006: 79) put it, this approach seemed the best available.

References

Åhman, M. (2006). Government policy and the development of electric vehicles in Japan. *Energy Policy*, *34*(4), 433–443.

Ambec, S., & Lanoie, P. (2008). Does it pay to be green? A systematic overview. *Academy of Management Perspectives*, (November), 45–62.

Bakker, S., Van Lente, H., & Engels, R. (2012). Competition in a technological niche : the cars of the future. *Technology Analysis & Strategic Management*, *24*(5), 421–434.

Bento, N. (2010). Dynamic competition between plug-in hybrid and hydrogen fuel cell vehicles for personal transportation. *International Journal of Hydrogen Energy*, *35*(20), 11271–11283.

Berggren, C., Magnusson, T., & Sushandoyo, D. (2009). Hybrids, diesel or both? The forgotten technological competition for sustainable solutions in the global automotive industry. *International Journal of Automotive Technology and Management*, *9*(2), 148–173.

Bourgeois, L., & Eisenhardt, K. (1988). Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. *Management Science*, *34*(7), 816–835.

Carlsson, B. (2006). Internationalization of innovation systems: A survey of the literature. *Research Policy*, *35*(1), 56–67.

Chanaron, J. J., & Teske, J. (2007). Hybrid vehicles: a temporary step. *International Journal of Automotive Technology and Management*, *7*(4), 268–288.

Christensen, T. (2011). Modularised eco-innovation in the auto industry. *Journal of Cleaner Production*, *19*, 212–220.

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy*, *41*(6), 968–979.

Cowan, R., & Hulten, S. (1996). Escaping lock-in: the case of the electric vehicle. *Technological Forecasting and Social Change*, *53*(1), 61–80.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy*, *37*(3), 972–983.

Dijk, M., Orsato, R. J., & Kemp, R. (2012). The emergence of an electric mobility trajectory. *Energy Policy*, (in Press).

Dijk, M., & Yarime, M. (2010). The emergence of hybrid-electric cars: Innovation path creation through co-evolution of supply and demand. *Technological Forecasting and Social Change*, *77*(8), 1371–1390.

Dyerson, R., & Pilkington, A. (2005). Gales of creative destruction and the opportunistic incumbent: The case of electric vehicles in California. *Technology Analysis & Strategic Management*, *17*(4), 391.

Frenken, K., Hekkert, M., & Godfroij, P. (2004). R&D portfolios in environmentally friendly automotive propulsion: Variety, competition and policy implications. *Technological Forecasting and Social Change*, *71*(5), 485–507.

Gallagher, K. S., & Muehlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *Journal of Environmental Economics and Management*, *61*(1), 1–15.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6-7), 897–920.

Geels, F. W. (2006). Co-evolutionary and multi-level dynamics in transitions: The transformation of aviation systems and the shift from propeller to turbojet (1930–1970). *Technovation*, *26*(9), 999–1016.

Geels, F. W., & Raven, R. (2006). Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). *Technology Analysis & Strategic Management*, (November 2012), 37–41.

Harborne, P., Hendry, C., & Brown, J. (2007). The Development and Diffusion of Radical Technological Innovation: The Role of Bus Demonstration Projects in Commercializing Fuel Cell Technology. *Technology Analysis & Strategic Management*, *19*(2), 167–188.

Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H. (2012). Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. *Journal of Industrial Ecology*, 1–12.

Hekkert, M., & Van den Hoed, R. (2004). Competing technologies and the struggle towards a new dominant design. *Greener Management International*, *47*(Autumn), 29–44.

Kolk, A., & Pinkse, J. (2008). A perspective on multinational enterprises and climate change: Learning from "an inconvenient truth"? *Journal of International Business Studies*, *39*(8), 1359–1378.

Langley, A. (1999). Strategies for theorizing from process data. *Academy of Management Review*, *24*(4), 691–710.

Lewin, A., & Volberda, H. (1999). Prolegomena on coevolution: A framework for research on strategy and new organizational forms. *Organization Science*, *10*(5), 519–534.

Link, A., & Scott, J. (2001). Public/private partnerships: stimulating competition in a dynamic market. *International Journal of Industrial Organization*, *19*(5), 763–794.

Magnusson, T., & Berggren, C. (2011). Entering an era of ferment – radical vs incrementalist strategies in automotive power train development. *Technology Analysis & Strategic Management*, *23*(3), 313–330.

Mikler, J. (2005). Institutional reasons for the effect of environmental regulations: Passenger car CO 2 emissions in the European Union, United States and Japan. *Global Society*, *19*(4), 409–444.

Moynihan, D., Shipan, C., & Volden, C. (2012). Policy Diffusion: Seven Lessons for Scholars and Practitioners. *Public Administration Review*, *72*(6), 788–796.

Nykvist, B., & Whitmarsh, L. (2008). A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technological Forecasting and Social Change*, *75*(9), 1373–1387.

Oltra, V., & Saint Jean, M. (2009a). Variety of technological trajectories in low emission vehicles (LEVs): A patent data analysis. *Journal of Cleaner Production*, *17*(2), 201–213.

Oltra, V., & Saint Jean, M. (2009b). Sectoral systems of environmental innovation: An application to the French automotive industry. *Technological Forecasting and Social Change*, *76*(4), 567–583.

Pilkington, A. (1998). The fit and misfit of technological capability: Responses to vehicle emission regulation in the US. *Technology Analysis & Strategic Management*, *10*(2), 211–224.

Pilkington, A., & Dyerson, R. (2006). Innovation in disruptive regulatory environments: A patent study of electric vehicle technology development. *European Journal of Innovation Management*, *9*(1), 79–91.

Pilkington, A., Dyerson, R., & Tissier, O. (2002). The electric vehicle: Patent data as indicators of technological development. *World Patent Information*, *24*(1), 5–12.

Reed, J. (2007). GM commits to selling hybrid car. *Financial Times*, p. 25. London.

Ross Morrow, W., Gallagher, K. S., Collantes, G., & Lee, H. (2010). Analysis of policies to reduce oil consumption and greenhouse-gas emissions from the US transportation sector. *Energy Policy*, *38*(3), 1305–1320.

Serra, J. (2012). *Electric vehicles: technology, policy, and commercial development*. New York: Earthscan.

Shaheen, S., Wright, J., & Sperling, D. (2001). California's Zero Emission Vehicle Mandate - Linking Clean Fuel Cars, Carsharing, and Station Car Strategies. Retrieved March 28, 2013, from http://escholarship.org/uc/item/447386zj

Struben, J., & Sterman, J. D. (2008). Transition challenges for alternative fuel vehicle and transportation systems. *Environment and Planning B: Planning and Design*, *35*(6), 1070–1097.

Unruh, G. (2002). Escaping carbon lock-in. *Energy Policy*, *30*(4), 317–325.

Van Bree, B., Verbong, G., & Kramer, G. (2010). A multi-level perspective on the introduction of hydrogen and battery-electric vehicles. *Technological Forecasting and Social Change*, *77*(4), 529–540.

Van den Hoed, R. (2007). Sources of radical technological innovation: the emergence of fuel cell technology in the automotive industry. *Journal of Cleaner Production*, *15*(11-12), 1014–1021.

Wesseling, J. H., Faber, J., & Hekkert, M. P. (2013). How competitive forces sustain electric vehicle development. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2013.02.005

Whitmarsh, L. (2012). How useful is the Multi-Level Perspective for transport and sustainability research? *Journal of Transport Geography*, *24*, 483–487.

Yin, R. K. (2009). *Case study research: Design and methods* (2nd ed.). Newbury Park, CA: Sage.

Zapata, C., & Nieuwenhuis, P. (2010). Exploring innovation in the automotive industry: new technologies for cleaner cars. *Journal of Cleaner Production*, *18*(1), 14–20.

5 The role of public and private protection in disruptive innovation: The automotive industry and the emergence of low-emission vehicles

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 paper 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 LEVs in three car incumbents—Daimler, General Motors and Toyota—in the context of European, Japanese and U.S. policies. The paper concludes with two different protection trajectories—a public protection trajectory and a private protection trajectory—which explain how carmakers leverage the various protection levers to deal with disruptive technology.

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4.1 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 & Teece, 1996; Garud & 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 & 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, 2004; 2002; 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 & 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 & Geels, 2007), the specific role of these different types of protection levers—private and/or public—has remained unclear. Therefore, this paper 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, we focus 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 U.S. policies. Using evidence from a longitudinal study, we examine 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, we will first present our synthesis of the disruptive innovation and technological transitions literatures, and describe the method and data collection.

4.2 Literature review

5.2.1 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: 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 & 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 & Teece, 1996), scholars have proposed what we refer 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: 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 & 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 & 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 & 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 & Kumaraswamy, 1995). The systemic aspect implies that companies also search for new industry standards in the form of a new dominant design (Anderson & 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 & Teece, 1996).

5.2.2 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 & 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 & Raven, 2012). That is, the government is seen as able to solve the collective action problem inherent to systemic innovation (Chesbrough & 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 we refer to as *public protection levers*. Because disruptive technologies still face difficulties competing with the dominant design in the market (Anderson & 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 & 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 & 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 & 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 & Raven, 2012).

5.2.3 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 5.1).

Table 5.1: Private and public protection levers and firm-level innovation: a framework

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

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 & 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 5.1, the type of disruptive innovation—i.e. autonomous, systemic, or socially embedded—influences the effective use of protection levers (Chesbrough & Teece, 1996; Garud & 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 paper two main research objectives guide the analysis. Our 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 we have presented each protection lever in isolation, in practice we expect interaction between private and public protection levers in their influence on firm-level innovation. Our 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.

4.3 Methodology and sample

Although the two literatures we draw upon as well as the framework we derived from them provide useful suggestions about the effectiveness of private and public protection levers under different circumstances (see Table 5.1), the aim of the empirical analysis is to further elaborate the theoretical depiction presented in the framework (Pratt, 2009). Since our 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*, we decided to collect qualitative process data, which "consist largely of stories about what happened and who did what when—that is, events, activities, and choices ordered over time" (Langley, 1999: 692). Using process data, we hoped to identify patterns in the way in which companies use private and public protection levers. Since we wanted to track developments

over time, we limited our multiple case study to three incumbents in the automotive industry that have made significant investments in LEVs: General Motors, Toyota, and Daimler.

We selected these three companies 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 & 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 we would have decided to analyze how the three companies were providing private protection and/or responding to public protection in the one country context only, for example, we would not have been able to fully understand the LEV development process. In other words, our 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 & Kolk, 2011). Our 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, we selected two trade magazines—*Automotive News* and *WardsAuto World*—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, we chose the *Financial Times* because of its focus on business strategies and its attention for environmental issues as well as the broader political and economic contexts. We decided to collect data from magazines and newspapers instead of company sources such as public announcements and annual reports to prevent a corporate, fully self-perceived, bias. By analyzing representative data that contains divergent perspectives on the main developments in the car industry, we tried to enhance the external validity of the findings. 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 paper and allow the collection of data that can be used for triangulation (Yin, 2009).

To build our 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 we generated a dataset 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, we used this source 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 us to track 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 we attempted to compensate for this caveat as good as possible. Furthermore, while we used an initial set of more than 9,000 articles, not all articles turned out to be relevant. We ended up having 6,663 coded excerpts that we used for the analysis.

To analyze the articles we used the qualitative data analysis software Atlas.ti 6.2, which can manage large datasets and enables users to define the length of selected quotations and thus fully capture the richness of the information. We followed a three-step approach for the data analysis. In the first stage, we tracked all relevant policy interventions from 1997 until 2010 found in the dataset and, to complete the picture, added interventions from 1990 until 1996 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, we analyzed, for each company, the LEV technology development processes and strategies from 1997 until 2010 as well as the impact of the public protection levers. We particularly looked at the LEV technologies they engaged in and until what stage they continued developing LEVs, i.e. concept/prototype, test/production ready, or mass production. We then analyzed the strategies of the case companies, 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, we examined how the case companies managed resource allocation, lobbying efforts and project development.

In the third stage, we analyzed the emerging protection levers—public as well as private—and their interplay. We first tracked the relevant public protection levers that affected the case companies. We then identified the private protection levers, 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 & 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.

4.4 Findings

In this section we present our findings as they have emerged from the data.[1] We start out by outlining the main policy interventions that have functioned as public protection levers. We present these by distinguishing the three main markets for the case companies, i.e. the U.S., EU and Japanese contexts, and identify the relevant government-business interactions. Subsequently, we examine strategic behavior of the three case companies more in-depth; we trace how the public protection levers have affected their LEV development process and which private protection levers have been put in place. In the discussion, we then focus on the interaction between public and private protection levers and suggest two protection trajectories.

5.4.1 Public protection levers and LEV development

Table 5.2 presents the main policy interventions in the U.S., the EU and Japan. Based on the data, we identified regulation, tax incentives, and public-private partnerships 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.

[1] Given the large number of sources for the findings presented here, we do 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.

Table 5.2: Public protection levers and firm-level LEV innovation

Public Protection	Influence on firm innovation	Interaction with private protection	Outcome of protection
Regulations			
Mandatory			
1990: ZEV program (California)	*1st stage* 6. GM: developed electric vehicle EV1, leased in specific areas 7. Toyota: built EV based on RAV4 8. Daimler: not required to participate	• Incumbents subsidized the limited commercialization with their own resources	• 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
	2nd stage • GM: built Club Car Pathway • DaimlerChrysler: bought GEM • Toyota: used hybrid credits	• GM announced giving away free leases for the Pathway to comply with regulation • Car companies integrated suppliers vertically	• GM and DaimlerChrysler obtained court injunction and were able to freeze the regulation
2004: CAFE increase for light-trucks (US)	• GM: integrated mild-hybrid technology • Toyota: benefited from Prius credits • Daimler: paid penalties	• Companies made no profit on LEV technology, but cross-subsidized with profits from light-trucks • GM collaborated with Daimler to develop full hybrids	• More stringent standards stimulated commercialization of LEV technology
2009: CO_2 regulation (EU)	• 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	• Required all carmakers to invest in LEV technology to comply • Daimler was particularly affected as they have the highest fleet average CO_2 emissions	• 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
Voluntary			
1997: BPEV Expansion Plan (Japan)	• The third electric vehicle expansion plan (BPEV) was altered and included hybrids and fuel cells	• Toyota presented various fuel cell cars	• Stimulated other governments to implement incentives and stimulated fuel-cell research
1998: Voluntary CO_2 regulation (EU)	• GM: average reduction achievement • Toyota: achieved highest reduction rate • Daimler: achieved lowest reduction	• Toyota built plant with Peugeot for small cars (not LEVs) • Daimler bought small car firm "Smart" to support compliance	• Voluntary targets did not trigger LEV commercialization

Tax incentives			
1996: Purchasing Incentive Program (Japan)	• Was targeted at EVs initially, but only 400 cars benefited, and program had little influence. • Later it included hybrids which allowed Toyota to benefit	• Toyota benefited from incentives but had to subsidize the Prius also with its own resources	• Toyota sold more than 70,000 hybrids until 2000
2000: PowerShift grant scheme (UK)	• Toyota: commercialized Prius in the UK • GM: n/a • Daimler: n/a	• Toyota subsidized Prius sales	• Stopped in 2006 as funds seemed insufficient to kick-start LEV mass commercialization
2005: Energy Act (US)	• GM: launched Silverado, Saturn Vue • Toyota: benefited from the incentives with the first 60,000 hybrids • Daimler: n/a	• GM: subsidized commercialization additionally with own resources • Toyota: reached break-even after it sold 200,000 cars, so was not required to subsidize	• Hybrids gained increasing popularity and large incumbents depleted the allotted incentives
Public-private partnerships			
1992: Rügen EV Test (Germany)	• Daimler and other German car producers tested 60 EVs.	• Stimulated Daimler to develop fuel-cell cars and design the A-Class which was prepared to integrate fuel cell or battery stacks	• Project was discontinued in 1996.
1993: PNGV (US)	• GM: developed Precept concept • Daimler and Toyota were not allowed to participate	• Toyota started G21 project to pre-empt potential competitive advantage of the Big 3; resulted in the Prius	• PNGV was seen as a means to avoid CAFE standard increases • Substituted by FreedomCAR which focused on fuel cell technology
2002: JHFC Project (Japan)	• All participated to obtain real-world driving information • GM: HydroGen • Toyota: FCHV • Daimler: F-Cell	• Incumbents provided cars, e.g. GM gave car free of charge for one year to FedEx	• Initial target of 5m FCVs by 2020 was abandoned in 2006 • Project was phased out in 2011
2002: Clean Energy Partnership (Germany)	• GM: Hydrogen • Toyota: FCHV • Daimler: F-Cell	• Incumbents provided cars	• Project still operating

The U.S. context. Since the U.S. was the largest car market in the world in the period under study, the U.S. government (federal and state) had an impact on carmakers well beyond those headquartered in the U.S. 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 two percent of their total sales as ZEVs by 1998; this would increase to ten percent 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 5.2 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': U.S. 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 U.S. 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 U.S. carmakers, but as will be argued below it helped to set off Toyota's development of the hybrid Prius (see Table 5.2).

While PNGV mainly protected LEV technology development, another policy instrument—tax incentives for car buyers—pushed commercialization, after being incluced 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 U.S. carmakers. Once Japanese companies, which reached their caps first, had depleted the allotted incentives, the set-up provided other (i.e. U.S.) 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 5.2). 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 USD 25 billion 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 percent (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 percent of the additional costs of EVs. In 1997, Japan increased its budget for LEV incentives to USD 68 million, 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 5 million 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 & 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

5.2). 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 percent 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 USD 1,025 to buyers of cars that emit 15 percent 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 CO_2 emissions reductions. In 1998, this culminated in a voluntary agreement whereby European carmakers, including subsidiaries of U.S. companies, committed to reducing the fleet average of CO_2 emissions by 20 percent to 140 gCO_2/km in 2008 (from 186 gCO_2/km in 1995). One year later, Japanese and Korean carmakers committed to a similar arrangement. Initially the EU had planned a 30 percent 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 165 gCO_2/km. Due to repeated failure of ACEA members to reach the voluntary targets, the EU finally implemented CO_2 performance standards of 130 gCO_2/km in 2008, with a further reduction objective to 95 gCO_2/km in 2020 (European Federation for Transport and Environment, 2010). When the CO_2 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 U.S. 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.

5.4.2 Private protection levers and LEV development

Table 5.3 presents the main private protection levers that GM, Toyota and Daimler have used while developing LEVs. Based on the literature, we identified resource allocation, niche occupation and collaboration-integration as 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.

Table 5.3: Private protection levers and firm-level LEV innovation

Private Protection	Influence on firm innovation	Interaction with public protection	Outcome of protection
Resource Allocation			
Leading	• 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	• 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	• 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
Learning	• GM, Toyota and Daimler developed and tested fuel-cell cars globally	• Supported by fuel infrastructure, e.g. German Clean Energy Partnership	• Fuel-cell cars never left the testing phase
Dumping	• GM: launched the EV1 below cost price • Toyota: sold initially Prius at a loss, break-even assumed at 200,000 cars	• GM: supported by local and national tax incentives • Toyota: supported by government incentives in Japan and US	• GM: EV1 never achieved scale and was scrapped • Toyota: Prius became the best-selling hybrid
Niche Occupation			
Targeting car rentals	• Toyota: sold Prius to car rentals at no discount	• Toyota: supported by tax credits, exemptions, and fast-lane usage	• Toyota: Customers of car rentals were attracted by novelty, green image and additional advantages • Prius became best-selling commercial vehicle in the US
Targeting fleet markets	• Toyota: targeted fleet markets with Prius	• Toyota: supported by tax credits, exemptions, and fast-lane usage	• Toyota: Prius became best selling fleet-market car
Collaboration/ Integration			
With competitors	• GM: teamed up with Toyota in 1999 to develop fuel cell technology which was dominated by Daimler	• Publicly funded test platforms were available, e.g. California Fuel Cell Partnership or Japan Hydrogen & Fuel Cell	• Collaboration was stopped as fuel cells proofed to be far away from commercialization

	• Daimler: teamed up with GM in 2004 to develop full hybrid technology to catch up with Toyota	demonstration project • Government incentives were available for hybrids in various countries	• Developed and integrated HV technology into product portfolio
With new entrants	• GM: collaborated with Reva to develop small EV for Asian market • Toyota: bought 10 percent stake in Tesla to speed up EV development • Daimler: had Zytek retrofit 100 Smarts to EVs	• GM: generous tax incentives for EVs were emerging • Daimler: tested Smart EV in London; benefited from free charging and tax exemption	• GM: ended partnership after Mahindra&Mahindra bought controlling stake • Toyota: no EV at the time of this study • Daimler: project still ongoing
With suppliers	• 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	• 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	• GM: eventually built its own battery plant • Toyota: increased stake • from 40 percent to 80 percent • Daimler: sold part of its shares in joint venture to Ford in 2007

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 USD 33,995, tax incentives reduced the price considerably, resulting in a final price of USD 25,595, which translated into a USD 399 three-year monthly lease. To compare, initially the monthly lease was USD 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 USD 350 million 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 USD 1 billion 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.[2] To counterbalance Toyota's success in the U.S. 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.[3] The company lobbied for government support for research on alternative battery technologies; the Bush Administration subsequently included USD 42 million 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 U.S. 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.

[2] Mild-hybrids merely support the ICE, but it is not possible to drive on battery power alone.
[3] A range extender is a small ICE that charges the battery when it is close to depletion.

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 USD 42,000, a figure that was denied by Toyota's president Okuda (Treece, 1997). ING Barings estimated losses at USD 6,670 per car at a sales volume of 1,000 vehicles per month. The car was launched with a price tag of USD 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 U.S. for USD 19,995, it declared that the break-even point of the Prius was reached at sales figures of 200,000 vehicles. Commercialization in the U.S. 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 U.S. 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 CO_2 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 percent 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 & 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 USD 310 million 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 CO_2 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 percent of its shares to Aabar Investments with the intention to cooperate in developing EVs. Subsequently, it bought a 10 percent 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 U.S. in 2010, with commercialization aimed to start between 2012 and 2015.

4.5 Discussion and conclusions

This paper 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 & Kumaraswamy, 1995; Moore, 1991) and technological trajectories (Geels, 2002; Kemp et al., 1998; Smith & Raven, 2012) identified various public and private protection levers to cross the initial stages of the innovation process, we further elaborated on this through an in-depth study of the development of low-emission vehicles in the car industry. As our starting point we 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.

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

As shown in Tables 5.2 and 5.3, we identified several public and private protection levers in the car industry that were used with varying degrees of success. Most of these levers

corresponded, to some degree, to the ones we derived from the literature (see Table 5.1). 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 & 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). We argued above that 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 & Saint Jean, 2009).

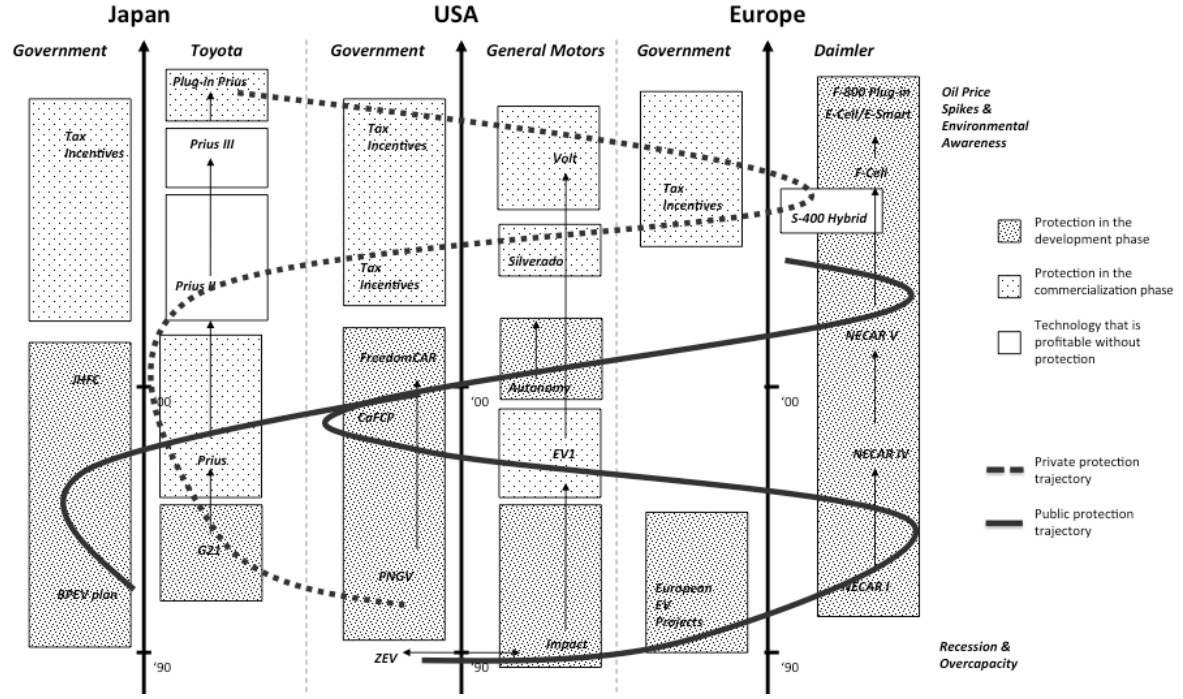
Regarding the additional private protection lever that we found, both GM and Toyota appeared to use dumping to gain access to mainstream markets. Interestingly, they refused to be fully transparent about it; instead of acknowledging that it was a way to gain a foothold in the market, they emphasized 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 U.S. markets. Nevertheless, findings for the U.S. 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.

5.5.2 Public and private protection trajectories

To gain further insight into the interaction between public and private protection levers and their sequencing, we suggest two protection trajectories, derived from our analysis (see Figure 5.1). 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,[4] and (2) the technological focus in terms of the type of disruption for the industry.

Figure 5.1: Private and public protection trajectories



[4] 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, we argue that the private protection trajectory also relies on protection from the government, and do not assume an unrestrained working of the market.

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 & 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 5.2). 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 & 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 5.2), 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 U.S. vis-à-vis Japan led to a lobby for and subsequent launch of PNGV. In turn, Toyota was anxious that its main U.S. competitors—the Big Three—would succeed with the help of the U.S. 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 U.S. 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 & Kumaraswamy, 1995). Hence, as figure 5.1 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 U.S. 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 5.2). 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 we used publicly available information, which means that our 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.

References

Afuah, A. (2000). How much do your co-opetitors' capabilities matter in the face of technological change? *Strategic Management Journal*, *21*(3), 397–404.

Afuah, A. (2001). Dynamic Boundaries of the Firm: Are Firms Better off Being Vertically Integrated in the Face of a Technological Change? *Academy of Management Journal*, *44*(6), 1211–1228.

Åhman, M. (2006). Government policy and the development of electric vehicles in Japan. *Energy Policy*, *34*(4), 433–443.

Anderson, P., & Tushman, M. (1990). Technological discontinuities and dominant designs: A cyclical model of technological change. *Administrative Science Quarterly*, *35*(4), 604–633.

Autoweek. (1997). World news this week. *Autoweek*, *12 May*.

Bakker, S., Van Lente, H., & Engels, R. (2012). Competition in a technological niche : the cars of the future. *Technology Analysis & Strategic Management*, *24*(5), 421–434.

Benjamin, D. (2010). *Prius (Green Cars)*. Tarrytown, NY: Marshall Cavendish.

Bourgeois, L., & Eisenhardt, K. (1988). Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. *Management Science*, *34*(7), 816–835.

Chesbrough, H., & Teece, D. (1996). Organizing for innovation: when is virtual virtuous? *Harvard Business Review*, *74*(1), 65–74.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Danneels, E. (2004). Disruptive Technology Reconsidered: A Critique and Research Agenda. *Journal of Product Innovation Management*, *21*(4), 246–258.

Dyer, J. H., & Singh, H. (1998). The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage. *The Academy of Management Review*, *23*(4), 660–679.

European Federation for Transport and Environment. (2010). *How clean are Europe's cars? An analysis of carmaker progress towards EU CO2 targets in 2009*. Last accessed on 21 December 2010 from http://www.transportenvironment.org/how_clean_are_europe-s_cars.

Garud, R., & Kumaraswamy, A. (1995). Technological and organizational designs for realizing economies of substitution. *Strategic Management Journal*, *16*, 93–109.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6-7), 897–920.

Govindarajan, V., & Kopalle, P. K. (2006). The Usefulness of Measuring Disruptiveness of Innovations Ex Post in Making Ex Ante Predictions. *Journal of Product Innovation Management*, *23*(1), 12–18.

Gray, E. R., & Balmer, J. M. T. (1998). Managing Corporate Image and Corporate Reputation. *Long Range Planning*, *31*(5), 695–702.

Hoogma, R., Kemp, R., Schot, J., & Truffer, B. (2002). *Experimenting for sustainable transport: the approach of strategic niche management*. London: Routledge.

Jackson, K. (1998). Pearce: cooperate on global warming. *Automotive News*, *71*(5749), 30.

Japanese Automobile Importers Association. (2009). *Imported Car Market of Japan 2009*. Last accessed on 21 December 2010 from http://www.jaia-jp.org/english/wp-content/uploads/pdf_data_2009icmj.pdf.

Kemp, R., Schot, J. W., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–195.

Langley, A. (1999). Strategies for theorizing from process data. *Academy of Management Review*, *24*(4), 691–710.

Lynn, B. (2004). *Today's Promises, Tomorrow's Cars?* Washington D.C.: Environmental Defense.

Mackintosh, J. (2006). Group orders focus on fuel economy. *Financial Times*, *19 July*.

Moore, G. A. (1991). *Crossing the Chasm - Marketing and Selling High-Tech products to Mainstream Customers*. New York: Harper-Collins.

Oltra, V., & Saint Jean, M. (2009). Variety of technological trajectories in low emission vehicles (LEVs): A patent data analysis. *Journal of Cleaner Production*, *17*(2), 201–213.

Pinkse, J., & Kolk, A. (2011). Multinational enterprises and climate change: Exploring institutional failures and embeddedness. *Journal of International Business Studies*, *43*(3), 332–341.

Pratt, M. G. (2009). For the lack of a boilerplate: Tips on writing up (and reviewing) qualitative research. *Academy of Management Journal*, *52*(5), 856–862.

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332.

Rice, M. P., Leifer, R., & O'Connor, G. C. (2002). Commercializing discontinuous innovations: bridging the gap from discontinuous innovation project to operations. *IEEE Transactions on Engineering Management*, *49*(4), 330–340.

Schot, J., & Geels, F. W. (2007). Niches in evolutionary theories of technical change. *Journal of Evolutionary Economics*, *17*(5), 605–622.

Simonian, H. (1997). You'll get a real charge from the Prius. *Financial Times*, *15 November*.

Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, *41*(6), 1025–1036.

Stoll, H. (2000). CARB forces issue of zero emissions. *Automotive News*, *18 September*.

Taylor III, A. (2006). Toyota: The birth of the Prius. *Fortune*, *21 February*.

Treece, J. B. (1997). Toyota to test hybrid market in Japan with $17,900 Prius. *Automotive News*, *20 October*.

Treece, J. B. (1998). Search for solutions. *Automotive News*, *23 February*.

Treece, J. B., & Soda, F. (2006). Japan's fuel cell forecast: Fact or fantasy. *Automotive News*, *20 November*.

Truett, R. (2001). Despite low numbers, EV1 was a triumph. *Automotive News*, *26 February*.

Van Bree, B., Verbong, G., & Kramer, G. (2010). A multi-level perspective on the introduction of hydrogen and battery-electric vehicles. *Technological Forecasting and Social Change*, *77*(4), 529–540.

Weber, W., & Hoogma, R. (1998). Beyond national and technological styles of innovation diffusion: a dynamic perspective on cases from the energy and transport sectors. *Technology Analysis & Strategic Management*, *10*(4), 545–566.

Yin, R. K. (2009). *Case study research: Design and methods* (2nd ed.). Newbury Park, CA: Sage.

Yu, D., & Hang, C. C. (2010). A reflective review of Disruptive Innovation Theory. *International Journal of Management Reviews*, *12*(4), 435–452.

6 Business models for sustainable innovation: Exploring strategic choices in the case of electric vehicles

Abstract

Sustainable innovations challenge prevailing business practices, especially in sectors with fossil fuel-based business models. Large incumbents in particular struggle to find new business models as they face path dependencies and are afraid to cannibalise their existing products. And while governments often provide incentives for sustainable innovation, these also restrain managerial discretion. Embedded in the literature on sustainable innovation and business models, this paper explores car firms' strategic choices about policies, assets and governance in the move towards a business model for electric vehicles (EVs), including the role of government support. Based on evidence over a five-year period for both incumbents and new entrants, it identifies crucial components of this new business model. Findings suggest that the few incumbents involved stay (too) close to prevailing approaches, while new entrants pioneer for niche markets only. EV activities frequently rely on government support that tends to steer firms towards uneconomic choices that may not last long. Implications of this combined incumbent and incentive 'curse' are outlined.

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6.1 Introduction

Innovation is often seen as key to dealing with challenges of sustainability, such as climate change, energy security and resource depletion (Hall & Vredenburg, 2003; Johnson & Suskewicz, 2009; Nidumolu, Prahalad, & Rangaswami, 2009; Schaltegger & Wagner, 2011), but the uptake of sustainable technologies for industrial production, electricity generation and mobility is still rather limited. One major barrier is that sustainable technologies challenge prevailing practices especially in sectors with fossil fuel-based business models, including oil and gas, electricity and automotive (Jacobsson & Bergek, 2004; Johnson & Suskewicz, 2009; Unruh, 2000). Large incumbents in particular struggle to find new business models as they face path dependencies (Zott & Amit, 2007) and are afraid to cannibalise their existing products (Christensen, 1997). They thus do not seem likely candidates to drive a change to more sustainable technologies; a role expected more often from start-ups or entrepreneurial new entrants. Nevertheless, it has been argued that both such new entrants and incumbents "have a role to play in the sustainability transformation of an industry" (Hockerts & Wüstenhagen, 2010: 488) . While incumbents might not be involved in the first stages of technological breakthroughs, once such technologies have reached a certain maturity through efforts of others, they are the ones with sufficient resources, a supply infrastructure, customer network and brand image to help reach the mass market (Hockerts & Wüstenhagen, 2010).

However, sustainable technologies have limitations in terms of market attractiveness, because they often do not fit existing production methods, managerial expertise and customer preferences (Johnson & Suskewicz, 2009), and it is therefore difficult to commercialise them. This appears to require a fundamental rethinking of the main value proposition, the structure of the value chain, the marketing segments targeted and a reconfiguration of the way revenues are generated (Chesbrough, 2010; Chesbrough & Rosenbloom, 2002; Johnson, Christensen, & Kagermann, 2008). What incumbents need in particular is "business model innovation" (Chesbrough, 2010; Shafer, Smith, & Linder, 2005; Teece, 2010); that is, they have to find ways to 'win' customers for their new technologies, while retaining their existing competitive position. Business models are usually difficult to change, however, because past successes with established models influence managerial decision-making in developing new ones (Chesbrough, 2010). Compared to new entrants, incumbents face more constraints in designing innovative business models because they tend to focus on preferences of existing customers (Christensen & Bower, 1996), stay close to familiar, mature technologies (Ahuja & Lampert, 2001; Bock, Opsahl, George, & Gann, 2012), often resist change to the corporate

identity (Bouchikhi & Kimberly, 2003), or follow the dominant logic of the industry (Prahalad & Bettis, 1986).

Although such path dependencies characterise all newly emerging technologies (Vergne & Durand, 2010), specific to sustainable technologies is what has been called a "double externality problem" (Rennings, 2000). Whereas it is not uncommon that innovation produces positive knowledge spillovers that cannot always be fully appropriated by the firms involved (Teece, 2010), sustainable technologies often yield an additional positive externality if they reduce environmental impact (Rennings, 2000). If such value created for 'society as a whole' cannot be captured by firms, this could further dampen their incentive to invest in sustainable innovation (Lepak, Smith, & Taylor, 2007). It should be noted, however, that in case technologies have broad societal value, governments regularly provide (initial) support to firms via subsidies, tax incentives, and/or infrastructural facilities (Åhman, 2006). While helpful for firms, this also leads to dependence on government support that is usually temporary and which steers them in a particular direction that may not be (the most) economically viable or otherwise strategically desirable one (Rennings, 2000; Spencer, Murtha, & Lenway, 2005). This clearly points at dilemmas faced by firms—as well as their stakeholders—in decision-making on whether and how to engage in sustainable innovation, and what a concomitant new business model should look like. This paper aims to help shed more light on this issue, considering both path dependencies and government support, taking the case of electric vehicles.

To this end, the paper explores car firms' strategic choices about policies, assets and governance in the move towards a business model for electric vehicles (EVs), including the role of government support, a component that has received only limited attention in this connection. We follow the conceptual approach proposed by Casadesus-Masanell and Ricart (2010), who understand a business model as an objective entity that emerges from the choices made in a firm (cf. Shafer et al., 2005). By identifying the choices of key players in a sector and the consequences of these choices for their competitive position, insight can be obtained in the business models that emerge and firms' related strategies (Casadesus-Masanell & Ricart, 2010). Our empirical setting is the automotive industry, where firms have started to invest in electric vehicles (EVs) as an alternative to cars with an internal combustion engine (ICE). Although EVs hold great promise to alleviate sustainability challenges, they also seem to require major changes in carmakers' business models (Kley, Lerch, & Dallinger, 2011; Pilkington, Dyerson, & Tissier, 2002). The industry's dominant business model is shaped around the century-old ICE, general-purpose design and all-steel body, but EVs require an

alternative business model built around an electric drivetrain, specific-purpose design and light-weight body (Orsato & Wells, 2007) to retain market attractiveness despite the technological and systemic challenges of EVs (Kley et al., 2011). We examine activities of both incumbents and new entrants over a five-year period to uncover developments and crucial components of the new business model. Before moving to the empirical analysis in relation to the conceptual framework, first the main tenets of the theoretical debate about sustainable technologies, disruptive innovation and business models will be discussed.

6.2 Sustainable technologies, disruptive innovation and business models

Sustainable technologies hold the promise to reduce harmful emissions and use resources more efficiently (Johnson & Suskewicz, 2009; Nidumolu et al., 2009). Despite being desirable for society, however, these technologies are often disruptive in nature (Christensen, 1997). Disruptive technologies can be a threat to incumbents if they change the basis of competition by adding performance metrics on which firms were not competing before (Danneels, 2004). Incumbents struggle with disruptive technologies for several reasons. First, they often fail to recognise demand outside the circle of their well-known key customers. Second, incumbents tend to find disruptive technologies unattractive because of small initial profit margins (Christensen & Bower, 1996). Furthermore, they are restricted by resource allocation processes that are not aligned to the new situation, and a 'familiarity trap' (Ahuja & Lampert, 2001) that favours past routines, prior knowledge and prevailing technologies. Hence, incumbents are often neither motivated nor able to develop disruptive technologies: they lack economic incentives and/or face organisational barriers (Henderson, 1993). This complex of factors has been coined the "incumbent's curse", and has led to the proposition that instead of incumbents, start-ups or entrepreneurial new entrants are the ones introducing disruptive technologies (Chandy & Tellis, 2000).

While this so-called incumbent's curse indicates the struggle of large firms with disruptive innovation, sustainable technologies have idiosyncrasies that further complicate this process. This includes a "double externality problem" which puts up an additional barrier to firms considering a move into the market for sustainable technologies (Rennings, 2000). Besides the more familiar challenge to capture *knowledge* spillovers, sustainable technologies also create *environmental* spillovers that are even more difficult to capture by firms. Positive environmental spillovers create value for society as a whole, but in the absence of proper pricing systems that put a cost on 'negative' environmental impact, there is no clear private

benefit accruing to the firm. By engaging in sustainable innovation, firms as such create value at an organisational level, but this is, to a large extent, captured at the societal level; hence value slips away, which further dampens firms' incentives to invest in such technologies (Lepak et al., 2007).

Since sustainable technologies have societal value, governments often intervene and create incentives that compensate for value slippage (Lepak et al., 2007; Schaltegger & Wagner, 2011). Government support can take the form of research funds in the development phase or tax incentives in the commercialisation phase (Åhman, 2006), thus creating a regulatory push or a regulatory pull effect, respectively (Rennings, 2000). The intervention of governments is not without consequences, however. While government intervention is "responsible for internalizing external costs imposed by competing, non-ecological products or services", it also forms "a key determinant for eco-innovative behaviour in firms" (Rennings, 2000: 326). This means, however, that "[f]irms that choose to participate in government-led industry development programs sometimes become so dependent that they cannot survive unaided", and that "the terms of assistance can reduce managerial discretion and the prospects of success" (Spencer et al., 2005: 334). Thus, the intervention of governments—while stimulating the introduction of sustainable technologies—also affects strategic choices and the viability of business models for sustainable innovation.

Despite the importance of sustainable innovation for a move to a lower-carbon economy, the role of business models and the acceptance of these new products and services has received "far too little attention" (Johnson & Suskewicz, 2009: 54). This adds to Teece's (2010: 183) more generic observation that "technological innovation does not guarantee business success – new product development efforts should be coupled with a business model defining their 'go to market' and 'capturing value' strategies." This also holds true for sustainable technologies (Nidumolu et al., 2009), which "require business models designed specifically for them" (Johnson & Suskewicz, 2009: 54). According to this logic, an appropriate business model can help to increase the market attractiveness of a technology, to better capture the full value of the innovation and lead to a competitive advantage (Björkdahl, 2009; Mitchell & Coles, 2003). It is unclear, however, what an appropriate or the 'right' business model involves in practice (Chesbrough, 2010).

Although the business model concept has been used widely by practitioners and increasingly by academics as well (Zott, Amit, & Massa, 2011), it remains difficult to pinpoint what it exactly entails (Teece, 2010). Business models tend to be rather complex (Casadesus-Masanell & Ricart, 2010; Zott & Amit, 2010) and a variety of approaches have

been mentioned. Some scholars refer to it as a 'scale model' that allows describing a business as such (Baden-Fuller & Morgan, 2010; Magretta, 2002), while others see it as a 'narrative device' that enables exploring new markets (Doganova & Eyquem-Renault, 2009). Business models can be seen to constitute the way in which an organisation creates and captures value (Chesbrough, 2007; Teece, 2010), and as "a representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network" (Shafer et al., 2005: 202). A key issue related to the commercialisation of emerging technologies, however, is that the right business model is not yet apparent (Teece, 2010) and requires experimentation with alternative business models (Chesbrough, 2010). As Teece (2010: 187) puts it, "one needs to distil fundamental truths about customer desires, customer assessments, the nature and likely future behaviour of costs, and the capabilities of competitors when designing a commercially viable business model".

Perhaps because of the need to explore alternatives including customers' wishes, there are different, often normative depictions of the various elements that an effective/successful business model should be made up of (Johnson et al., 2008; Teece, 2010). While one might want to develop an 'ideal' business model for commercialising sustainable technologies along these lines, this paper takes an emergent strategy perspective (Mintzberg & Waters, 1985), with a business model as a reflection of a firm's realised strategy, following Casadesus-Masanell and Ricart (2010). They argue that "the particular set of choices an organization makes about policies, assets and governance – and their associated consequences – *are* the organization's business model, because they determine '*the logic of the firm, the way it operates and how it creates value for its stakeholders*'" (Casadesus-Masanell and Ricart, (2010: 201); emphasis in original).

Without prescribing explicitly which elements a business model should contain, a distinction between policy, asset and governance choices gives general guidance about the different types of choices that together form a representation of a firm's underlying core logic to create and capture value. In this context, policy choices refer to general courses of actions, such as which customers' needs to meet and which markets to target. Asset choices define the use of tangible resources; that is, what kind of production facilities and technologies to invest in. Governance structures link policies with asset choices by means of contractual modes, which refer to ways to manage transactions with customers, suppliers and competitors (Casadesus-Masanell & Ricart, 2010). In the next sections, we will explore strategic choices of both incumbents and new entrants about policies, assets and governance in the move towards a business model for electric vehicles, including the role of governments, to identify

crucial components that appear to be important. First, more information will be given about the sample and methodology of the study.

6.3 Sample and methodology

To explore carmakers' strategic choices as outlined above, we identified all EV projects of key industry players from 2006 onwards, covering electric vehicles—cars that drive on battery power alone—as well as plug-in hybrids such as the Chevy Volt, given that they can drive on battery power for an extended range (>20 km). To this end, and as part of a larger study on environmental issues in the automotive industry, we did a content analysis of two industry trade magazines—*Automotive News* and *WardsAuto World*—and a car magazine—*Autoweek*—which were selected because they provide insight into industry and firm perceptions and offer rich descriptions of technologies and associated business models. We also analysed the *Financial Times* because of its focus on business strategies and its attention for sustainability as well as the broader political and economic contexts. A keyword search was performed for the period from 2006 until 2010 using search terms referring to plug-in and EV technologies.

To analyse the articles, we conducted a content analysis and used the qualitative data analysis software Atlas.ti 6.2. This software package can manage large datasets, enabling users to define the length of selected quotations and thus fully capture the richness of the information. The generated set of 4,796 articles was further coded for firm names and technologies. Methodologically we used a method of 'systematic combining', going back and forth between a simple theoretical framework and an evolving coding scheme (Dubois & Gadde, 2002). We initially started out with a simple coding scheme based on our literature review, using a process of pattern matching and comparing empirically-based patterns with the relevant theoretical concepts (Yin, 2009). Subsequently, using an inductive coding technique with codes emerging from the data rather than having them pre-defined, the coding scheme was extended based on the first empirical findings. We then recoded the previously coded articles and further developed our narrative based on a process of axial coding (Strauss & Corbin, 1998).[1] We reorganized the outcomes of open coding and used axial coding to relate these to the subcategories derived from Casadesus-Masanell and Ricart (2010) to consider a business model as emerging from the policy, asset and governance choices made

[1] Given the large number of sources for the findings presented here, we do 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.

by firms. These choices were also related to the main government policies that have been put in place to stimulate the development of electric mobility. It must be noted that directly linking government policy and/or historical decisions to firms' strategic choices is a rather provisional exercise, which means that these relations have to be considered with some caution.

We analysed the automotive industry beginning from 2006 when EVs increasingly appeared on the agenda. After an initial period of interest in EVs in the 1990s, 2006 forms a landmark because various firms all took first steps towards (re)launching EVs: Tesla launched its Roadster, Mitsubishi its concept of the Colt EV, and GM, Toyota and Daimler started developing a plug-in hybrid. Table 6.1 provides an overview of all carmakers engaging in EV projects, and also gives an indication of the increasing attention to electric and plug-in hybrid vehicles over the period from 2006 until 2010. It also shows the firms that received most attention in this period, the incumbents GM, Renault-Nissan[2], Toyota and Mitsubishi, which together accounted for more than 50 percent of all articles, as well as Tesla, the most visible entrepreneurial firm. In total 1,220 excerpts were coded. One excerpt can be coded using multiple codes simultaneously. After the dataset had been coded, quotations were used to construct tables to reflect on the conditions to engage in EVs and the way in which firms seem to deal with the business model dilemmas involved.

[2] Renault and Nissan are in a cross-shareholding strategic partnership and have the same CEO, Charles Ghosn. The firms work closely together in the EV venture and therefore are here referred to as Renault-Nissan, except in cases of brand-specific information, e.g. regarding the Nissan Leaf or the Renault Fluence Z.E.

Table 6.1: Excerpt counts per firm for electric and plug-in vehicle technology (in absolute numbers and as percentage of all articles on electric vehicles in total)

Firm	2006	2007	2008	2009	2010	Total	Share
Incumbents							
GM	18	70	52	71	56	267	22%
Nissan	0	9	32	75	69	185	15%
Toyota	5	18	22	29	25	99	8%
Mitsubishi	5	9	18	22	28	82	7%
Daimler	3	3	10	31	18	65	5%
Chrysler	0	6	29	16	4	55	5%
Ford	2	11	8	16	10	47	4%
BMW	0	0	11	9	24	44	4%
Renault	0	1	9	14	10	34	3%
Peugeot	0	0	4	14	5	23	2%
Audi	0	1	1	5	6	13	1%
Honda	1	1	4	2	5	13	1%
Hyundai	0	0	2	8	1	11	1%
VW	0	0	3	6	2	11	1%
Subaru	0	0	2	2	0	4	0%
New entrants							
Tesla	2	12	14	23	23	74	6%
Fisker	0	2	9	17	11	39	3%
BYD	0	4	5	6	5	20	2%
Think	0	5	6	6	2	19	2%
Reva	0	0	0	3	0	3	0%
Chery	0	0	0	1	1	2	0%
*Others**	14	26	21	35	14	110	9%
Total	50	178	262	411	319	1,220	

* Others include firms such as Tanfield, Smith Electric Vehicle, Aptera, Coda, V-Vehicle, etc.

6.4 Findings

6.4.1 The Emergence of Government Support and EV Projects

The involvement of governments in the car industry has often been related to the overall lack of sustainability of the prevailing business model in economic, social and environmental terms (P. Wells, 2004). Economically there has been a gap between market demand and the capacity of the established production system, resulting in insufficient profitability, coupled with high capital intensity and inflexibility in production (Wells & Nieuwenhuis, 2006). There is a strong reliance on new cars' sales, as carmakers do not earn money with car usage. The production system is highly centralized which tends to cause stock inefficiencies, expensive and long deliveries and frequent overcapacity. From a social perspective, the sheer size of production leads to areas of concentrated economic activity, with large plants on which communities depend, involving urban migration and, in case of closures or downsizing, large vulnerability. Moreover, car traffic can be related to quite some fatalities

every year. Environmentally, besides the use of resources and emissions of toxic and greenhouse gases, cars also create noise and have visually disturbing effects on cities (Orsato & Wells, 2007; Wells, 2004). For the purpose of this paper, particularly the environmental dimensions deserve attention.

It was massive smog and congestion in Los Angeles that prompted the California Air Resource Board to implement its pioneering zero-emission vehicle (ZEV) programme in 1990. Its aim was to gradually increase the number of low-emission vehicles (LEVs) in California. Subsequently, other U.S. states and other countries began adopting similar programs intended to spur LEV development. Countries offered incentives for the commercialisation of LEVs—Japan, for example, promoted battery-electric vehicles (Åhman, 2006)—or created platforms stimulating LEV development, such as the Partnership for a New Generation Vehicle in the U.S. In this context, carmakers increasingly started to engage in sustainable technologies, also because climate change became of concern to the industry (Kolk & Levy, 2004). From the mid-2000s onwards, with rising environmental awareness and spikes in oil prices, attention for hybrid vehicles emerged, and EVs followed suit, although in a more limited way. In 2008 the global financial crisis put further pressure on carmakers, because it required governments to implement bail-out plans for the industry to prevent massive job losses. The U.S. government, for example, launched the Advanced Technology Vehicles Manufacturing loan programme, with USD 25 billion for green technologies, for which carmakers could also apply. In the UK, the Automotive Assistance Programme provided GBP 2.3 billion of loans and loan guarantees for R&D and production of green vehicles. Both programmes intended to bail out the industry while stimulating the development of EV technologies, thus trying to kill two birds with one stone (cf. Kolk and Pinkse, 2009).

Over the past years, several government support initiatives have emerged; a selection of tax incentives in various countries is summarised in Table 6.2. Many governments want to promote EVs: Germany, for example, intends to have 1 million EVs on the road by 2020: the French government aims to purchase 50,000 EVs; and the UK is also active in stimulating EV technologies through various initiatives. Moreover, China has actively promoted EVs and made USD 15 billion available for their development, while the U.S. Electric Vehicle Deployment Act of 2010 supports the introduction of EVs and plug-in hybrids in the U.S., promoting research in batteries and infrastructure, providing loans for infrastructure and funding for the creation of a secondary battery market, including scrappage.

Table 6.2: Government support initiatives related to EVs

Country	Type	Incentive	Specification	Ends in/amount available
Belgium	Tax credit	$ 12,545.30	30 percent of the purchase price of an EV deductable	-
Netherlands	Registration tax exemption	$ 8,921.10	registration tax	2010
China	Rebate	$ 8,785.00	only in urban areas, price paid to the carmaker to reduce the price	will be reduced when 50,000 cars are sold
Spain	Tax credit	$ 8,363.53	in various regions	-
UK	Rebate	$ 8,096.50	GBP 5000 rebate of up to 25 percent of the price of the car; no circulation tax	GBP 230 million
U.S.	Tax credit	$ 7,500.00	based on battery capacity	After 200,000 cars have been sold per manufacturer
France	Tax credit	$ 6,969.61	up to 20 percent of the price of the car (Bonus-Malus system)	2012
Ireland	Registration tax exemption	$ 3,484.81	Maximum amount	2010
Japan	Subsidy	$ 1,212.56	for the purchase of a new car	USD 3.7 billion
Czech Republic	Road tax	Free	-	-
Denmark	Registration tax	Free	for cars up to 2,000 kg	-
Germany	Circulation Tax	Free	-	-
Greece	Registration tax	Free	-	-
Portugal	Registration tax	Free	-	-

**Sources*: ACEA (http://www.acea.be/images/uploads/files/20100420_EV_tax_overview.pdf), New York Times (http://wheels.blogs.nytimes.com/2010/06/02/china-to-start-pilot-program-providing-subsidies-for-electric-cars-and-hybrids/), U.S. Department of Energy (http://www.afdc.energy.gov/afdc/laws/laws/US/tech/3270), JAMA (http://jama.org/pdf/FactSheet10-2009-09-24.pdf), last accessed 3 August 2011.

Coinciding with this government support, carmakers have increasingly engaged in EV projects. Table 6.3 provides an overview of 19 EV projects for the commercialisation of EVs. Up to 2010, a considerable number of carmakers (10) have been active in that regard, including several incumbents as well as a few start-ups. Six cars were launched for sale in (niche or mainstream) markets, while four were made available for small test markets only. Projects most often targeted the U.S., followed by Japan and the EU. Most firms did not develop or commercialise a purpose-built electric vehicle, but used an available mainstream market model and equipped it with an electric motor (11). Only three firms—GM, Think and Renault-Nissan—developed and commercialised a purpose-built EV. While many carmakers engage in the commercialisation of EVs, most of them focus on small-scale projects. They build a small series of EVs, such as Toyota and BMW, or have them produced through a third-party provider, as Ford and Daimler did. Only a handful of firms have already begun EV production on a considerable scale: GM (Chevy Volt), Tesla (Roadster), Think (City), Nissan (Leaf) and Mitsubishi (iMiev) (see Table 6.4). These firms have developed purpose-built and production-ready electric vehicles with dedicated production sites. Their intended production volumes range from 1,000 cars a year (Tesla Roadster) up to 500,000 a year (Nissan Leaf).

Table 6.3: Main EV projects found in the period until 2010

Carmaker organized by area of origin	**Model** (EV Type)	**Electric range** (approx.)	**Scale of availability** (C=Concept T=Test M=Mass production)	**Target market**	**Available** (since)	**Country(ies) of availability**
U.S.						
GM	Chevy Volt (PIHV)	56 km	M	Mainstream	Yes (2010)	U.S.
Ford	Transit (EV)	130 km	T	-	Yes (2010)	U.S.
Chrysler	Chrysler (EV)	64 km	C	-	-	-
Tesla	Roadster (EV)	300 km	M	Niche	Yes (2010)	>28
Fisker	Karma (PIHV)	80 km	C	-	-	-
Europe						
Daimler	Smart EV	135 km	T	-	Yes (2010)	U.S.
BMW	MINI EV	160 km	T	-	Yes (2009)	U.S.
VW	E Up EV	-	C	-	-	-
Renault	Fluence Z.E.	160km	C	-	-	-
Peugeot	iOn*	160 km	M*	Mainstream	Yes (2010)	UK
THINK	City EV	160 km	M	Niche	Yes (2010)	EU
Asia						
Toyota	Prius PIHV	20 km	C	-	-	-
Honda	EN-V concept	-	C	-	-	-
Nissan	Leaf	120 km	M	Mainstream	Yes (2010)	Japan, U.S.
Subaru	Stella EV	90 km	T	-	Yes (2009)	Japan
Mitsubishi	iMiev	160 km	M	Mainstream	Yes (2009)	Japan
Rest of Asia						
BYD	E6 (EV)	300 km	C	-	-	-
Chery	S18 (EV)	150 km	C	-	-	-
Hyundai	BlueWill (PIHV)	-	C	-	-	-

PIHV: Plug-In Hybrid Vehicle; EV: Electric Vehicle

* Rebadged, based on the Mitsubishi iMiev, also for Peugeot's brand Citroen as the C-Zero

Table 6.4: Larger-scale EV ventures already available

	Vehicle	**Available since**	**Location of availability**	**Own production site**	**Price in USD**	**Production plan** (FY = First year; EP = Eventual production volume per year)
Nissan	Leaf	2010	Japan, U.S.	Yes	32,780	FY: 13,000 EP: 500,000
GM	Chevy Volt	2010	U.S.	Yes	41,000	FY: 10,000 EP: 100,000
Mitsubishi	iMiev	2009	Japan	Yes	30,700	FY: 1,400 EP: 55,000
THINK	City	2010	8 countries including the U.S., EU	No*	30,000 after incentives	FY: 2,500 EP: 20,000
Tesla	Roadster	2008	28+ countries including the U.S.	Yes**	98,000	FY: 1,000 EP: 2,000

* The City is currently being built by Valmet, Finland, and in Elkhart, Indiana in Think's own plant.

** The Roadster is built largely in the UK; the Model S will be built at Tesla's production plant NUMMI, California.

6.4.2 From the ICE to an EV Business Model: Exploring Policies, Assets and Governance

It has been argued that technological differences between the ICE and EV will have implications for the business model to commercialise EVs on a sizable scale, because the higher costs and limited driving range form barriers to market acceptance (Kley et al., 2011). The decisive difference between electric vehicles and vehicles with an ICE is the propulsion technology: an EV has an electric engine with a battery while the ICE uses petrol. This

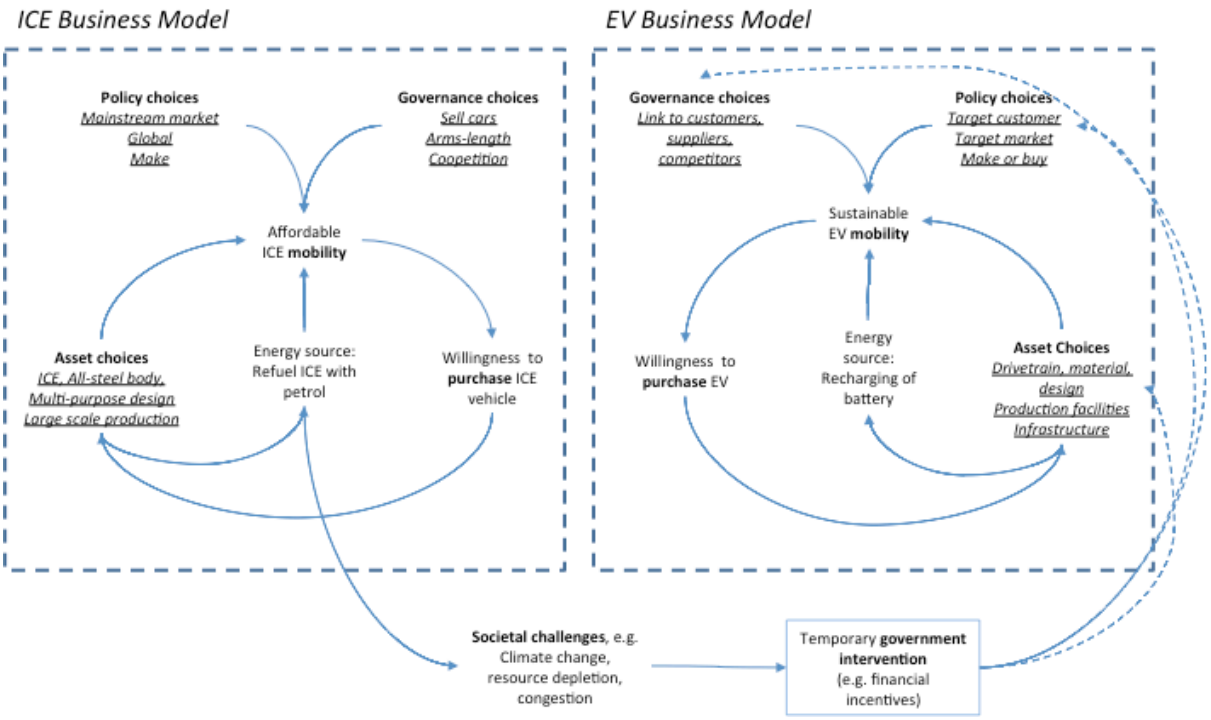
difference in propulsion has a considerable impact on the functioning of cars (Chan, 2007).

First, the electric drivetrain alters driving characteristics such as torque, sound and feel of the car, which changes customers' driving experience. Power is available immediately and equally at all speeds, which improves acceleration. The electric engine is close to mute so that EVs' main sound originates from the tires on the road and from wind (this silence also entails safety issues for other traffic users, who no longer hear cars coming). Currently, however, the energy density of batteries is less than that of petrol, lowering the range of EVs to about 200 kilometres, with recharging requiring up to eight hours.

Second, the power issue has implications for production and design. The all-steel body of ICE cars—while being safe and cost-efficient to produce—is heavy and reduces the driving range of EVs if applied unaltered. Consequently, lightweight materials are required. EVs' range can be enhanced by reducing redundancy in the multi-purpose design, for instance by developing specific purpose-design EVs such as two-seaters for cities. This would have consequences for the economies of scale, however. Third, low power of the batteries also has implications for the infrastructure and causes new recharging patterns. EV owners need to use an electric cord, charge more often, and for a longer duration. Besides, the battery is a costly component (about USD 10,000).

To explore main implications of these technological differences, Figure 6.1 shows a representation of the prevailing ICE business model and a stylized picture of an emerging EV business model (underlined elements are choices, non-underlined elements are consequences), in terms of policy, asset, and governance choices (cf. Casadesus-Masanell & Ricart, 2010). On the left side, which shows the ICE business model prevailing amongst incumbents, mainstream customers are targeted on a global scale and firms produce cars themselves (policy choice). They produce multi-purpose cars in high-output production facilities (asset choice), which are developed and produced collaboratively with suppliers and competitors, and sold or leased as a whole to customers (governance choice). These choices have resulted in an affordable ICE-based mobility system that stimulates customers' buying decisions, and which is firmly rooted in a widespread petrol-station network warranting refuelling possibilities.

Figure 6.1: Comparison of the ICE and EV business models



In the emerging EV business model (right hand side of Figure 6.1), carmakers need to reconsider policy, asset and governance choices to design a competitive business model that enables sustainable EV mobility, addresses infrastructure issues and triggers customers' willingness to buy. Firms face questions regarding policy choices, such as the target customer and market as well as whether to make or buy EVs. Moreover, they encounter asset choices, considering the drivetrain, material and design, production facilities and infrastructure issues. Lastly, there are governance choices referring to different ways to establish linkages with customers, suppliers and other producers. Due to the technological challenges and delivery issues of EVs, firms are pushed into the direction of providing additional services, such as leasing batteries, that continue after the purchase of the vehicle has taken place—this is rather different than the ICE business model (Kley et al., 2011). To help shed more light on the components of a possible EV business model, we will below present the strategic choices carmakers seem to have been making so far, as reflected in their decisions about policies, assets and governance, also considering the role of government support.

Policy Choices: Customers, Markets and Production

Policy choices refer to decisions regarding which *customers* to target (niche; mainstream), which *geographic markets* to enter (local; international), and whether to *make or buy* (in-

house; outsourced). We will explore these aspects consecutively, illustrated with examples from our analysis, and explicitly considering government support; Table 6.5 summarises main policy choices found for the firms in the sample.

Table 6.5: Policy choices in business models

Carmaker by region of origin	**Model** (EV Type)	**Scale of availability** (C=Concept T=Test M=Mass production)	**Target market**	**Country(ies) of availability**	**Make or buy**
U.S.					
GM	Chevy Volt (PIHV)	M	Mainstream	U.S.	Make
Ford	Transit (EV)	T	-	U.S.	Buy
Chrysler	Chrysler (EV)	C	-	-	Buy
Tesla	Roadster (EV)	M	Niche	>28	Make
Fisker	Karma (PIHV)	C	-	-	Make
Europe					
Daimler	Smart EV	T	-	U.S.	Make
BMW	MINI EV	T	-	U.S.	Make
VW	E Up EV	C	-	-	-
Renault	Fluence Z.E.	C	-	-	Make
Peugeot	iON*	M*	Mainstream	UK	Buy
THINK	City EV	M	Niche	EU	Make
Asia					
Toyota	Prius PIHV	C	-	-	Make
Honda	EN-V concept	C	-	-	-
Nissan	Leaf	M	Mainstream	Japan, U.S.	Make
Subaru	Stella EV	T	-	Japan	Make
Mitsubishi	iMiev	M	Mainstream	Japan	Make

PIHV: Plug-In Hybrid Vehicle; EV: Electric Vehicle

First, the *customer* choice is not only crucial for how to position the car, but also for subsequent choices of markets, technology and infrastructure. We found different approaches here, with entrepreneurs predominantly targeting niche markets on their own. California-based start-up Tesla, for example, developed a luxury EV—the Roadster—for more than USD 100,000 on the basis of an existing Lotus sports car. Their target customers are not very price-sensitive; they use the car largely for pleasure and usually have a garage where they can recharge it. Tesla can therefore charge the extra costs of the expensive EV propulsion system; the limited range of EVs is also less important and lack of infrastructure forms no real constraint. Tesla has not depended on government support for the Roadster. Still, it is also developing a new model, the Model S for USD 50,000, that targets the upper mainstream market; a purpose-built sedan EV for which it requested and received government support.

Rather differently, GM decided to develop an electric car for the mainstream market. The firm estimated the price of the Volt to be around USD 40,000 due to its expensive batteries. Their customers are price sensitive; they require a sufficient range and need a recharging infrastructure. Already in 2008, when GM presented the concept version of the Chevy Volt, it began pushing for subsidies. Martin, spokesman of GM, commented: “We

need to make sure the legislative language does include extended-range electric vehicles" (LaReau, 2008: 1). The Volt qualified for the full tax credit for EVs in the U.S. worth USD 7,500, eventually.

The majority of the cases in our sample, however, tried EVs only on a small scale, most often in test settings, such as Daimler with the Smart EV in London or BMW with the Mini E in California. In these cases, customers were often utilities, other firms, or a selected group of people. For example, for the Mini E, only 400 customers in California were allowed to test the vehicle.

In addition to deciding which customers to target in general, carmakers also need to take a decision about specific *geographic target markets*. Mitsubishi, for example, decided to commercialise the full-EV iMiev first in Japan, the home market, as it was close to the development and production site. This allowed the firm to gain experience with the technology, learn from this commercialisation process and then develop capabilities for a larger rollout to other markets. Only after having passed through this first phase in 2009 did Mitsubishi move outside Japan in the subsequent year. This lag was also due to the fact that Mitsubishi needed to develop left-hand-drive cars first. GM's Volt was also first available in the U.S. only.

By contrast, Nissan commercialised the Leaf internationally right away. In fact, the first Leaf was sold in the U.S., not in the firm's home country Japan. Besides being a large market for Nissan, generous subsidies made available by the U.S. federal government and by individual states appeared to have furthered this early internationalisation. Nissan's U.S. website provides a comprehensive list and calculation tool which factors in all available incentives considering one's postal code. This allows customers to calculate the price and become aware of the various incentives to thus stimulate them to buy the car. As subsidies seem to play a considerable role in the (initial) viability of an EV business model, a good insight into what is available is crucial, as noted by Nissan's product planning director for the Nissan Leaf: "Nissan obviously doesn't want to be penalized for bringing our car in at an [un]competitive price"; "There are a lot of offerings out there from states and municipalities. […] Our mission is to bring them all to the consumer's attention" (Chappell, 2010a: 4). Nissan's CEO, Mr. Ghosn, stated: "Two years of government support are needed to jump-start these markets, and then the products will grow on their own and take off" (Guilford, 2010: 6). He also indicated that profitability without subsidies would require annual sales of 1 million Leafs.

After the U.S. government launched the Advanced Technology Vehicles

Manufacturing Loan Programme following the 2008 financial crisis, various firms applied for funding for the development of EVs. Think, a small-scale Norwegian EV producer, received a loan from the U.S. Department of Energy. Before this ATVM programme was in place, the company had sold its cars in Spain, the Netherlands and Austria. Using the funding, Think started to internationalise and built production facilities for 20,000 cars per year in Elkhart, Indiana, to sell the small two-seater Think in the U.S. as well. The suggested retail price of the Think was USD 35,500, but including a discount from Think, as well as federal and state credits of USD 10,000, the 'pint-sized' car would cost USD 22,500. Think initially targeted 15 cities in the U.S. However, the 123-inch (3.12 m) car is even shorter than a Mini Cooper and also needs additional technical adjustments to be allowed for sale in the U.S. Thus, despite the generous incentives—which still left the car more expensive than an average passenger car—the Think City was ill-fitted for U.S. traffic.

The third policy choice is whether to *make or buy*; that is, develop and produce the EVs in-house or buy the technology (partly) from suppliers and have the EVs (co-)produced by third parties. Only a few incumbents committed to mass production of EVs in-house: i.e. GM, Renault-Nissan, and Mitsubishi. Besides building on available resources and capabilities, they also committed to large investments to develop and produce key EV components in-house, such as batteries, power control systems and engines. GM's CEO, Akerson, stated to see these as "core competences" (Barkholz, 2010: 8). "This needs to be a core General Motors technology. […] Back in 2002 and 2003 we saw hybrid motors as a niche product with low volume. Since then it has become obvious that vehicles are going to become increasingly electrified and motors are going to be critically important" (Chappell, 2010b: 4)

Incumbents that were only testing the technology either engaged third-party firms to produce the EVs or converted existing vehicles. Ford, for example, decided to have the Ford Transit (a transporter) converted to an EV by Azure Dynamics Corporation. This reflected Ford's expectation about sales: "Very low, a handful of vehicles, but a handful of vehicles for very significant customers. […] We think a reasonable expectation is 1,000 vehicles per year" (Kranz, 2010: 8). Chrysler was also moderately ambitious about EVs, but after the takeover by Fiat, it cancelled its ENVI project that intended a large-scale rollout of EVs and decided to test 140 RAM EVs. Peugeot entered into a strategic alliance with Mitsubishi and ordered 100,000 iMievs for four years. The cars will be sold rebadged as the Peugeot iON or Citroen C-ZERO. Tesla decided to use the chassis and most of the technology of the Lotus roadster, and converted a mainstream model into an electric vehicle. Tesla's value added

focused particularly on the electric control system that deployed established battery technology used in laptops.

Asset Choices: Facilities, Technology and Infrastructure

Asset choices refer to actions regarding tangible resources, such as *manufacturing facilities* (dedicated plant; same assembly line), a particular *technology* (full EV; range extender) and *infrastructure* preferences (standard; proprietary). Below we will give some illustrative examples how firms in our sample approached these three components, and how government support seems to have shaped their choices.

As mentioned above already, only a few firms decided for *mass production* of EVs. This included Fisker, which received two development funds from the U.S. Department of Energy (amounting to USD 169 million and USD 359 million respectively) that it used to develop two purpose-built EV models: the Karma and the Nina. The Karma is a luxury plug-in with a range extender; the Nina a small hybrid vehicle. Initially, Fisker intended to outsource production to Valmet in Finland, a firm specialised in low-volume production and luxury vehicles. However, as the DOE only allowed spending the money in the U.S., Fisker had to comply with these requirements: it thus raised additional private capital and looked for a place to produce in the U.S. to be able to profit from government support. However, the annual output of 20,000 cars is far below the economically viable number, looking at economies of scale calculations for the industry.

Another example is Nissan's decision-making concerning the location of production for its Leaf, next to its EV production in Japan. To persuade Nissan to also produce the Leaf in the UK, where the firm already had a plant in Sunderland, the UK government offered to extend existing loans, declared the region a low-carbon economic area and decided to put more than 1,300 charging stations in place. In response, Nissan committed to building facilities to produce 50,000 cars per year in Sunderland, as the only assembly plant for Nissan's EVs in Europe. Usually, key components are produced close to the main assembly of cars, as they tend to be heavy and this warrants in time delivery. However, because the Portuguese government provided Nissan with support for EVs (a grant for the production, infrastructure for recharging, and the promise to switch a considerable part of the government fleet to EVs), the firm decided to build a GBP 200m battery plant in Portugal to produce the 300 kg heavy battery and ship them to the UK, even though this increased overall (transportation) costs and uncertainty.

Technology is another key choice in relation to EVs. GM's decision for an EV with a range extender was informed by its previous EV project, the EV1, which was developed and manufactured in the 1990s as the world's first mass-produced EV. Production seized due to low demand, insufficient infrastructure and high costs, however. The Volt was designed to address these problems. It is equipped with a range extender which solves the infrastructure and range issue and is therefore expected to result in higher demand as drivers do not need to fear running out of electricity. Nonetheless, this approach also adds considerable costs to the car. Compared to the Leaf and iMiev, the Volt is the most expensive EV. Just before the launch, GM revealed that the backup engine would also directly propel the wheels, which essentially means that the Volt is a plug-in hybrid. However, GM insists that the Volt is an EV, presumably to be able to qualify for higher incentives of governments.

Rather differently, Toyota is developing a plug-in hybrid vehicle version of its Prius. The key difference is that the primary source of power remains the ICE, not an electric engine. Consequently, the all-electric range is limited to about 20 km. Although the car fails to qualify for the highest incentives, it is enhancing Toyota's competences in hybrids. Interestingly, Mitsubishi regarded EVs as an alternative to investing in hybrid technology in which competitors such as Toyota had a strong lead; this is presented as a way to leapfrog hybrid technology and gain a green and innovative halo.

A final asset choice involves *infrastructure*, which refers to recharging in particular. For the prevailing ICE technology the infrastructure is available, but this is not the case for EVs, which need to be recharged at the plug. To make EVs attractive to the mainstream market, a nationwide infrastructure is necessary.[3] GM solved the infrastructure problem by adding a range extender to the Volt. Yet, full EVs are dependent on a widespread network of recharging stations and this still needs to be developed. Nissan has a team that promotes the full EV Leaf and lobbies governments in the U.S. for infrastructure and financial support. It collaborates with eight cities, regions and states to develop recharging infrastructure, and concomitant power-grid planning and policies, as well as with the U.S. Department of Energy to improve recharging stations for projects such as one in Phoenix where 12,500 recharging stations are planned.

Taking a somewhat different approach, Renault-Nissan partners with Better Place, a start-up from California, which builds a battery-swapping and fast-charging infrastructure in

[3] EVs can be plugged in at home like any electronic device and be recharged. However, this requires owners to have a garage. Moreover, even though recharging at home might be possible, the limited range necessitates recharging possibilities on the road.

various countries such as Israel, Denmark, and Australia. Better Place customers do not own their EVs' batteries but rather pay per km. Renault-Nissan has an exclusive agreement with Better Place to supply the vehicles in Israel. Other carmakers rely on the recharging infrastructure put in place by utilities or governments. This means that sales areas are by and large limited to locations where infrastructure is in place; not those that would be commercially optimal. For example, as the performance of batteries decreases with cold temperatures, cities such as Miami or Madrid would by suitable for EVs. Nevertheless, London and Amsterdam (cities with longer colder periods) are ones that have infrastructure in place. Thus, EV producers are rather dependent on governments to fulfil their promises and thus take decisions that seem far from optimal in economic terms.

Governance Choices: Links to Customers, Suppliers and Competitors

Governance choices depict the contractual decisions about asset and policy choices, such as the *link to customers* (selling; leasing; tenders), *suppliers* (arm-length; collaboration), and *competitors* (collaboration; competition; coopetition). As previous examples showed, tax incentives have been crucial for carmakers to commercialise EVs somewhat more competitively, as production costs exceed customers' willingness to pay. For customers, a comparably-sized car with an ICE is the reference point. This means that with the traditional payment model, in which customers pay the entire costs of the vehicle, EVs require support.

Some carmakers have therefore chosen to change the traditional *link to customers*. Commonly, a car is sold or leased to the customer as a complete product. For EVs, however, carmakers have started to sell the car independent from the battery. In such a set-up, batteries can be rented for a monthly fee, thus provide an additional source of income for the carmaker, while considerably reducing the price of the EV given that the battery is an expensive item. Firms such as Think also integrate insurance and electricity consumption in the monthly payment for the battery, calling it a "mobility pack", thus creating additional revenue streams. Moreover, it should be noted that EV producers receive a disproportionally large share of contracts from fleet owners and governments. If governments purchase a certain number of EVs, this increases volumes and thus allows for a larger scale and for more certainty in planning. For example, Renault-Nissan obtained a contract from the Israeli government for the delivery of 100,000 Fluence Z.E. cars. The French government indicated that it aims to purchase 100,000 EVs, the Portuguese government requires 20 percent of all its public vehicle purchases to be EVs, while the Japanese government urged the national

post to convert its fleet of 21,000 cars to EVs.

The development of EVs has also forced carmakers to collaborate with new *suppliers* for electric engines, batteries and other components, as well as with infrastructure providers. They have had to rethink the value of these relationships, however, in relation to what supplies are essential for a newly emerging EV business model. While still sourcing parts from suppliers, GM, for example, has decided to develop its own proprietary technology for batteries and engines as these are regarded as future sources of competitive advantage. Nissan mainly produces key components in-house. Mitsubishi, however, produces the battery through its joint venture with GS Yuasa, which also supplies to other carmakers such as Honda. The smaller entrepreneurial firms source relatively larger parts of their cars from suppliers. For its Roadster, for example, Tesla converts a Lotus and also sources batteries. As mentioned above, Tesla's core capability appears to be the control system of the batteries.

A final choice faced by EV producers concerns the *link to competitors*. If we look at the firms in our sample, Mitsubishi collaborates with Peugeot in its EV venture (and beyond). The French carmaker ordered 100,000 cars over 4 years, which it intends to sell rebadged. This strategy allows Peugeot to sell EVs, gain an innovative and green image this way, while circumventing the risk of investing in a technology itself that might not be successful. At the same time, it gives Mitsubishi more scale, planning certainty and a lead in the technology.

Rather differently, government incentives stimulated Tesla's collaboration with incumbents that have remained inactive with regard to EVs in somewhat unexpected ways. The State of California mandated that seven of the largest incumbents needed to sell 7,500 zero-emission vehicles and 60,000 low-emission vehicles by 2012. Every carmaker can earn credits per ZEV sold. Small firms like Tesla are exempted from that requirement, yet they are allowed to earn credits. The credits are estimated to be worth USD 5,000. One Tesla Roadster earns four credits which equals approximately USD 20,000 per car as these credits can be traded. Honda, for example, has bought credits from Tesla equivalent to 368 cars, and ordered credits of another 287 cars. Other incumbents also bought credits from Tesla, but details were not disclosed. Other small EV producers, such as Aptera, also applied this strategy, but in smaller numbers.

6.5 Discussion and conclusions

At the background of the general challenges that firms face with regard to a change to more sustainable technologies, this paper set out to understand the role of business model

innovation for the commercialisation of such technologies. Where the extant literature has particularly focused on the technology and system attributes of sustainable innovation (Hall & Martin, 2005; Hall & Vredenburg, 2003; Jacobsson & Bergek, 2004), we paid attention to the needs for changing existing business models to bring emerging sustainable technologies to the market (cf. Chesbrough, 2007). While it has been argued that there is a role for both incumbents and new entrants in a sustainability transformation of fossil fuel-based industries (Hockerts & Wüstenhagen, 2010), new entrants tend to be relatively less constrained by past performance and decision-making (Zott & Amit, 2007). Hence, our study considered the influence of path dependencies on business model design of sustainable technologies. It also took account of the so-called "double externality problem" of sustainable technologies if they create value for society as a whole that cannot be captured by firms. To address this issue and stimulate sustainable innovation, governments often provide support in the first stages of development and concomitant business model design (Lepak et al., 2007; Rennings, 2000).

We aimed to contribute to the emergent literature on business models (Zott et al., 2011) by an empirical exploration of the influence of path dependencies and government support on business model design (cf. Chesbrough, 2010) in the case of electric vehicles. Moreover, with the analysis of car firms' strategic choices about policies, assets and governance in the move towards a business model for EVs, the paper contributes to the sustainable innovation literature (Hall & Vredenburg, 2003; Hockerts & Wüstenhagen, 2010; Schaltegger & Wagner, 2011) by shedding light into the way in which technology and system attributes (e.g. limited driving range due to inadequate battery technology and lack of refuelling infrastructure) may 'translate' into a specific business model design for commercialising sustainable technologies. While business model innovation could in principle help to retain market attractiveness despite the technological and systemic challenges of sustainable technologies (Kley et al., 2011), our findings suggest that path dependencies and government support might create incentives to stay (too) close to prevailing commercialisation approaches, or steer firms in the direction of uneconomic choices, respectively.

6.5.1 Discussion of findings

Our findings show that incumbents and start-ups or entrepreneurial new entrants in the car industry approach business model design rather differently; a difference which might be explained from the fact that incumbents are more constrained by path dependencies than new

entrants (Zott & Amit, 2007). Entrepreneurial firms such as Tesla and Better Place introduced disruptive concepts—concurring with the 'incumbent's curse' (Chandy & Tellis, 2000)—and thus seem to change the prevalent business model in the car industry. Tesla, for example, targeted the luxury niche market and found customers who are willing to pay a premium for an electric sports car. Better Place, by introducing a mobile phone payment method for electric cars, aimed to provide a solution for the range and recharging challenges. Think leased the battery separately from selling the car, thus trying to achieve competitive pricing for the car while generating revenues through a mobility option.

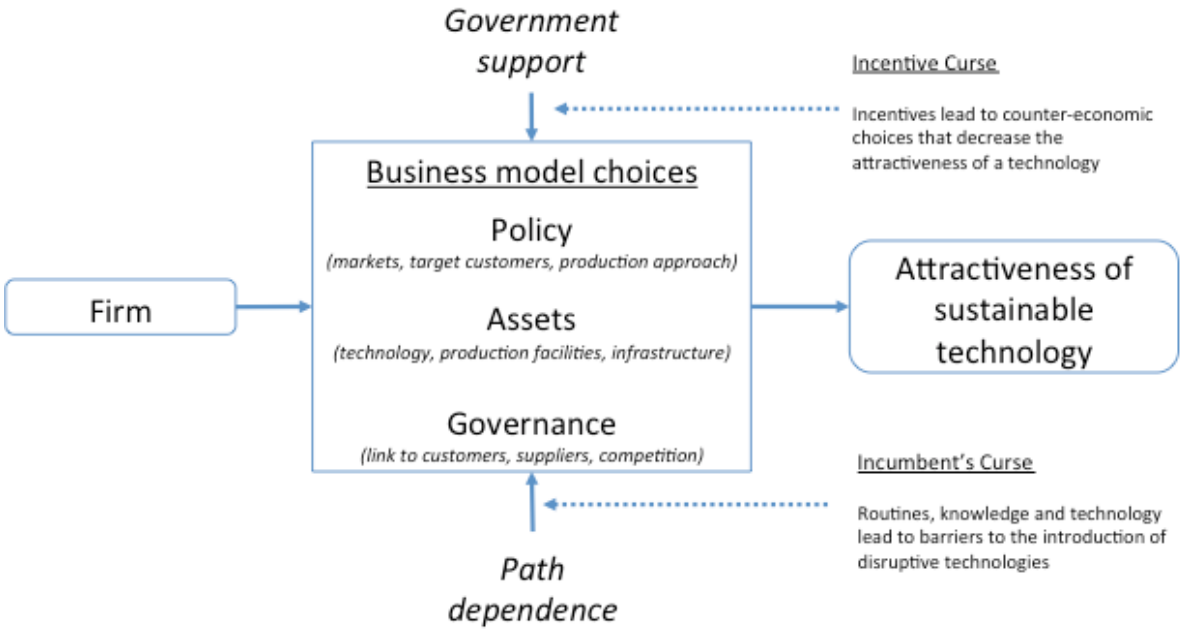
The entrepreneurial firms in the sample that attempted new business models predominantly followed a novelty-based approach (Zott & Amit, 2007). That is, rather than competing with incumbents head-on, the new entrants preferred to design new transaction mechanisms—e.g. in the form of leasing the battery separately—that targeted customers in distinctive ways and that involved collaboration with incumbents. While the relative 'success' or failure is something that cannot be assessed at this stage, the case of Better Place seems to contain the largest degree of 'novelty' in this regard. Its business model with a mobile phone payment method increases a customer's switching costs and the provision of an infrastructure instead of (car) manufacturing allows the firm to cooperate, not to compete, with incumbents, as seen in the exclusive agreement with Renault-Nissan.

Overall, incumbents in the car industry still seem rather hesitant to introduce a potentially disruptive technology like the EV; only three of them engaged in EV mass production. The few that did engage in EVs stayed close to familiar technologies, such as GM with its Volt based on a range extender or Toyota that upgraded its existing Prius hybrid, and commercialised them through familiar business models (Ahuja & Lampert, 2001). These incumbents thus tend to follow an efficiency-centred rather than a novelty-centred business model (Zott & Amit, 2007). A recurrent theme was incumbents' aim to achieve efficiency by leveraging existing assets and by creating a much larger scale than their entrepreneurial counterparts. It has been argued, however, that "[f]irms that follow traditional resource-driven reconfiguration, assuming that demonstrated capabilities may be leveraged to novel opportunities, may find themselves unable to find or adapt to novel opportunities" (Bock et al., 2012: 300). In other words, a strong attachment to existing asset configurations reduces a firm's flexibility to experiment with novelty-centred business models.

The choice for efficiency-centred business models may be explained by looking at the history and thus the path dependencies of the firms (see Figure 6.2). Due to its history with the EV1, GM's dominant logic appears to be that full EVs are not viable, which seems to

have influenced its decision for a range extender; this also enabled the company to build on its resources and capabilities related to the ICE. Nissan decided to produce the Leaf in the UK based on its geographical asset configuration (Zott & Amit, 2007), while Mitsubishi's arrears in hybrids facilitated the move to try full EVs instead. Nevertheless, incumbents have also tried to pick up some of the entrepreneurial ideas embodied in the novelty-centred business models of the new entrants. Renault-Nissan considered selling the battery separately and partnered with Better Place; Porsche announced an EV sports car; and both Toyota and Daimler bought a share in Tesla. Hence, the argument that entrepreneurial firms lay the groundwork for incumbents in a sustainability transformation of an industry seems to be reflected in some of the developments in our case (Hockerts & Wüstenhagen, 2010).

Figure 6.2: Business model design for sustainable innovations



A dimension that has not been considered yet with regard to (choices in) business model design is the effect of government intervention. In their attempts to 'compensate' for the double externality problem of sustainable technologies, governments have been shown to affect companies' behaviour (Rennings, 2000), which also came to the fore in our study. Nissan built a plant for key components in another country than where it already had production facilities due to government support. GM developed a technology that, while alleviating customers' range anxiety, is (too) expensive for the mainstream market. In addition, firms also received loans and funding for manufacturing facilities that seemed to

stimulate commercialisation of EVs in cold areas where the technology performs suboptimal. The impact of government support sometimes also influenced new entrants. For example, Think commercialised mini-EV cars in the U.S., which apparent lacked success as the company had to file for bankruptcy in 2011 (in the period after our empirical data collection had taken place).

Various countries and U.S. states provided support for EVs to reduce the high costs, providing seemingly essential support to compensate for value that benefits society but not the individual firm (Lepak et al., 2007). Although the compensation intended to improve EVs' attractiveness, these examples also appear to indicate that, due to the incentives, firms have made some counter-economic choices. While it is still too early to judge the effect on the future success of EVs, the findings raise doubts about whether the geographically localised nature of most government incentives leads firms to take the best decision for their internationally organized supply chain (Pinkse & Kolk, 2011). While international incumbent firms in particular have more options to utilise different forms of local government support, this may well be an 'incentive curse' as well.

This phenomenon also points at complexities and even trade-offs for managers, who on the one hand prefer generic innovation policies rather than incentives for specific technologies or programmes (cf. Rubenstein et al., 1977) while they, on the other hand, lobby and vie for incentives, even though the effect may be counterproductive, also at the firm level, beyond the immediate benefits. Even these can be questioned, however. Purchasing incentives for hybrids in the U.S., for example, turned out to have had a weak relationship to sales (Diamond, 2009). This is something that requires further research, however, as follow-up to our exploratory study.

6.5.2 Limitations and future research

Although our findings suggest that path dependencies and government support affect firms' strategic choices about policies, assets and governance in the move towards a business model for EVs, they have to be taken with caution as most EV business models are still in their formative stages and have not yet reached a definite design. Despite a growing interest in EVs in the car industry, most firms still seem to struggle with issues such as range and lack of infrastructure. We could thus merely observe first contours of emergent EV business models, also because our data was restricted to a five-year period. Tracking further developments in EV business model design is therefore worth further investigation, especially because the

global financial crisis and economic recession has not (yet) led major car firms to drop their EV plans; to the contrary, the number of incumbents moving in this direction have only increased since the period covered in this study.

Although we were able to collect and analyse vast amounts of data, the industry trade and car magazines that were used as main sources are all based in the U.S. Despite their global orientation, it might be that these magazines missed some developments in Europe and/or the Asia-Pacific region. For Europe in particular, the inclusion of the Financial Times was a counterbalance, but this outlet contains less details on the car industry. There were also limitations in identifying all the components of a business model from the information provided by the magazines and newspaper, as this is not their main aim. To address this problem as good as possible, we decided to the follow Casadesus-Masanell and Ricart (2010) and consider a business model as emerging from firms' policy, asset and governance choices, which were easier to track.

Finally, as mentioned above already, relating government policies and/or historical decisions to firms' strategic choices can only be done provisionally. We have tried to establish linkages in a qualitative way through a process of pattern matching and comparing empirically-based patterns with relevant theoretical concepts (Yin, 2009). Future research could build on this, however, using quantitative coding techniques instead, to track and establish relationships based on statistical methods, perhaps supplemented with in-depth industry and expert interviews. And where we focused on path dependencies and government supports as possible explanatory variables, a quantitative approach would also allow inclusion of a wider set of factors that might have played a role.

6.5.3 Implications of the study

This paper aimed to understand the influence of path dependence and government interventions on business model design for emerging sustainable innovations. More specifically, we explored how firms on the one hand handle the so-called 'incumbent's curse' and on the other hand deal with consequences of government support, what might be labelled the 'incentive curse'. Our study suggests that, despite the potentially disruptive nature of the technology, incumbents' interest in and choices related to EVs has been influenced considerably by government support programmes. Nevertheless, it also seems that government intervention can result in counter-economic choices of incumbents and new entrants, raising doubts about the effectiveness of such support in the longer run. This also

leads to the question of whether firms, and incumbents in particular, should follow government incentives so readily, and when they do, how far they should go along with all the additional requirements that are part-and-parcel of such support programmes. This is line with Spencer et al. (2005), who stated that companies should avoid engaging in new industry formation that is contingent on government support.

Still, there might be value in government support provided it is handled with caution. One suggestion might be for companies that intend to commercialise a disruptive sustainable technology to be wary of an incumbent business model, and not become too dependent on government support. Partnering with entrepreneurial firms that have introduced innovative business models may assist in addressing the incumbent's curse to some extent. Regarding the available government incentives, firms could consider to try to 'skim' the benefits, and only use those parts that remain an add-on to a business model that has a clear potential to become sound in economic terms under normal circumstances as well. Government incentives often seem to limit strategic options, distract from key issues, and lure firms into investments with a potential lock-in effect. However, using government incentives might also be a calculated risk to partially offset the costs of creating a green or innovative halo effect. To avoid the risk of the incentive curse, managers might want to establish a 'walk away price', i.e. to determine the costs that the company is willing to bear for the introduction of the sustainable product. These are issues that require further in-depth assessment based on additional research as well, however.

References

Åhman, M. (2006). Government policy and the development of electric vehicles in Japan. *Energy Policy*, *34*(4), 433–443.

Ahuja, G., & Lampert, C. M. (2001). Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. *Strategic Management Journal*, *22*(6-7), 521–543.

Baden-Fuller, C., & Morgan, M. S. (2010). Business Models as Models. *Long Range Planning*, *43*(2-3), 156–171.

Barkholz, D. (2010). Engineers wanted: GM will add 1,000 to work on electrification. *Automotive News*, *85*(6441), 8.

Björkdahl, J. (2009). Technology cross-fertilization and the business model: The case of integrating ICTs in mechanical engineering products. *Research Policy*, *38*(9), 1468–1477.

Bock, A. J., Opsahl, T., George, G., & Gann, D. M. (2012). The Effects of Culture and Structure on Strategic Flexibility during Business Model Innovation. *Journal of Management Studies*, *49*(2), 279–305.

Bouchikhi, H., & Kimberly, J. R. (2003). Escaping the identity trap. *MIT Sloan Management Review*, (Spring), 20–26.

Casadesus-Masanell, R., & Ricart, J. E. (2010). From Strategy to Business Models and onto Tactics. *Long Range Planning*, *43*(2-3), 195–215.

Chan, C. C. (2007). The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles. *Proceedings of the IEEE*, *95*(4), 704–718.

Chandy, R. K., & Tellis, G. J. (2000). The incumbent's curse? Incumbency, size, and radical product innovation. *The Journal of Marketing*, *64*(3), 1–17.

Chappell, L. (2010a). Spiffs will slice price of Nissan EV. *Automotive News*, *84*(6408), 4.

Chappell, L. (2010b). Supplier fumes as carmakers take electric motors in-house. *Automotive News*, *84*(6417), 4.

Chesbrough, H. W. (2007). Business model innovation: it's not just about technology anymore. *Strategy & Leadership*, *35*(6), 12–17.

Chesbrough, H. W. (2010). Business Model Innovation: Opportunities and Barriers. *Long Range Planning*, *43*(2-3), 354–363.

Chesbrough, H. W., & Rosenbloom, R. S. (2002). The role of the business model in capturing value from innovation : evidence from Xerox Corporation ' s technology spin-off companies, *11*(3), 529–555.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Christensen, C., & Bower, J. (1996). Customer power, strategic investment, and the failure of leading firms. *Strategic Management Journal*, *17*(3), 197–218.

Danneels, E. (2004). Disruptive Technology Reconsidered: A Critique and Research Agenda. *Journal of Product Innovation Management*, *21*(4), 246–258.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy*, *37*(3), 972–983.

Doganova, L., & Eyquem-Renault, M. (2009). What do business models do? *Research Policy*, *38*(10), 1559–1570.

Dubois, A., & Gadde, L.-E. (2002). Systematic combining: an abductive approach to case research. *Journal of Business Research*, *55*(7), 553–560.

Guilford, D. (2010). For EVs, key number is price, not range. *Automotive News*, *85*(6436), 6.

Hall, J. K., & Martin, M. J. C. (2005). Disruptive technologies, stakeholders and the innovation value-added chain: a framework for evaluating radical technology development. *R&D Management*, *35*(3), 273–284.

Hall, J., & Vredenburg, H. (2003). The Challenges of Innovating for Sustainable Development. *MIT Sloan Management Review*, *45*(1), 61–68.

Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic alignment equipment industry. *The RAND Journal of Economics*, *24*(2), 248–270.

Hockerts, K., & Wüstenhagen, R. (2010). Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. *Journal of Business Venturing*, *25*(5), 481–492.

Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and Corporate Change*, *13*(5), 815–849.

Johnson, M. W., Christensen, C. M., & Kagermann, H. (2008). Reinventing your business model. *Harvard Business Review*, *December*, 57–67.

Johnson, M. W., & Suskewicz, J. (2009). How to Jump-start the clean-tech economy. *Harvard Business Review*, *November*, 52–60.

Kley, F., Lerch, C., & Dallinger, D. (2011). New business models for electric cars — A holistic approach. *Energy Policy*, *39*(6), 3392–3403.

Kolk, A., & Levy, D. L. (2004). Multinationals and global climate change: issue for the automotive and oil industries. In S. M. Lundan (Ed.), *Multinationals, Environment and Global Competition* (pp. 171–193). Amsterdam: Elsevier.

Kranz, R. (2010). Ford plans electric Transit Connect. *Automotive News*, *84*(6399), 8.

LaReau, J. (2008). GM seeks Volt tax break to avoid $40k sticker. *Automotive News*, *82*(6309), 1–55.

Lepak, D. P., Smith, K. G., & Taylor, M. S. (2007). Value creation and value capture: A multilevel perspective. *Academy of Management Review*, *32*(1), 180–194.

Magretta, J. (2002). Why business models matter. *Harvard Business Review*, *80*(5), 86–93.

Mintzberg, H., & Waters, J. (1985). Of strategies, deliberate and emergent. *Strategic Management Journal*, *6*(3), 257–272.

Mitchell, D., & Coles, C. (2003). The ultimate competitive advantage of continuing business model innovation. *Journal of Business Strategy*, *24*(5), 15–21.

Nidumolu, R., Prahalad, C., & Rangaswami, M. (2009). Why sustainability is now the key driver of innovation. *Harvard Business Review*, *87*(9), 56–64.

Orsato, R. J., & Wells, P. (2007). U-turn: the rise and demise of the automobile industry. *Journal of Cleaner Production*, *15*(11-12), 994–1006.

Pilkington, A., Dyerson, R., & Tissier, O. (2002). The electric vehicle: Patent data as indicators of technological development. *World Patent Information*, *24*(1), 5–12.

Pinkse, J., & Kolk, A. (2011). Multinational enterprises and climate change: Exploring institutional failures and embeddedness. *Journal of International Business Studies*, *43*(3), 332–341.

Prahalad, C. K., & Bettis, R. A. (1986). The Dominant Logic: A New Linkage between Diversity and Performance. *Strategic Management Journal*, *7*(6), 485–501.

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332.

Rubenstein, A. H., Douds, C. F., Geschka, H., Kawase, T., Miller, J. P., Saintpaul, R., & Watkins, D. (1977). Management perceptions of government incentives to technological innovation in England, France, West Germany and Japan. *Research Policy*, *6*(4), 324–357.

Schaltegger, S., & Wagner, M. (2011). Sustainable entrepreneurship and sustainability innovation: categories and interactions. *Business Strategy and the Environment*, *20*(4), 222–237.

Shafer, S., Smith, H., & Linder, J. (2005). The power of business models. *Business Horizons*, *48*(3), 199–207.

Spencer, J. W., Murtha, T. P., & Lenway, S. A. (2005). How governments matter to new industry creation. *The Academy of Management Review*, *30*(2), 321–337.

Strauss, A. L., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage.

Teece, D. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning*, *43*(2-3), 172–194.

Unruh, G. (2000). Understanding carbon lock-in. *Energy Policy*, *28*(12), 817–830.

Vergne, J.-P., & Durand, R. (2010). The Missing Link Between the Theory and Empirics of Path Dependence: Conceptual Clarification, Testability Issue, and Methodological Implications. *Journal of Management Studies*, *47*, 736–759.

Wells, P. (2004). Business Models : The Case of the Automotive Industry. *IIMB Management Review*, *16*(4), 15–24.

Wells, Peter, & Nieuwenhuis, P. (2006). Business models for relocalisation to deliver sustainability. *Greener Management International*, *47*, 89–98.

Yin, R. K. (2009). *Case study research: Design and methods* (2nd ed.). Newbury Park, CA: Sage.

Zott, C., & Amit, R. (2007). Business Model Design and the Performance of Entrepreneurial Firms. *Organization Science*, *18*(2), 181–199.

Zott, C., & Amit, R. (2010). Business Model Design: An Activity System Perspective. *Long Range Planning*, *43*(2-3), 216–226.

Zott, C., Amit, R., & Massa, L. (2011). The Business Model: Recent Developments and Future Research. *Journal of Management*, *37*(4), 1019–1042.

7 Exploring incumbent motivations for producing electric vehicles

7.1 Introduction

The previous chapters have explored the evolution of low-emission vehicles (LEVs) from different perspectives, predominantly examining the interplay between car manufacturers and policy developments. Chapters 2 and 3 set the stage by giving an overview of the car industry, introducing the emerging alternatives to the internal combustion engine (ICE) and presenting the perspectives of car manufacturers and policy makers on LEVs. Chapter 4 looked at how LEVs evolved internationally, considering the interplay of car firm's innovation strategies and global policies. Chapter 5 investigated the role of public and private protection mechanisms in the development and commercialization of LEVs. Next, Chapter 6 examined business models for electric vehicles (EVs) by incumbents and new entrants in light of path dependencies and government incentives.

The findings of the preceding chapters point out various factors that impeded incumbents in the car industry from engaging in LEVs, let alone producing them on a large scale beyond concept/test cars and for niche markets: Incumbents focused on incremental product innovation (Chapter 2) and were averse to technological change (Chapter 3). The complexity of global LEV policies posed uncertainties regarding future technological developments (Chapter 4). Higher production costs of LEVs relative to ICE cars required subsidies from public and private actors (Chapter 5). And, finally, path dependencies and government incentives constrained incumbents to conceive new business models for EVs that may have induced managers to take counter-economic decisions (Chapter 6).

Nevertheless, incumbents in the industry invested in LEVs. Chapter 4 described the phases in the evolution of LEVs and showed that hybrid vehicles (HVs) established their position in the product portfolio of car manufacturers over time and are now mass-produced by many incumbents. On the contrary, fuel-cell vehicles (FCs) were tested in several demonstration projects and proved to be not economically viable, mainly due to high costs and a lack of infrastructure. Intriguingly, EVs followed a different trajectory. EVs went through two periods in which incumbents invested in them. However, after an initial exploration phase of EVs in the 1990s, EV development lost momentum (Chapter 4). For example, GM launched the first mass-produced purpose-built EV, but soon afterward stopped

its engagement and scrapped all cars (Chapter 5). EVs faced several problems, such as a short driving range, long recharging times and a different driving experience compared to a car with an ICE. Most importantly, they were too expensive to produce which, in the absence of government incentives, made them unattractive for mainstream consumers and poor business propositions for producers. Surprisingly, various car manufacturers began engaging in EVs again, beginning in 2006, despite the problems remaining largely unresolved (Chapter 4). Chapter 6 revealed that a few incumbents—GM, Nissan and Mitsubishi—re-engaged in the large scale production of EVs, yet left details about their underlying reasons unexplained. This raises the question why these firms committed vast resources to the development and commercialization of EVs while the majority of the incumbents refrained and only developed concept cars, prototypes or test cars.

Previous chapters have explained the engagement of car firms in LEVs mainly with the influence of government policies (Chapters 4 and 5). While policies were a key driver for LEV engagement, the firm's motivations were more varied. Specifically, the strategic motivations of car firms have been underexplored in previous chapters. To gain more nuanced insights into the reasons why incumbents invested in the production of EVs, this chapter theoretically and empirically studies a firm's motivations to engage. Scholars have suggested that first-mover advantages, CSR activities, policy pre-emption and/or organizational decline stimulate engagement in sustainable technologies such as EVs (Ambec & Lanoie, 2008; Kemp, Schot, & Hoogma, 1998; Mone, McKinley, & Barker, 1998; Pinkse & Kolk, 2009; Rennings, 2000; Trahms, Ndofor, & Sirmon, 2013; Van den Hoed, 2007). Based on an exploratory multiple-case study, the findings of this chapter corroborate these motivations. Moreover, the results indicate that perceptions about the EV market also influenced their EV engagement.

This chapter is structured as follows: in the theory section, the challenges car manufacturers face when commercializing EVs are depicted and the potential motivations that stimulate incumbents to engage in EVs nevertheless are discussed. The approach applied to analyze the data is described in the subsequent section. Next, an overview of all the incumbents that developed EVs is presented, and their perceptions using case studies of three firms that produced EVs on a large scale are explored. The subsequent section examines whether the empirical findings confirm the theoretically developed motivations. Finally, the discussion section reflects on the motivations, presents managerial implications, and discusses limitations and directions for future research.

7.2 Value slippage of EVs

Electric vehicles (EVs) have received increasing public attention over the past several years since they hold the promise of alleviating various societal challenges: EVs can be a carbon-free technology if charged with electricity from renewable sources, they can reduce dependence on oil and increase energy security, and they have the potential to mitigate climate change (Tate, Harpster, & Savagian, 2008). Although some scholars have raised the question whether EVs are, in fact sustainable due to the high amounts of energy and rare-earth metals required for their production, and due to the limitation that their use is only sustainable if the electricity is supplied by renewable sources (see Chapter 3), EVs are often regarded as a sustainable technology (Hockerts & Wüstenhagen, 2010).

Despite their environmental credentials, EVs have not yet been brought to the market on a large scale. With the current available technology and the incumbent business model, they are not attractive to consumers when compared to cars with an ICE (see Chapter 6). The prices for EVs are simply too high a disadvantage compounded by their short driving range, long recharging times, and unfamiliar driving experience. Production costs for EVs are substantially higher than those of comparable conventional vehicles with an ICE (Kley, Lerch, & Dallinger, 2011). Car firms and industry insiders believe that many customers are not willing to pay the premium: "When they find out how much a green vehicle is going to cost, their altruistic inclination declines considerably […] People definitely think with their wallet" states J.D. Powers, a leading automotive consultancy (Automotive News, 85(6436), 2010, p. 6). While EVs may produce benefits for society as a whole, these benefits are seldom valued by the customer. Customers are often not willing to pay for the additional costs. Therefore, car manufacturers are unlikely to recover the full development and production costs of EVs from a mainstream customer—a process coined 'value slippage' (Lepak, Smith, & Taylor, 2007). Value slippage occurs if "value created by one source or at one level of analysis may be captured at another" (Lepak et al., 2007: 181). Thus, for EVs a share of the value created by a firm slips to society. As a result, the majority of car manufacturers have refrained from producing EVs.

Characterizing and quantifying 'value slippage' is complicated by the fact that value is subjective and context-specific. Individuals perceive value differently and are influenced by their situation (Lepak et al., 2007). Bowman and Ambrosini (2000) suggest that the perceived worthiness on an individual level results from "the specific qualities of the product perceived by customers in relation to their needs," which is called 'use value' (Bowman & Ambrosini,

2000: 2). For example, a car provides both mobility and a unique experience to individuals, which, together, define its use value. The use value determines the price a customer is willing to pay and thus the value a firm can capture. The difference between the captured (i.e. paid for by the consumer) use value and the costs of creating the product generates rents for firms (Bowman & Ambrosini, 2000). Yet, in the case of EVs, the costs of value creation exceed the 'use value' for most customers—e.g., the additional costs of electric cars compared to those with an internal combustion engine. The additional costs can be attributed to the technology's potential for generating societal value that stems from not emitting polluting particles.

Although some customers claim they are willing to pay for the societal value (e.g. in surveys), very few really do, a phenomenon known as the consumer attitude-action gap (Lane & Potter, 2007). This also complicates estimating the use value of an EV. Because firms have insufficient real market experience with EVs and because of the consumer attitude-action gap, it is difficult for managers to determine what the use value of an EV might be for a customer. Therefore, managers often have to rely on their perceptions and vision about the market. This is necessary for innovative, so-called market driving firms, which are firms that introduce radical new products or processes and in doing so "gain a more sustainable competitive advantage by delivering a leap in customer value" (Kumar, Scheer, & Kotler, 2000: 129). Kumar et al. (2000: 132) claim that "customers are usually unable to conceptualize or readily visualize the benefits of revolutionary products, concepts, and technologies […] Market driving firms instead coalesce around vision." Consequently, this chapter explores managers' perceptions of the use value that EVs may have (or not) for customers rather than looking at (individual) customers.

7.3 Motivations to engage in EVs

Considering the value slippage of EVs, what stimulates incumbents to engage in them? Scholars have studied such motivations to develop and commercialize sustainable technologies such as EVs (Schaltegger & Wagner, 2011) and have conceptualized the process of how firms engage in sustainable innovation (Hockerts & Wüstenhagen, 2010). Several studies provide evidence that incumbents can be a source of sustainable innovation (Ahuja & Lampert, 2001; Hockerts & Wüstenhagen, 2010; Méthe, Swaminathan, & Mitchell, 1996). Yet, what are the motivations to invest in sustainable technologies in the face of value slippage? The existing literature suggests four main factors that are potentially at play.

First, incumbents often innovate in order to gain a first-mover advantage (Lieberman & Montgomery, 1988). By being the first to launch a sustainable product, the innovator may yield technological leadership which might allow an eventual increase in its market share (Van den Hoed, 2007). A case in point is Toyota, which gained a first-mover advantage with its introduction of the hybrid Prius (Porter & Kramer, 2006). Moreover, by anticipating and seizing opportunities from climate change, firms may be able to achieve a competitive advantage (Hoffman, 2005; Pinkse & Kolk, 2009). Additionally, if applicable, the pre-emption of scarce resources may create an advantage. Car manufacturers, for example, can secure rare earth metals for its production of batteries through backward integration. Last, a first-mover advantage can create switching costs for consumers. This might be the case if EV manufacturers create industry standards with regard to recharging infrastructure.

Second, incumbents may invest in sustainable innovations as part of their corporate social responsibility (CSR) activities (Ambec & Lanoie, 2008). Different concepts and perceptions have emerged around the notion of CSR (Bassen, Jastram, & Meyer, 2005; Carroll, 1999; Kolk, 2010). Broadly the literature may be separated into two streams (Kolk, 2010). One line of literature, known as the 'beyond compliance' perspective, would suggest that socially responsible firms may invest in sustainable innovations to contribute to society and enhance quality of life (WBCSD, 2000). Another body of literature would argue that engaging in CSR and investing in sustainable innovation may lead to a competitive advantage (Porter & Van der Linde, 1995), to a better reputation (Rindova et al., 2005), or to increased access to markets (Ambec & Lanoie, 2008). Thus, investing in sustainable innovations such as EVs may be part of firms' aspiration to contribute to society and 'doing well while doing good' while at the same time using these innovations as strategic moves to enhance their competitiveness.

Third, incumbents may invest in sustainable innovations to pre-empt government policies. In other words, firms may invest in sustainable innovation because they anticipate future regulation (Nidumolu, Prahalad, & Rangaswami, 2009) and want to pre-empt more stringent regulation (Van den Hoed, 2005). Sceptics have argued, for example, that the commitments car manufacturers made to fuel cell technologies were merely 'window-dressing' to prevent more stringent regulation (Van den Hoed, 2005). Consequently, Van den Hoed (2005: 271) suggests a more nuanced perspective, arguing that investments were "balancing the pressures from external stakeholders (regulators, consumers, competitors) and internal barriers for innovation in uncertain technologies." Thus, pre-emptive behaviour—

next to already explained government incentives (see Chapters 4, 5 and 6)—could stimulate incumbents to engage in sustainable technologies.

Finally, investing in sustainable innovations may be part of a strategic turnaround to prevent organizational decline (Ba, Lisic, Liu, & Stallaert, 2012; Hofer, 1980; Pearce II & Robbins, 1993; Trahms et al., 2013). Recent research on green product innovation in the car industry found that stock markets not just reacted positively if manufacturers invested in green technologies, but even progressively more positively the less profitable a firm was at the outset of the investment (Ba et al., 2012). "Investors expect automakers that are doing well with existing business to concentrate on their existing business and less profitable automakers to find a competitive edge through green vehicle innovations" (Ba et al., 2012: 25). Two schools of thought have emerged to explain innovative reactions to organizational decline. On the one hand, the 'necessity is the mother of rigidity' stream argues that organizations become less inventive in situations of decline. On the other hand, the 'necessity is the mother of invention' stream argues that troubled situations induce innovation (Bolton, 1993; Mone et al., 1998; Trahms et al., 2013). The latter 'strategic change' perspective claims that firms will offer new products or services in reaction to organizational decline (Ketchen & Palmer, 1999). Firms engage in strategic change when a troubled situation is controllable and permanent, and when the organization has enough slack resources, sufficient top-management support and is flexible in adapting its mission (Mone et al., 1998). If these conditions are not fulfilled, organizations are not likely to implement strategic changes and instead react with routines firms are familiar with, such as cost savings (Mone et al., 1998).

In summary, first-mover advantages, CSR activities, policy pre-emption and organizational decline may motivate incumbents to invest in sustainable innovations such as EVs. Most incumbents in the car industry only developed concept cars or conducted small tests. This raises the question why some car firms invested in the large-scale production of EVs but other car manufacturers refrained from doing so. To shed light on the underlying reasons, the remainder of this chapter will empirically describe the developments in the industry in general and explore the motivations of the three incumbents to engage in mass production of EVs in particular.

7.4 Methodology

To analyze the motivations to engage in EV mass production, I used the same methodology as explained in Chapter 6, i.e. the same case-study approach, case selection and data collection.

I adopted a three-step approach (cf. Bourgeois & Eisenhardt, 1988). First, I tracked all EV projects from 2006 to 2010 found in the database. Plug-in hybrids were included given that they can drive on battery power for an extended range (>20 km). The database was compiled using a keyword search using search terms referring to plug-in and EV technologies in two industry trade magazines (*Automotive News* and *WardsAuto World)*, a car magazine (*Autoweek*), and the *Financial Times*. EV projects were classified as being in a concept, test, or mass production stage. Concepts are used to present technologies or designs but are not intended for production. It should be noted that, in this study, concepts and prototypes were aggregated, with both terms being used interchangeably because the analysis suggested blurring boundaries between concept cars and prototypes. Prototypes are usually the preliminary models of a new car to experiment with novel technologies. However, concepts were also often used to assess new technologies. Test cars encompass vehicles that are examined under controlled, real-world conditions to learn from and improve the technology based on a wider test group. Mass-produced cars were assumed when car manufacturers had a dedicated production line in place for standardized products.

Subsequently, I analyzed the motivations of the car firms that either invested at each stage by examining their generic, production, development, commercialization and government strategies, as well as their opinions of EVs and the expected market size. These results were compared with the initial coding and refined accordingly.

7.5 EV industry overview

In the following sections, I will examine the EV engagements of incumbents from 2006 until 2010 and depict the diverging EV market expectations of car manufacturers. Next, I present the cases of three firms—General Motors, Nissan and Mitsubishi—which were the only incumbents that prepared for EV mass production, and explore their reasons for doing so.

As described in Chapters 4 and 6, EVs have experienced a revival since 2006. Numerous incumbents have invested in EV technologies again since then. However, most of them focused on concepts or test cars (see Table 7.1). Out of 65 EVs, 49 were prototypes or concepts, 13 were test cars and only 3 went into production.

Table 7.1: Car manufacturers' engagement in electric vehicles and plug-in vehicles

Car manufacturers	Concept/prototype of EV or PI-EV	Test of EV or PI-EV	Purpose-built mass produced EV or PI-EV
U.S. origin			
Chrysler	6	-	-
Ford	2	2	-
General Motors	7	2	1
European origin			
BMW	2	2	-
Daimler	5	2	-
Fiat	1	-	-
Peugeot	2	-	-
Renault	4	-	-
Volvo	1	-	-
VW	3	-	-
Asian origin			
BYD	3	1	-
Great Wall Motors	1	-	-
Honda	1	-	-
Hyundai	1	-	-
Mitsubishi	1	1	1
Nissan	4	2	1
Subaru	-	1	-
Suzuki	1	-	-
Tata	1	-	-
Toyota	3	2	-
Grand Total	**49**	**13**	**3**

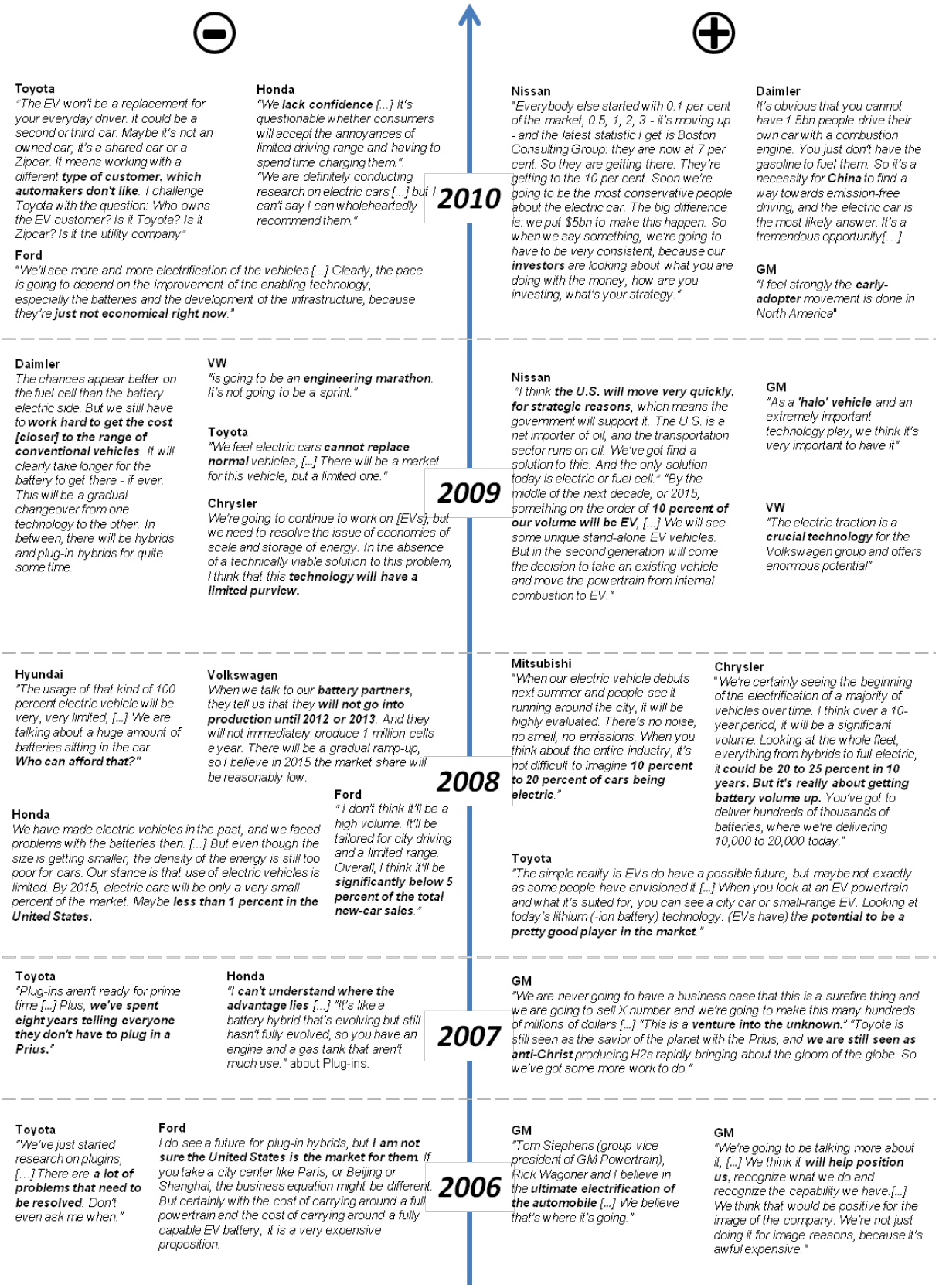
The majority of the incumbents built concepts or prototypes. For instance, incumbents such as Chrysler, Renault or BYD presented several concept cars, learned about technologies and gained some green credentials. Some incumbents also produced test cars. Ford (Focus EV), BMW (Mini E) and Daimler (E-Smart) tested EVs in controlled environments, received feedback from test customers and improved its reputation for being sustainable. Often these cars were modified conventional vehicles built in small series, or were produced or modified through a third-party provider (see Chapter 6). Nonetheless, a few incumbents have begun mass production—namely GM (Chevy Volt), Nissan (Leaf) and Mitsubishi (iMiev) (see Table 7.1). These firms have developed purpose-built and production-ready electric vehicles and have dedicated production sites. Their intended production volumes started at 55,000 cars per year (Mitsubishi iMiev) up to 500,000 a year (Nissan Leaf) (see Chapter 6). The three incumbents, GM, Nissan and Mitsubishi targeted the mainstream market with their EVs. Thus, these firms were the only ones that invested in EVs on a large scale.

Why did a few car manufacturers engage in mass production while most car manufacturers only presented concepts or tested a limited number of EVs? The analysis of the empirical data revealed that perceptions of the EV market differed. On the one hand, the

majority of incumbents doubted whether the market was ready for EVs. These incumbents were content to present concepts or conduct tests. The three incumbents, however, had a more positive perception. Interestingly, some firms had ‘conflicting’ perceptions, i.e. they exposed negative and positive perceptions at the same time. Toyota, for instance was mostly doubtful about the applicability of EVs, but also admitted that EVs could have the potential to enter the market on a larger scale in the future. Daimler pointed to the barriers EVs generally face but also conceded the opportunity for EVs in the Chinese market as an option to circumvent petrol supply shortages and reduce CO_2 emissions. Furthermore, while regarding EVs as a crucial technology, Volkswagen (VW) acknowledged that it will take long for EVs to enter the market on a larger scale.

Figure 7.1 shows illustrative quotes of incumbents’ EV market perceptions as found in the analysis. It gives an overview of statements made by firm representatives in public in the period 2006-2010, divided into negative market expectations (left side of the figure) and positive ones (right side). In the Figure I put some parts in bold to highlight the core themes of the quotes and to enhance clarity.

Figure 7.1: Illustrative quotes of incumbents' EV market perceptions over time



The majority of the incumbents wondered whether EVs would be the ideal technology. Honda and Daimler believed that fuel-cell vehicles would provide a better long-term solution than EVs. Honda, though, expected fuel-cell cars to be the future: “The ultimate electric car will have to be the fuel cell vehicle. Battery-based electric vehicles aren’t really practical at this point in time” (Automotive News, 83(6332), 2008, p. 24). Daimler was also more convinced of the success of fuel-cell vehicles: “The chances appear better on the fuel cell than the battery electric side” (Automotive News, 84(6380), 2010, p. 9). Hyundai had doubts about the practicality and cost of the battery: “The usage of that kind of 100 percent electric vehicle will be very, very limited. […] We are talking about a huge amount of batteries sitting in the car. Who can afford that?” (Automotive News, 83(6327), 2008, p. 8). Honda pointed to the practicality of using EVs: “It’s questionable whether consumers will accept the annoyances of limited driving range and having to spend time charging them" (Automotive News, 84(6413), 2010, p. 38). Toyota saw some promise, but doubted whether EVs would, in fact, be able to replace vehicles with an internal combustion engine: “We feel electric cars cannot replace normal vehicles. […] There will be a market for this vehicle, but a limited one” (Reed, 2010).

Expectations of incumbents with regard to when EVs would leave the niche status (if at all) also varied considerably. VW and Ford had doubts about whether the market would be large enough in the future. VW regarded EVs as having a distant timeline and believed that bringing EVs to the market would be “an engineering marathon. It’s not going to be a sprint. […] Electric powertrains […] will be "a supplement" to internal combustion engines. […] [B]y 2020 EVs will have a global share of 1.5 to 2 percent” (Automotive News, 84(6378), 2009, p. 3). Ford agreed that due to its characteristics, EVs would remain a niche product as Ford’s Gerhard Schmidt, vice president of research and advanced engineering, stated: “I don’t think it’ll be a high volume. It’ll be tailored for city driving and a limited range. Overall, I think it’ll be significantly below 5 percent of the total new-car sales” (Automotive News, 83(6332), 2008, p. 22). Honda concurred with this scepticism of the technology and argued that investing in EVs would be risky.

While Figure 7.1 illustrates the divide in the industry, it also shows that differences are more nuanced and can alter over time. Although Toyota was pessimistic about EVs in most years, the firm also acknowledged in 2007 that “EVs do have a possible future, but maybe not exactly as some people have envisioned it” (WardsAuto World, 12(5), 2008, p. 11). Toyota developed three concept cars (e.g. the Toyota FT-EV) and tested two cars (e.g. the Toyota Plug-in) (see Chapter 4). In a similar vein, Daimler was mostly in favour of fuel-cell technology (see Chapter 5), but also later tested EVs. The firm suggested that EVs would be

ideal for the Chinese market and saw an opportunity there (see Figure 7.1). Chrysler was notable in its disagreement with these assessments. Its Vice-President estimated in 2008 that the market for EVs could make up to 25 percent of the total market in the future and that large scale commercialization was mainly deterred by battery production capacity. However, in 2009, its CEO stated the opposite, claiming that it would take a long time for EVs to enter the market, if at all. Although the underlying reasons for the change in perception are unclear, it should be noted that the first statement was given at the beginning of the financial crisis just before Chrysler asked the government for a USD 7 billion loan, which was essential for Chrysler to survive. Government loans were pegged to the development of green vehicle development. The second statement was given just a month after Chrysler emerged from bankruptcy.

As already shown in Chapter 6, perceptions about EVs are path dependent. For instance, Toyota in 2007 argued that they educated their Prius customers that they would not need to charge the car. That was important to position the Prius like a conventional car and would reduce the barrier for customers. “We’ve spent eight years telling everyone they don’t have to plug in a Prius” (Automotive News, 82(6282), 2007, p. 50). An engagement in EVs would have required re-educating customers, which was unattractive for Toyota. What is more, experiences from previous EV projects still influenced car manufacturers. Throughout the period studied, Honda was sceptical about EVs due to their past experimentation with EVs for the ZEV programme (see Chapter 4). “We have made electric vehicles in the past, and we faced problems with the batteries then. The energy density in the battery was far below that in gasoline engines. Nowadays, the most advanced batteries are lithium ion batteries. But even though the size is getting smaller, the density of the energy is still too poor for cars. Our stance is that use of electric vehicles is limited” (Automotive News, 83(6332), 2008, p. 22). Incumbents such as Ford or Toyota that experimented with EVs before had similar perceptions (see Figure 7.1).

In contrast to the more cautious firms, the three incumbents GM, Nissan and Mitsubishi had very positive market expectations. While also acknowledging that EVs are most suitable for city use, Mitsubishi saw EVs as the ideal future technology, considering its environmental credentials: “When our electric vehicle debuts next summer and people see it running around the city, it will be highly evaluated. There's no noise, no smell, no emissions. When you think about the entire industry, it’s not difficult to imagine 10 percent to 20 percent of cars being electric” (Automotive News, 83(6334), 2008, p. 24). Nissan equally envisioned a large future market for EVs: “Electric vehicles could take 10 percent of the global market by

2020, or roughly 6 million units in annual sales. […] We see it as mass market" (Automotive News, 83(6372), 2009, p. 14). In a more nuanced way, GM asserted that EVs would become mainstream vehicles, yet not primary vehicles: "The mass market EV has to be CAPABLE [emphasis in original] of being your primary vehicle. […] I think pure battery electric vehicles—they're not going to be niche vehicles, but they're not going to be a primary vehicle" (Automotive News, 84(6417), 2010, p. 1). This perspective was informed by GM's previous less successful engagement in the EV1 (see Chapter 5). Therefore, GM's strategy was to develop an EV with a back-up ICE rather than an EV that relies on batteries only.

Moreover, the three incumbents saw EVs as the successor of hybrids. Nissan claimed that "there is a segment of eco-friendly consumers who are interested in going to the next level. They own a hybrid vehicle. But if the next step is available, they want to take it" (Automotive News, 84(6414), 2010, p. 6). Mitsubishi equally believed that their customers "have already had hybrids and are ready to make the next step" (Automotive News, 84(6420), 2010, p. 6). Last, GM's Bob Lutz believed "in the ultimate electrification of the automobile. […] We believe that's where it's going" (Automotive News, 81(6228), 2006, p. 6).

Certainly, the interpretation of these opinions requires caution as the opinions might be pure rhetoric to back the incumbents' (political) agendas and statements are also path-dependent and context-specific. For instance, Daimler has invested in fuel-cell technologies for almost two decades and has maintained a vested interest in that technology (see Chapter 5). For car manufacturers that invested in EVs, it is sensible to have a positive outlook and to popularize it. GM, for example, announced at the beginning of the decade that it would be the first car manufacturer to bring one million fuel-cell vehicles on the road. With the rise of EVs, the firm shifted its opinion and became a strong proponent of plug-in EV technology. However, the scope of this chapter does not allow me to analyze the rhetoric of car manufacturers in great detail. Regardless of whether the opinion follows the investment decision or vice versa, it still reflects a position and commitment to EVs that is central to the purpose of this chapter.

7.6 Profiles of EV forerunners: General Motors, Nissan & Mitsubishi

As mentioned above, most incumbents in the industry adopted a cautious strategy. They had modest market expectations for EVs and focused their attention on their main markets. General Motors, Nissan and Mitsubishi can be considered forerunners in EV

commercialization. In what follows, I provide a profile of the three firms with regard to their EV engagement.

General Motors

For most of the 20th century, Detroit-based General Motors was the world's largest car manufacturer. Along with GM's U.S. competitors, Ford and Chrysler, Toyota was the fiercest competitor striving for the position of the largest car manufacturer, and it eventually succeeded in overtaking GM in 2008. GM, among other reasons, failed to address trends towards more economical green cars and instead relied too much on producing 'gas-guzzlers.' GM's engagement in green technologies focused initially on electric vehicles (see Chapter 5). In the 1990s, the EV1 was the world's first purpose-built and mass-produced EV. However, due to lack of demand, GM discontinued the model, and customers had to return their cars to GM after the lease contract ended. GM also developed prototypes of fuel-cell cars, most notably the Sequel and the Autonomy.

In 2005, however, GM announced a shift in its strategy—to focus on fuel efficiency—for several reasons. First, GM faced financial distress due to increasing healthcare costs for unionized workers and decreasing sales, particularly of high-margin sport utility vehicles (SUVs). The U.S. government demanded that GM develop green technologies in order to receive loans that were essential for the firm to survive. Second, GM faced difficulty in meeting the Corporate Average Fuel Economy (CAFE) standards for its fleet in the U.S. which could result in penalties.

Therefore, GM decided to make changes in its product portfolio; on the one hand, it sold the brand Hummer which produced large fuel inefficient SUVs (e.g. the H2) and, on the other hand, GM began developing the Volt. Bob Lutz, GM's president of product development, called for an 'iCar,' hinting at Apple's successful product strategy in order to revive the firm. The 'Volt' was given top management priority. The firm argued: "As a 'halo' vehicle and an extremely important technology play, we think it's very important to have [the Volt]" (Reed, 2009) indicating the importance of the vehicle as part of their turnaround.

In 2006, GM presented the prototype of the Volt at the Detroit Motor Show. The Volt was announced as an electric vehicle with a range extender and seen as the much-needed saviour of GM. Building on the knowledge of producing EVs and the experience of the infrastructure challenge, GM decided to build an EV with a short range (40km) and to integrate a backup ICE to circumvent range fears and refuelling issues. Just before the launch, GM revealed that the backup engine could also directly propel the wheels, which essentially

meant that the Volt was a plug-in hybrid. That caused disappointment among car enthusiasts but did not impede the launch of the Volt in the Fall of 2010. The planned annual production capacity was about 10,000 in 2011 and 45,000 in 2012.

Nissan

In 2010, Nissan was part of Renault-Nissan, the world's third-largest car-producing group, headed by CEO Carlos Ghosn. When the alliance was initiated at the end of the 1990s, Nissan was in financial distress. Ghosn, who was at the time a manager at Renault, became the Chief Operating Officer of Nissan in 1999 (Magee, 2003) and promised a turnaround within three years. In fact, he was able to make Nissan profitable within a year and turned the firm into one of the most profitable firms in the industry. Subsequently, he became CEO of Nissan in 2001 and, in 2005, CEO of Renault-Nissan.

Despite being profitable, the firm still needed to re-establish its brand position as a technology leader and was seeking a green image. The CEO announced the importance of technology for Nissan. "Focused technology will once again be a pillar of Nissan's competitive strength [...] and the core of our brand identity" (Ghosn, 2007).

Before Nissan started to develop EVs, it engaged little in green propulsion technologies. In fact, for a long time, Ghosn had been a sceptic of hybrid technology. He particularly doubted the mass-market appeal. When, in 2006, the group announced its new strategy, the Nissan Green Program 2010, Ghosn (2007) announced his change of heart—that Nissan wanted to fulfil environmental expectations:

> 'Our most urgent R&D challenge today is to meet society's environmental expectations. That's why 40% of our budget for advanced engineering is devoted to Nissan Green Program 2010, our five-year environmental blueprint. For our industry, environmental sustainability represents the biggest engineering challenge. And no matter what you may hear, there is no silver bullet, no quick fix. In this race, the finish line is still nowhere in sight.'

Most notably, the program involved developing a test EV, building a Lithium Ion battery plant in a joint venture and reducing its CO_2 emissions from production activities by seven percent. In 2007, Nissan announced that it would bring an EV to the market by 2010. The firm committed about USD 5 billion to the development of EVs. The result was the Nissan Leaf, a full-sized, purpose-built EV with a range of 160 km. The car was launched in December 2010, with an initial production volume of 20,000 cars annually.

For the production of Lithium Ion batteries for the Leaf, Renault-Nissan established the joint venture Automotive Energy Supply Corp. with NEC in 2007. For the recharging infrastructure, the group collaborated with Better Place, a U.S. start-up that built battery-swapping stations and leased batteries to their customers. The car was planned to be produced in Japan in the Oppama plant south of Tokyo, in Europe in Sunderland, UK, and in the U.S. in Smyrna, Tennessee. The total planned production was larger than 200,000 EVs. Additionally, Nissan planned battery-producing plants in the U.S. and in Europe (see Chapter 6).

The Leaf was meant to establish Nissan's image as a technology leader. Nissan's top management argued that a shift away from styling and performance was a differentiator: "We think that innovation has bigger legs. It's a point of differentiation from Toyota and Honda" (Automotive News, 85(6434), 2010, p. 22). In other words, the Leaf was a means for Nissan to reposition the brand, to be perceived as distinct. The Leaf, as the firm's flagship project, enabled Nissan to credibly implement its program to become an environmentally-friendly firm with a technology focus. Furthermore, green technology also allowed the firm to improve its dealer network. Due to the Leaf, Nissan could establish a San Francisco dealer network, which had not been possible before. Nissan had more than 30 open dealer spots to fill. Because Californian consumers were considered more environmentally friendly, the Leaf made Nissan more attractive to franchise dealers and enabled the creation of the network. Overall, the Leaf was instrumental for Nissan's strategic turnaround. As Brian Carolin, Nissan's North American senior vice president for sales and marketing stated: "I think this car can act as a real halo for the Nissan brand. […] It can have a transformative effect on the Nissan brand and how people perceive us" (Automotive News, 84(6410), 2010, p. 6).

Mitsubishi Motors

The Japanese car manufacturer Mitsubishi is part of the Mitsubishi Keiretsu—the Mitsubishi Group of companies—and was the 16th-largest car manufacturer in 2010. In 2000, Daimler bought a 37 percent share in Mitsubishi while Mitsubishi was in financial distress. However, Mitsubishi's performance worsened, and Daimler sold its stake fully in 2005.

Mitsubishi faced three problems at the time. First, it faced losses for the third consecutive year. Second, it had to react to tightening CAFE standards in the U.S. due to their too high CAFE fleet average. CAFE standards prescribe the minimum fuel economy a car manufacturer's annual total sold cars need to achieve otherwise the firm faces penalties. And third, it had to compensate for its lack of knowledge in hybrid technology, in which its competitors had a lead. Therefore, the firm committed to EVs and announced that it was

planning to commercialize EVs by 2010. Before, Mitsubishi had engaged in green technologies only for small-scale projects. It was generally known for its capabilities in direct-injection engines and powertrains.

In 2007, Mitsubishi presented the iMiev concept (Mitsubishi innovative electric vehicle), a full EV with a range of 160 km. The car, which was based on a subcompact sedan, started to be produced in Japan. For the production of the Lithium Ion batteries, Mitsubishi entered into a joint venture with GS Yuasa. In 2009, Mitsubishi began selling the car to fleet customers in Japan and announced the launch in the U.S. for Fall 2011. What is more, Mitsubishi reached an agreement to supply Peugeot with 100,000 iMievs that the French manufacturer will sell rebadged as the Peugeot iOn.

Engaging in the full-EV iMiev promised to be a solution to all three problems faced by the firm. Mitsubishi leapfrogged its technology gap; EVs could compensate for deficiencies of their CAFE; and, by being perceived as innovative and green, the firm strove to increase sales and regain profitability. Also, Mitsubishi used the iMiev as a means to restore its shrinking dealer network in the U.S. and as a means for repositioning. The firm argued that the iMiev is one of the "new pillars for penetrating different markets" (Automotive News, 85(6433), 2010, p. 28).

7.7 Motivations of EV mass production

As mentioned above, scholars argue that firms engage in sustainable innovation to gain first-mover advantages (Lieberman & Montgomery, 1988; Pinkse & Kolk, 2009; Van den Hoed, 2007). Indeed, the empirical findings illustrate that the three case firms were seeking first-mover advantages (see Table 7.2). Nissan, for instance, intended to become the leading EV manufacturer by investing in the Leaf, arguing that "[t]his is an opportunity to go into a whole new technology and own that space" (Automotive News, 83(6367), 2009, p. 20). It regarded the Leaf as a means to newly position the firm as fast as possible: "We are going directly to zero-emissions vehicle positioning, and we are trying to go there as fast as we can" (Automotive News, 82(6309), 2008, p. 16).

Table 7.2: Motivations to engage in EVs, strategic decisions and outcomes

Firm	Motivations	Strategic decision	(Desired) outcomes
General Motors	*First-mover advantage* Catch up and overtake Toyota *CSR* Reputation for fuel inefficient cars, EV could help improve reputation *Policy pre-emption* GM was not going to meet U.S. CAFE standards, EVs could prevent CAFE fines *Organizational decline* Faced financial troubles, and needed government loans to survive	Invest in Volt Plug-in EV Divest Hummer brand	- Eligibility for government loans - More innovative and green image - Improve CAFE compliance - Halo effect
Nissan	*First-mover advantage* Become leader in EV technology *CSR* Lacked desired reputation *Policy pre-emption* Anticipate future regulation, particularly for urban areas *Organizational decline* Shrinking dealer network	Green Programme Invest in Leaf EV	- Positioning as a technological leader - First-mover advantage in EVs - Enhance dealer network - Halo effect
Mitsubishi	*First-mover advantage* Lacked technological knowledge in HV technology and intended to leapfrog HVs *Policy pre-emption* Feared to not meet U.S. CAFE standards *Organizational decline* Faced financial distress	Invest in iMiev EV	- Leapfrog hybrid technology - Improve CAFE compliance - Restore dealer network - Penetrate new markets

In a different way, Mitsubishi strove for a first-mover advantage as well. Due to resource constraints, Mitsubishi was unable to invest the same large sums in hybrid technology as its bigger rivals. To compensate for the lack of resources but still be a technological leader, the firm decided to invest in EVs. "We were not able to put all our resources into hybrids. […] We are climbing the mountain, but we are finding a different route to the summit" (Automotive News, 82(6279), 2007, p. 55). In a way, investing in EVs was a leapfrogging strategy against the hybrid technology. GM had again slightly different motivations. The U.S. incumbent saw its engagement in the Volt as a strategy against its fierce Japanese competitor Toyota. GM wanted to regain its leadership position in the industry. "Toyota is still seen as the saviour of the planet with the Prius, and we are still seen as anti-Christ producing H2s

[large sport-utility truck] rapidly bringing about the gloom of the globe. So we've got some more work to do" (Automotive News, 82(6273), 2007, p. 36).

Scholars have posited specific conditions required to gain first-mover advantages (Barczak, 1995; Golder & Tellis, 1993; Tetrault Sirsly & Lamertz, 2007). First-mover advantages require the right preconditions, namely firm resources and top-management support. The three firms made funds available and top management fully supported the projects for an extended period of time, which are necessary conditions to achieve first-mover advantages (Golder & Tellis, 1993). The case firms also either had the required knowledge for the EV technology due to previous projects or they obtained it externally through joint ventures. General Motors had knowledge from the EV1, while Nissan and Mitsubishi both liaised with battery suppliers. In addition, a first-mover advantage from sustainable innovations requires that a firm's investments not only fit the firm's mission, but also result in firm benefits and be successfully communicated to the public (Tetrault Sirsly & Lamertz, 2007). I found that all three firms communicated their efforts widely and also expected firm benefits (e.g., envisaged a growing market). Nonetheless, only in the case of Nissan was the Leaf project evidently aligned to the firm's mission. Interestingly, while striving for first-mover advantages, to some extent doing so forced other incumbents to engage in EVs. In order to be prepared for the uncertain case that EV mass production would be successful, the other incumbents began developing concepts or testing prototypes (Barczak, 1995).

Next, engaging in sustainable innovations can be part of a firms' CSR activities. CSR can arise due to institutional pressures on different levels (Aguilera et al., 2007), because of personal values of individual managers (Hemingway & Maclagan, 2004), or because of reputational or performance-driven motivations (Ambec & Lanoie, 2008; Porter & van der Linde, 1995). While EV-investing firms engaged in sustainable technology and also benefited from improved reputation, analysis reveals little evidence that the firms engaged as a result of their CSR activities. According to GM, Toyota gained an image of being green and innovative with the launch of the hybrid Prius. GM claimed that the halo effect that Toyota gained benefited the sales of their other models. Consequently, GM's CEO, Fritz Henderson in relation to the Volt asserted: "We think that would be positive for the image of the company" but also added that it is not solely for image, because it is "awful[ly] expensive" (Automotive News, 81(6231), 2006, p. 46). Thus, while reputation played a role, EVs were not necessarily a result of CSR activities, but rather it is regarded as a beneficial side effect and as a means to differentiate the firm.

The third motivation, policy pre-emption, did stimulate the EV engagement of the three firms (Geels, 2002; Kemp et al., 1998; Rennings, 2000). EV mass production allowed them to alleviate threats of tightening emission standards in Europe and fuel-efficiency standards in the U.S. Mitsubishi argued that "[a]fter 2016, the regulations will get tighter, so we would like to introduce electric vehicles or plug-in hybrids" (Automotive News, 85(6433), 2010, p. 28). Also, the firms were concerned about cities banning cars with internal combustion engines to reduce smog and alleviate congestion, a development that has already started in Europe—in London, for example. A Nissan executive elaborated: "That's something we can anticipate. […] And it might not be limited to Europe. I would be blind if I didn't recognize this pattern" (Automotive News, 82(6279), 2007, p. 55). Also, EVs enabled the firms to apply for government loans. Nissan was able to secure a loan from the European Investment Bank that was granted specifically for the development of low-carbon technologies. Moreover, during the financial crisis, when GM went into bankruptcy, the car manufacturer applied for loans, pointing to its efforts with the Volt in order to underline its future potential. The loans had an interest rate of about five percent, which was considerably lower than loans from banks. In order to be eligible, carmakers had to invest the money in alternative technologies that improved fuel efficiency by at least 25 percent compared to a conventional car. Thus, pre-emption in particular and government policies in general (as has been established in previous chapters) were decisive in the decision to invest in EVs.

Finally, the three cases suggest that engaging in EV mass production was a means to generate a strategic turnaround (Ba et al., 2012; Hofer, 1980; Ketchen & Palmer, 1999; Pearce II & Robbins, 1993). It appears that the firms hoped that the halo effect of the EVs could aid the transformation of the firms or at least lead to better competitive positions. All three firms were in some sort of troubled situation at the time of engagement. GM's and Mitsubishi's situation was, however, worse than Nissan's which only needed to reposition its brand. GM and Mitsubishi were in severe financial problems (see Table 7.3). Their earnings before interest and tax (EBIT) in 2005 were negative. In fact, they were the worst performing major firms in the industry. As Table 7.3 is only a snapshot, it may be influenced by 'strategic' accounting and admittedly the financial situation for some of the firms changed dramatically (positively or negatively) in following years. It does, however give a good perspective on the financial situation of the industry at the crucial moment of EV investment ramp-up. It illustrates the financial trouble faced by GM and Mitsubishi at the time.

Table 7.3: EBIT of major car manufacturers in 2004/2005

Firm Name	Data Date	Data Year - Fiscal	EBIT in USD
Toyota	2005/03/31	2004	$ 155.925.243,61
Nissan	2005/03/31	2004	$ 80.299.980,08
Ford	2005/12/31	2005	$ 68.670.000,00
Honda	2005/03/31	2004	$ 58.830.952,94
BMW	2005/12/31	2005	$ 43.532.003,00
Daimler	2005/12/31	2005	$ 40.288.117,00
Volkswagen	2005/12/31	2005	$ 37.553.308,00
Peugeot	2005/12/31	2005	$ 22.967.660,00
Renault	2005/12/31	2005	$ 17.071.838,00
Fiat	2005/12/31	2005	$ 11.839.000,00
Suzuki	2005/03/31	2004	$ 10.027.986,39
Mitsubishi	2005/03/31	2004	$ -11.986.251,85
General Motors	2005/12/31	2005	$ -35.520.000,00
Exchange rates (Source: x-rates.com)	***31.03.2005***	***31.12.2005***	
EUR-YEN	*139,0511*	*139,3450*	
EUR-USD	*1,2966*	*1,1839*	

(Source: Compustat)

Ketchen and Palmer (1999: 683) argued that "poor performing organizations will make strategic changes in, for example, the products and services they offer." This explains why GM and Mitsubishi developed new products, but it also raises the question of why they decided to engage in EVs and not conventional cars with an ICE but with a distinctive design or extraordinary functionality. This would have made the cost and value slippage problem obsolete. However, an investment in a new model with an ICE is unlikely to have resulted in a strategic turnaround. This is because the car industry is characterized by a proliferation of new models (Orsato & Wells, 2007). For instance, in 2005, the time when the three firms were in distress, customers in Britain could select amongst 3,155 different variants of cars (Orsato & Wells, 2007). Consequently any new model is unlikely to have had a significant effect. On the contrary, Table 7.1 indicates how rare EVs are. Also, the disruptive character of EVs has a more profound impact on the organization and its image then for instance a new model or design. In addition, the stock price of less-profitable firms—compared to their competition—benefits from the introduction of sustainable innovations (Ba et al., 2012). The analysis did not consider stock price reactions, which may be an area for further research.

In summary, all three incumbents appear to have been driven by all four motivations, with some motivations more prominent than others, depending on the case firm. First-mover advantages were most important for Nissan to reposition their brand, but the incumbent also benefited from improved green reputation, and pre-empted potential regulation. For GM and

Mitsubishi, the need for a strategic turnaround was a somewhat dominant motivation, but both firms also clearly strove for first-mover advantages and wanted to pre-empt CAFE fines. The reputation as a green(er) firm was also extremely important to GM. In the case of GM and Mitsubishi it seems to some extent that strategic turnaround was the end-goal of EV investment, and the other motivations, i.e. first-mover advantages, CSR activities and government policies were means to that end. In that sense, organizational decline might have been the underlying motivation. Results suggest that a confluence of motivations led the firms to invest in the mass production of EVs.

7.8 Conclusions

The preceding chapters have explored the evolution of LEVs, looking particularly at the interplay of car manufacturers and governments. Prior chapters illustrated that government policies have been a key driver for LEV engagement. This chapter extends that work by examining the strategic motivations of car manufacturers. Specifically, it reviewed the underlying strategic motivations that caused incumbents to invest in LEVs, and set out to understand why a few incumbents engaged in mass production of EVs despite value slippage (Lepak et al., 2007). Drawing on a wide body of literature, this review found four motivations to engage in EVs, namely first-mover advantages, policy pre-emption, CSR and organizational decline. The results suggest that strategic considerations play a role when engaging in EVs.

A review of the recent LEV history of the industry revealed that many firms engaged in the development of concepts, but few built test cars and only three firms mass-produced EVs. Incumbents' perceptions of EVs divided the industry: firms that were less optimistic about EVs engaged also less and firms that were optimistic engaged more in EVs. Although the qualitative nature of the analysis prevents a direct finding of causality, it does show that the three incumbents had significantly more optimistic perceptions of the market. Further, while most incumbents expected the future EV market to cover a niche and not to grow beyond two per cent, the three incumbents saw a much larger market for EVs—with a market share of up to 20 percent, i.e. ten times higher than what the more pessimistic incumbents expected.

The findings further suggest that although some of the four proposed motivations were more dominant than others, some combination of these motivations led the incumbents to engage in EVs. First-mover advantages and policy pre-emption were key motivations. CSR

activities were less prominent as a motivation, likely due to the enormous costs of engaging in EV mass production which cannot be justified as CSR value propositions. However, car manufacturers appreciated the green credentials that came with the engagement in EVs, and benefitted from them. Finally, organizational decline seems to have been a core motivation for GM and Mitsubishi. The two firms used EV engagement as a means for a strategic turnaround to escape their organizational decline. In doing so, the firms were able to retain government funds, establish a new image, or leapfrog competitors' environmental technologies. While it is too early to discern whether these strategies led to a sustainable turnaround, financial results from 2010 show that both GM and Mitsubishi had a positive EBITA position. GM also returned from bankruptcy. This corroborates studies which have shown that strategic responses rather than operational actions are more likely to improve performance after a decline (Ketchen & Palmer, 1999; Trahms et al., 2013). It also confirms that the turnaround is more likely to be successful if new products are based on resources that are valuable and difficult to imitate, which is the case for EVs (Morrow, Sirmon, Hitt, & Holcomb, 2007).

These insights offer a new perspective on sustainable innovations. New product introductions in general have been established in the literature as a means for strategic turnarounds because they are likely to improve long-term performance (Bolton, 1993; Ketchen & Palmer, 1999; Trahms et al., 2013). However, sustainable innovations seem not to be a sensible means for a turnaround when they suffer from value slippage. The findings of this chapter suggest that sustainable innovations such as EVs may provide the necessary halo effect to turn around an organization in decline and therefore justify the value slippage. This fits the results of recent studies which have shown that the engagement of poorly performing firms in sustainable innovations improves stock performance (Ba et al., 2012). This opens an interesting path for future research in sustainable innovations including such questions as: (1) Under which conditions are sustainable innovations beneficial for strategic turnarounds, and (2) when do firms invest in sustainable innovation rather than 'common' innovation for a strategic turnaround? Additionally, this suggests that managers of firms in organizational decline may consider engaging in sustainable innovations. While the investment might come at a high price due to value slippage, the firm may more than offset this slippage with the 'halo' that the sustainable innovation creates. In fact, the car industry has seen similar cases in its history as the example of the car brand AMC shows (Hofer, 1980: 19):

> ‘In the 1950s, George Romney became the president of the newly created American Motors Corporation. For three years, he waged a "Campaign Survival" to keep AMC afloat by discontinuing low-volume products, shutting plants, cutting over-head (including executive salaries), and selling off nonautomotive assets. Still the red ink flowed. He even took to the road in the middle of a recession to convince Americans that the Rambler was the answer to the “gas-guzzling dinosaurs” of the Big 3. He succeeded, and AMC was saved.’

Finally, the results of this chapter complement findings of previous chapters. For instance, this chapter enriches Chapter 4 in that it provides an additional explanation why EV engagement in general and EV mass production in particular increased remarkably, starting in 2006. Chapter 5 described how car manufacturers subsidized LEV commercialization; this chapter provides possible underlying reasons why the case firms were protecting technologies beyond stimuli from governments. This chapter also allows taking a different perspective on seemingly counter-economic choices of car manufacturers, depicted in Chapter 6. If car manufacturers indeed used EVs as means of strategic turnaround, then counter-economic choices might have been calculated costs. Further implications and future research areas will be discussed in the final chapter.

References

Aguilera, R. V., Rupp, D. E., Williams, C. a., & Ganapathi, J. (2007). Putting the S Back in Corporate Social Responsibility: a Multilevel Theory of Social Change in Organizations. *Academy of Management Review*, *32*(3), 836–863.

Ahuja, G., & Lampert, C. M. (2001). Entrepreneurship in the large corporation: a longitudinal study of how established firms create breakthrough inventions. *Strategic Management Journal*, *22*(6-7), 521–543.

Ambec, S., & Lanoie, P. (2008). Does it pay to be green? A systematic overview. *Academy of Management Perspectives*, (November), 45–62.

Ba, S., Lisic, L. L., Liu, Q., & Stallaert, J. (2012). Stock Market Reaction to Green Vehicle Innovation. *SSRN Electronic Journal*. doi:10.2139/ssrn.2033413

Barczak, G. (1995). New product strategy, structure, process, and performance in the telecommunications industry. *Journal of Product Innovation Management*, *6782*(95), 224–234.

Bassen, A., Jastram, S., & Meyer, K. (2005). Corporate Social Responsibility: Eine Begriffserläuterung. *Zeitschrift für Wirtschafts- und Unternehmensethik*, *6*(2), 231–236.

Bolton, M. (1993). Organizational innovation and substandard performance: when is necessity the mother of innovation? *Organization Science*, *4*(1), 57–75.

Bourgeois, L., & Eisenhardt, K. (1988). Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. *Management Science*, *34*(7), 816–835.

Bowman, C., & Ambrosini, V. (2000). Value Creation Versus Value Capture: Towards a Coherent Definition of Value in Strategy. *British Journal of Management*, *11*(1), 1–15.

Carroll, A. (1999). Corporate Social Responsibility: Evolution of a Definitional Construct. *Business & Society*, *38*(3), 268–295.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274.

Ghosn, C. (2007). Annual General Shareholders' Meeting - Remarks for Carlos Ghosn. Retrieved November 28, 2011, from http://www.nissan-global.com/EN/DOCUMENT/HTML/FINANCIAL/SPEECH/2007/fs_speech20070620.html

Golder, P. N., & Tellis, G. J. (1993). Pioneer advantage: marketing logic or marketing legend? *Journal of Marketing Research*, *30*(2), 158–170.

Hemingway, C., & Maclagan, P. (2004). Managers' Personal Values as Drivers of Corporate Social Responsibility. *Journal of Business Ethics*, *50*(1), 33–44.

Hockerts, K., & Wüstenhagen, R. (2010). Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. *Journal of Business Venturing*, *25*(5), 481–492.

Hofer, C. (1980). Turnaround strategies. *Journal of Business Strategy*, *1*(1), 19–31.

Hoffman, A. (2005). Climate change strategy: The business logic behind voluntary greenhouse gas reductions. *California Management Review*, *47*(3), 21–46.

Kemp, R., Schot, J. W., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–195.

Ketchen, D., & Palmer, T. (1999). Strategic responses to poor organizational performance: A test of competing perspectives. *Journal of Management*, *25*(5), 683–707.

Kley, F., Lerch, C., & Dallinger, D. (2011). New business models for electric cars — A holistic approach. *Energy Policy*, *39*(6), 3392–3403.

Kolk, A. (2010). Multinationals and corporate social responsibility. *Politeia*, 1–16. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1616845

Kumar, N., Scheer, L., & Kotler, P. (2000). From market driven to market driving. *European Management Journal*, *18*(2), 129–142.

Lane, B., & Potter, S. (2007). The adoption of cleaner vehicles in the UK: exploring the consumer attitude–action gap. *Journal of Cleaner Production*, *15*(11-12), 1085–1092.

Lepak, D. P., Smith, K. G., & Taylor, M. S. (2007). Value creation and value capture: A multilevel perspective. *Academy of Management Review*, *32*(1), 180–194.

Lieberman, M. B., & Montgomery, D. B. (1988). First-mover (dis)advantages: retrospective and link with the resource-based view. *Strategic Management Journal*, *19*(12), 1111–1125.

Magee, D. (2003). *Turnaround: How Carlos Ghosn rescued Nissan* (1st ed.). New York: HarperCollins.

Méthe, D., Swaminathan, A., & Mitchell, W. (1996). The underemphasized role of established firms as the sources of major innovations. *Industrial and Corporate Change*, *5*(4), 1181–1203.

Mone, M., McKinley, W., & Barker, V. (1998). Organizational decline and innovation: A contingency framework. *Academy of Management Review*, *23*(1), 115–132.

Morrow, J., Sirmon, D., Hitt, M., & Holcomb, T. (2007). Creating value in the face of declining performance: firm strategies and organizational recovery. *Strategic Management Journal*, *28*(3), 271–283.

Nidumolu, R., Prahalad, C., & Rangaswami, M. (2009). Why sustainability is now the key driver of innovation. *Harvard Business Review*, *87*(9), 56–64.

Orsato, R. J., & Wells, P. (2007). U-turn : the rise and demise of the automobile industry. *Journal of Cleaner Production*, *15*, 994–1006.

Pearce II, J., & Robbins, K. (1993). Toward improved theory and research on business turnaround. *Journal of Management*, *19*(3), 613–636.

Pinkse, J., & Kolk, A. (2009). *International business and global climate change*. London: Routledge.

Porter, M., & Kramer, M. (2006). Strategy and society. *Harvard Business Review*, *84*(12), 78–92.

Porter, M., & Van der Linde, C. (1995). Green and competitive: ending the stalemate. *Harvard Business Review*, *73*(5), 120–134.

Reed, J. (2009, September 18). GM plans public offering. *Financial Times Online*. Retrieved from http://www.ft.com/intl/cms/s/0/d9d3a296-a471-11de-92d4-00144feabdc0.html#axzz2Tdm0HMUZ

Reed, J. (2010). Renault chief commits to four electric models. *Financial Times*, p. 27.

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332.

Rindova, V. P., Williamson, I. O., Petkova, A. P., & Sever, J. M. (2005). Being good or being known: An empirical examination of the dimensions, antecedents, and consequences of organizational reputation. *The Academy of Management Journal*, *48*(6), 1033–1049.

Schaltegger, S., & Wagner, M. (2011). Sustainable entrepreneurship and sustainability innovation: categories and interactions. *Business Strategy and the Environment*, *20*(4), 222–237.

Tate, E., Harpster, M., & Savagian, P. (2008). The electrification of the automobile: From conventional hybrid, to plug-in hybrids, to extended-range electric vehicles. *2008 SAE World Congress, Detroit, Michigan, April 14–17, 2008* (Vol. 2008). Retrieved from http://www.media.gm.com/content/dam/Media/microsites/product/volt/docs/paper.pdf

Tetrault Sirsly, C., & Lamertz, K. (2007). When Does a Corporate Social Responsibility Initiative Provide a First-Mover Advantage? *Business & Society*, *47*(3), 343–369.

Trahms, C., Ndofor, H., & Sirmon, D. (2013). Organizational Decline and Turnaround: A Review and Agenda for Future Research. *Journal of Management*. doi:10.1177/0149206312471390

Van den Hoed, R. (2005). Commitment to fuel cell technology? *Journal of Power Sources*, *141*(2), 265–271.

Van den Hoed, R. (2007). Sources of radical technological innovation: the emergence of fuel cell technology in the automotive industry. *Journal of Cleaner Production*, *15*(11-12), 1014–1021.

WBCSD. (2000). *Corporate Social Responsibility. Making good business sense*. Genf.

8 Conclusions and implications

This dissertation studied the car industry and the evolution of low-emission vehicles under the influence of policy interventions. Four empirical chapters shed light on the factors central to this development. This final chapter reflects on the findings, discusses the study's implications for theory and practice and its limitations, and it suggests directions for future research.

8.1 Car firms, LEVs and the influence of policy interventions

As mentioned in the introduction, in 1998, John Wallace, director of Ford's alternative-fuel vehicle program, stated that the world of low-emission vehicles (LEVs) would be complicated and that not one fuel or one powertrain would dominate. He was right. The car industry has been in an era of ferment. The century-long dominance of the internal combustion engine has been challenged due to its negative effects, such as resource depletion, pollution and climate change. Incumbents in the industry have sought ways to react. While cars with an internal combustion engine have been made more efficient by incumbents to defend its dominance (Geels & Schot, 2007; Snow, 2010), car firms have also increasingly engaged in various low-emission vehicle technologies, namely hybrid, electric and fuel-cell vehicles (Frenken, Hekkert, & Godfroij, 2004). Although some studies have found that the sustainability of LEVs depends on the form of energy generation and in some cases LEVs cold even cause higher CO_2 emissions than ICE vehicles (Granovskii, Dincer, & Rosen, 2006; Romm, 2006), LEVs are generally considered more sustainable than cars with an internal combustion engine (ICE). The increasing engagement in LEVs was stimulated by policy interventions in most developed and in some developing countries. This trend has raised several questions, such as how LEV development evolved internationally, what impact governments and firms have had on this trajectory, and how and why firms brought LEVs to the market.

Investigating the evolution of incumbents' LEV strategies in relation to policy developments aimed to answer these questions. This dissertation offered insights into the process of technological change from different perspectives. It illustrated how sustainable technologies evolve and depicted the complex influence of business and government actions in different geographical areas at different policy levels on the transition. To shed light on the

interplay between firm innovation and policy interventions, this dissertation studied international LEV developments over the past 14 years. It sought to answer four research questions: 1) How have low-emission vehicles evolved internationally over the years, and in what way have government policies influenced firm innovation?, 2) in the trajectory of low-emission vehicles, what has been the influence of protection mechanisms of governments and incumbents, respectively?, 3) in designing business models, how have incumbents dealt with the tension of the disruptive character of electric vehicles and the influence of government intervention?, and 4) considering the disruptiveness of low-emission vehicles, what have been the strategic motivations of car firms to engage in electric vehicles? The empirical chapters were based on a large dataset of multiple industry and newspaper sources from 1997 until 2010. Performing a keyword search of the most important LEV technologies a dataset was compiled that included 9,908 articles from two trade magazines (*Automotive News* and *WardsAuto World*), a car magazine (*Autoweek*) and a daily newspaper (*Financial Times*). The dataset was carefully analyzed using the qualitative data analysis software Atlas.ti 6.2.

The first empirical chapter (Chapter 4) gave an overview of developments throughout the whole period. It enabled an understanding of the major international players in the industry over several years in light of technological, market and policy developments. Chapter 4 also heeded the call for a better geographical conceptualization of technological transitions in the socio-technical systems literature (Bakker, Van Lente, & Engels, 2012; Dijk, Orsato, & Kemp, 2012). The analysis illustrated that the LEV trajectory evolved through three periods with changing technological foci. The chapter demonstrated that the LEV trajectory was shaped by governments and car manufacturers in different geographical areas at different policy levels: local, national, and international. At the beginning of the studied period, particularly U.S. and Japanese car manufacturers explored EVs, stimulated by government policies in California and Japan. Subsequently, from 1998 until 2005, the focus changed toward hybrid vehicles (HVs) and fuel-cell vehicles (FCs) due to disappointing performance of EVs, the promise of FCs to alleviate the problems of EVs, and favorable policies for HVs. In 2006, government support for green technologies and improved battery technology triggered a revival of EV technology. European car manufacturers began engaging more in LEVs stimulated by stricter government policies in Europe and HVs maintained their position in the product portfolios of most car manufacturers. So far, most studies on LEV development have looked at a single country context and have neglected the fact that technological transitions take place internationally. Based on the empirical analysis of the international LEV development, the chapter proposed three mechanisms which explain

why and how technological trajectories occur internationally: (1) policy diffusion and international policies, (2) international operations of firms, and (3) the fit between policy demands and firm capabilities. The mechanisms increase the explanatory power of the socio-technical systems framework in international contexts, account for the diversity in transitions and link the transition literature to existing research that investigates different spatial dimensions (Dijk et al., 2012; Dyerson & Pilkington, 2005; Whitmarsh, 2012).

Next, in describing how LEVs emerged, explanations commonly refer to government regulation, incentives or public-private projects. The analysis in Chapter 5 showed that in addition to such 'protected spaces' provided by governments, incumbents also 'protected' the development and commercialization of green cars themselves by supporting 'unprofitable' activities (Smith & Raven, 2012). In scrutinizing 'protection mechanisms'—i.e., means to shelter innovations from market forces in the initial development and commercialization phase such as through incentives or dumping—Chapter 5 contributed to debates in the socio-technical systems literature (Geels, 2002; Kemp et al., 1998) and the innovation management literature (Christensen, 1997; Danneels, 2004). Based on an examination of Daimler, General Motors and Toyota in the context of European, U.S. and Japanese policies, protection by firms appeared to be more successful in promoting hybrids and electric vehicles in specific periods and locations. These firms—while leveraging public protection—adopted private protection levers such as allocating resources, targeting specific niches (e.g. fleet managers), or collaborating with other stakeholders (e.g. new entrants). Linking insights from the innovation management literature with the socio-technical systems literature, Chapter 5 puts forward a framework that allows us to distinguish the type of protection and for whom it is most suitable, depending on the type of innovation—disruptive, systemic, or socially embedded. The analysis of the LEV trajectory shows that both governments and incumbents protected the LEVs. The interplay was illustrated in two trajectories, and this study found that although private protection was more effective, government support was necessary to trigger the trajectory.

The third empirical chapter (Chapter 6) studied business models for the commercialization of electric vehicles (EVs) in more detail. The commercialization of EVs has been a struggle for car manufacturers, as EVs are expensive, require a new recharging infrastructure, and have a shorter driving range than 'current' cars (with customers thus having to change their driving and recharging patterns). It is generally assumed that EVs can become attractive only via a disruptive technology or radical change in business models. Based on a sample of incumbent as well as entrepreneurial companies Chapter 6 not only

drew upon but also contributed to the surging business model literature, investigating policy, asset and governance choices in EV business models (Casadesus-Masanell & Ricart, 2010; Cowan & Hulten, 1996; Zapata & Nieuwenhuis, 2010). In order to understand why incumbents face difficulties in bringing disruptive innovations such as EVs through new business models to the market, Chapter 6 made use of the concept of path dependence. The empirical results implied that, in addition to the 'incumbents' curse due to a firm's history—i.e., path dependence (Chandy & Tellis, 2000)—surprisingly, government support also impeded the successful diffusion of EVs through what is, for now, coined the 'incentive curse.' Firms face the incentive curse when government incentives foster counter-economic choices; this may occur, for example, when governments support selling products to a market to which they are ill-suited.

The last empirical chapter (Chapter 7) subsequently explored incumbents' motivations to engage in sustainable innovations such as EVs and contributed to the sustainable innovation debate. Sustainable innovations suffer often from value slippage; that is they create environmental or social value but it is difficult for firms to capture this value (i.e. it slips away) as most customers are not willing to pay the often higher price (Lepak, Smith, & Taylor, 2007; Rennings, 2000). As mentioned already, EVs are currently unattractive for most private customers. Indeed, an analysis of firms' opinions indicated that most car manufacturers do not see a market for EVs. This explains why the majority of the incumbents only developed concept cars or built small test fleets based on refitting existing cars. Only a few—General Motors, Nissan and Mitsubishi—decided to develop and produce purpose-built EVs. Besides the fact that these firms envisaged a large market for EVs, they regarded their EVs—the Volt, the Leaf and the iMiev—as 'halo' vehicles to gain technological leadership, as a way to get government support, to prevent government fines, or as a means for a strategic turnaround. The chapter revealed that one of the benefits of engaging in sustainable innovations—in addition to first-mover advantages, CSR activities and policy pre-emption—is the possibility to facilitate strategic turnarounds. These motivations provide insights as to why and when firms invest in sustainable innovation which is valuable for analyzing and differentiating reasons for firms' engagement in, for example, environmentally-friendly technologies.

8.2 Contributions

This dissertation examined the influence of the interplay between car firms' strategies and policies on the LEV trajectory. The empirical chapters shed light on different aspects of this relationship. Each chapter added specific contributions as laid out above. In the following I discuss the broader contributions of this dissertation.

First and foremost, this dissertation bridges two disparate literatures: one on strategic management of innovation which regards firms as the main driver of innovation (Christensen, 1997; Danneels, 2004; Keupp, Palmié, & Gassmann, 2012; Lengnick-Hall, 1992)—and another on technological transitions which studies governments and their influence on technological change (Geels, 2002, 2004; Kemp et al., 1998). Innovation management scholars have predominantly taken a micro perspective on innovation and paid less attention to the systemic influence, particularly the role of government policy. The results of this dissertation showed, however, that for technologies that are socially embedded, as is the case for LEVs (see Chapter 5), such a conceptualization does not suffice. In contrast to autonomous or systemic innovations, for these technologies to succeed, firms are not only dependent on their own innovativeness, suppliers, competitors or customers, but also rely on governments (Garud & Kumaraswamy, 1995).

Thus, a more encompassing perspective is needed. Transition theorists have conceptualized innovation trajectories for such socially embedded technologies. This strand of literature has integrated the role of the relevant actors at different levels and in different stages of transition trajectories (Geels, 2002; Kemp et al., 1998). Studies in this realm have particularly depicted the transition from the development stage of innovations to the commercialization stage and its respective implications with regard to protection from market forces. The focus is primarily on how governments provide protected spaces in which new technologies are nurtured and actors learn about the technology (Smith & Raven, 2012). However, while the role of firms in the transition literature gains more attention, the idiosyncrasies of firm innovation, such as how firms protect technologies internally, or how they bring these technologies to the market are still underexposed.

Therefore, in combining these two streams of literature on the strategic management of innovation and technological transitions, this dissertation overcomes their respective explanatory limitations and provides a more complete picture on technological change of socially embedded technologies. In the transition of socially embedded technologies, both a firm and a policy perspective are necessary, as firm strategies and government policies

influence technological trajectories concomitantly. That is, the technological trajectory of LEVs is a result of the combined actions of the actors, particularly firms and governments (see Chapter 4). Consequently, to understand the LEV trajectory, it is pertinent to recognize on the one hand the influence of governments that stimulate its development through policies and on the other hand the influence of firms which bring LEVs to the market (see Chapter 5). In other words, this dissertation opened the black box of institutional influences on firm innovation and intra-firm innovation respectively. Furthermore, the LEV trajectory itself is illustrated. In the following the contributions to these literature streams are discussed in more detail.

Strategic management of innovation

This dissertation contributes to the extant literature on the strategic management of innovation (Keupp et al., 2012) and adds in specific to the debates on disruptive innovation (Christensen, 1997), business model innovation (Chesbrough, 2010) and sustainable innovation (Hockerts & Wüstenhagen, 2010). One of the main themes in this dissertation has been the influence of the external environment on firm innovation in LEVs. So far, the external environment has not received much attention in the innovation literature (Keupp et al., 2012). Most studies have investigated autonomous or systemic innovations and rarely considered external influences (Keupp et al., 2012). Yet, besides being systemic innovations, with their inherent challenges (Chesbrough & Teece, 2002), LEVs are also socially embedded and therefore necessitate an integrated conceptual perspective which includes the external environment. Chapters 4, 5 and 6 explored the influence of government policies as one of the most important factors (Hekkert & Van den Hoed, 2004; Pilkington & Dyerson, 2006). The empirical chapters unravelled the interdependence between firm innovation and policies. Different mechanisms came to the fore which enable a more complete understanding of factors that influence socially embedded innovations.

Thus, the first contribution for the strategic management of innovation literature was to show how firm innovation co-evolves with government policies. Chapter 5 illustrated the mechanisms between firm innovation and government policies. Chapter 4 demonstrated the international dimension of the co-evolution considering policies across borders and firm innovation of car manufacturers from different home countries. The chapters revealed that government policies were highly influential for the LEV trajectory, underlining the fact that an integrated perspective is pertinent for a greater understanding of socially embedded

innovations. The consideration of government influences on firm innovation also raised the question of the impact of government policies on the business models of firms (in addition to the impact on technological change). Hence, the second contribution relates to the understanding of government influence on business models (Rennings, 2000). Chapter 6, for example, showed that government incentives may induce firms to take counter-economic decisions. While this finding requires further validation, it points to the saliency of governments in commercializing socially embedded innovations beyond its impact on technological change.

Finally, the dissertation adds to the sustainable innovation debate (Hall & Vredenburg, 2003; Hockerts & Wüstenhagen, 2010; Schaltegger & Wagner, 2011). So far it has been assumed that entrepreneurs are more likely to bring sustainable technologies to the market (Hockerts & Wüstenhagen, 2010). This dissertation showed, however, that incumbents could also be the source of disruptive sustainable innovations. Nevertheless, in bringing LEVs to the market, incumbents tended to adopt efficiency-centred rather than novelty-centred business models (Zott & Amit, 2007). Moreover, this dissertation added the unexpected insight that sustainable innovations might have the additional benefit for firms to serve as a halo product which can support organizational turnarounds (Chapter 7).

Technological transitions

This dissertation also contributes to the technological transitions literature (Geels, 2002; Kemp et al., 1998). First, it illuminated the role of protection of technologies provided by firms and the interplay with government protection mechanisms (Chapter 5). While the transition literature has acknowledged that firms can protect sustainable technologies, it has mostly focussed on protection from governments (Geels, 2002; Raven, 2007; Smith & Raven, 2012). This dissertation elucidated protection from a firm perspective and how firm protection interacts with government protection. The notion of ‘public and private protection levers’ was introduced in chapter 5 to illustrate how public and private protection was necessary for LEVs to emerge. In combination these levers facilitated a more comprehensive picture on the protection of LEVs in the early stages of the trajectory. With the explicit introduction of the mechanisms of private and public protection their respective roles were stressed.

A second contribution relates to the spatial dimension of technological transitions. So far, transitions have mostly been studied irrespective of geographically dispersed

developments (Carlsson, 2006; Coenen, Benneworth, & Truffer, 2012). As the case of the car industry illustrated, however, technological transitions of internationally available products do not develop in a geographically isolated way. Internationally operating car firms are influenced by multiple policy environments (Chapter 4). LEVs have emerged increasingly on the agenda of many governments. Yet, policies have not been coordinated or orchestrated at a higher level. This has stimulated different localized trajectories that influence the international trajectories. In this context Chapter 4 conceptualized the mechanisms that are at play in the international co-evolution, added a framework to understand geographically dispersed technological transitions and presented an international perspective on the LEV trajectory (Whitmarsh, 2012).

Altogether, then, the picture emerges that the LEV trajectory is a complex interplay of public and private protection in dispersed locations. This enriches the technological transition literature in that it illustrates the implications of geography and the role of firms and governments.

Low emission vehicle literature

This dissertation also contributes to the bourgeoning stream of studies on LEVs (Bakker et al., 2012; Dijk et al., 2012; Dyerson & Pilkington, 2005; Frenken et al., 2004). The emergence of LEVs has received growing attention, particularly from technology scholars. Studies on LEVs have examined how LEVs emerged, how they might replace the ICE and which technology might become the dominant LEV technology (Bakker et al., 2012; Cowan & Hulten, 1996; Van Bree, Verbong, & Kramer, 2010; Zapata & Nieuwenhuis, 2010). Most studies have taken a systemic or policy perspective. Only few adopted a firm perspective on LEV development (Kley, Lerch, & Dallinger, 2011; Wesseling, Faber, & Hekkert, 2013).

However, firms have a significant influence on LEV development. Understanding firm motivations, challenges and actions are indispensable for a comprehensive depiction of LEV development. While car firms have been the target of government policies they also have been the entities that develop and commercialize LEVs. This dissertation examined the LEV trajectory from 1997 to 2010 from a firm perspective and shed light on where (Chapter 4), how (Chapters 5 and 6) and why car firms engaged in LEVs (Chapter 7). This has provided a more complete picture on LEVs by shedding light on the interdependence between the LEV trajectory, car firms and policies, which might enable better informed predictions for future developments.

Finally, this dissertation contributed to a more accurate and comprehensive perspective on the LEV trajectory in and of itself (Chapter 4). Events, turns in the path, and phases in the development were described based on rich data and actual LEVs launched. Prior studies relied on patents (Wesseling et al., 2013), number of articles on specific technologies (Bakker et al., 2012) or anecdotal evidence (Cowan & Hulten, 1996; Dijk et al., 2012). Also, this dissertation included all three main LEV types (i.e. hybrid vehicles, electric vehicles and fuel-cell vehicles), instead of grouping technologies (Bakker et al., 2012) or studying only one technology type (Cowan & Hulten, 1996; Dijk et al., 2012).

8.3 Implications for practice

Although Chapters 4 to 7 have already suggested implications for practice, this section discusses a few overarching considerations for businesses. A central topic of this dissertation were business models for LEVs and the inertia of incumbents in the industry to change existing business practices. The extant literature suggests that disruptive business models should be established in new entities such as spin-offs. However, the general opinion is that this practice is not feasible in the car industry due to the large investments in product development and production. General Motors established a new business unit—the Saturn brand, which was also responsible for the EV1. Nonetheless, the attempt failed and Saturn was discontinued. Still, in the case of LEVs, creating a separate business unit might be a worthwhile consideration because LEVs require different business practices which can be best developed in a separate organizational entity (see Chapter 6). Interestingly, BMW has planned to start a new entity for its green cars, called project ‘i,’ and Toyota also has considered spinning out the Prius to a separate brand.

In the future, LEVs will likely continue to play a role for car firms. However, the transition to one or the other technology will continue to evolve slowly. While hybrids have become established in car manufacturers’ product portfolios, they are probably a transition technology towards electric or fuel-cell vehicles which have the potential to be CO_2-emission-free (depending on which energy sources are used). Currently, electric vehicles seem to be the most likely candidate to become the leading LEV technology (see Chapter 4). Yet, optimistic outlooks forecasting a speedy electrification of cars—for instance, in consultancy reports—should be regarded with caution. As Chapters 5, 6 and 7 illustrated, the industry moves slowly, not only due to its path dependence, but also due to inertia which is a result of the social embeddedness of cars. The industry has a slower ‘clockspeed’ than, for

example, the IT industry, in which new technologies are brought to the market much faster. The lack of a proper infrastructure and the necessary large investments in development and production facilities are not the only impediments to the transition—consumers also need to be enticed into the new technology. Car manufacturers need to find smart ways of alleviating or circumventing costs, perceptional issues and infrastructure challenges before the transition can pick up speed. Cars are usually the second-most-expensive investment (after buying a home) and, on average, vehicles remain on the road for about 17 years (Spitzley et al., 2004). Thus, innovative business models are needed to speed up this process.

8.4 Limitations and further research

This dissertation is not without limitations. The study relied on an extensive, in-depth analysis of publicly available trade journals, magazines, and newspapers. The trade journals (*Automotive News* and *WardsAuto World*) and car magazine (*Autoweek*) have the advantage that they report about the car industry from a well-informed outsider perspective which provides insight into industry and firm developments as well as relevant policies. The *Financial Times* was selected for its focus on firm strategy as well as its attention to environmental, political and economic developments. Moreover, newspapers are regarded as being exact, stable and unobtrusive (Yin, 2009). Despite the advantages of using these sources, information might be subject to reporting bias (Yin, 2009). I tried to overcome this problem by using four different sources. Certainly, gathering data directly from the industry, such as through interviews with managers or archival data of car firms would provide finer results, however, "given the often highly secretive nature of new product development activities in the car industry and the highly emotive political atmosphere of these initiatives" the adopted approach seemed proper given these circumstances (Pilkington & Dyerson, 2006: 79). What is more, the car industry in general as well car manufacturers and the LEV trajectory in particular have special characteristics, for instance a vast scale and enormous complexity. Therefore, some of the findings of this dissertation might be idiosyncratic to the car industry and not generalizable. Finally, the adopted case study methodology in itself has limitations, which impede generalizability and reliability. I attempted to overcome these limitations by adopting a longitudinal perspective, rigorous analysis and the inclusion of multiple cases. Multiple cases provide the possibility to augment a within-case analysis with cross-case comparisons (Eisenhardt, 1989) and improve results through pattern matching which increases the reliability of theoretical findings (Yin, 2009).

Future research could replicate this study in a different industry not only to uncover differences between technologies, but also to examine in more detail when and why trajectories take a certain direction due to different types of actions by incumbents and governments at different policy levels and in different geographical areas. Such information is important for managers and policy makers alike to foster technological change more effectively—particularly for sustainable innovations. Next, the proposed concept of the incentive curse could warrant better insights into why government support sometimes fails to yield the expected outcomes. However, the concept needs further empirical examination in different contexts to determine when and why these situations occur. Also, the link between the incentive curse and the incumbents' curse needs further validation. And to conclude, future studies could investigate the role of sustainable innovation in strategic turnarounds. The findings suggested that sustainable innovations may provide the necessary halo effect to turnaround an organization in decline and therefore justify the value slippage. This requires further examination, particularly with regard to how much value slippage could be justified.

References

Bakker, S., Van Lente, H., & Engels, R. (2012). Competition in a technological niche : the cars of the future. *Technology Analysis & Strategic Management*, *24*(5), 421–434.

Bento, N. (2010). Dynamic competition between plug-in hybrid and hydrogen fuel cell vehicles for personal transportation. *International Journal of Hydrogen Energy*, *35*(20), 11271–11283.

Berggren, C., Magnusson, T., & Sushandoyo, D. (2009). Hybrids, diesel or both? The forgotten technological competition for sustainable solutions in the global automotive industry. *International Journal of Automotive Technology and Management*, *9*(2), 148–173.

Carlsson, B. (2006). Internationalization of innovation systems: A survey of the literature. *Research Policy*, *35*(1), 56–67.

Casadesus-Masanell, R., & Ricart, J. E. (2010). From Strategy to Business Models and onto Tactics. *Long Range Planning*, *43*(2-3), 195–215.

Chanaron, J. J., & Teske, J. (2007). Hybrid vehicles: a temporary step. *International Journal of Automotive Technology and Management*, *7*(4), 268–288.

Chesbrough, H. (2010). Business Model Innovation: Opportunities and Barriers. *Long Range Planning*, *43*(2-3), 354–363.

Chesbrough, H., & Teece, D. (2002). Organizing for innovation: when is virtual virtuous? *Harvard Business Review*, *80*(8), 127–134.

Christensen, C. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy*, *41*(6), 968–979.

Cowan, R., & Hulten, S. (1996). Escaping lock-in: the case of the electric vehicle. *Technological Forecasting and Social Change*, *53*(1), 61–80.

Danneels, E. (2004). Disruptive Technology Reconsidered: A Critique and Research Agenda. *Journal of Product Innovation Management*, *21*(4), 246–258.

Dijk, M., Orsato, R. J., & Kemp, R. (2012). The emergence of an electric mobility trajectory. *Energy Policy*, (in Press).

Dyerson, R., & Pilkington, A. (2005). Gales of creative destruction and the opportunistic incumbent: The case of electric vehicles in California. *Technology Analysis & Strategic Management*, *17*(4), 391.

Eisenhardt, K. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

Frenken, K., Hekkert, M., & Godfroij, P. (2004). R&D portfolios in environmentally friendly automotive propulsion: Variety, competition and policy implications. *Technological Forecasting and Social Change*, *71*(5), 485–507.

Garud, R., & Kumaraswamy, A. (1995). Technological and organizational designs for realizing economies of substitution. *Strategic Management Journal*, *16*, 93–109.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6-7), 897–920.

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417.

Granovskii, M., Dincer, I., & Rosen, M. (2006). Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles. *Journal of Power Sources*, *159*(2), 1186–1193.

Hall, J., & Vredenburg, H. (2003). The Challenges of Innovating for Sustainable Development. *MIT Sloan Management Review*, *45*(1), 61–68.

Hekkert, M., & Van den Hoed, R. (2004). Competing technologies and the struggle towards a new dominant design. *Greener Management International*, *47*(Autumn), 29–44.

Hockerts, K., & Wüstenhagen, R. (2010). Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. *Journal of Business Venturing*, *25*(5), 481–492.

Kemp, R., Schot, J. W., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–195.

Keupp, M. M., Palmié, M., & Gassmann, O. (2012). The Strategic Management of Innovation: A Systematic Review and Paths for Future Research. *International Journal of Management Reviews*, *14*(4), 367–390.

Kley, F., Lerch, C., & Dallinger, D. (2011). New business models for electric cars — A holistic approach. *Energy Policy*, *39*(6), 3392–3403.

Lengnick-Hall, C. (1992). Innovation and competitive advantage: what we know and what we need to learn. *Journal of Management*, *18*(2), 399–429.

Lepak, D. P., Smith, K. G., & Taylor, M. S. (2007). Value creation and value capture: A multilevel perspective. *Academy of Management Review*, *32*(1), 180–194.

Pilkington, A., & Dyerson, R. (2006). Innovation in disruptive regulatory environments: A patent study of electric vehicle technology development. *European Journal of Innovation Management*, *9*(1), 79–91.

Raven, R. (2007). Niche accumulation and hybridisation strategies in transition processes towards a sustainable energy system: An assessment of differences and pitfalls. *Energy Policy*, *35*(4), 2390–2400.

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332.

Romm, J. (2006). The car and fuel of the future. *Energy Policy*, *34*(17), 2609–2614.

Schaltegger, S., & Wagner, M. (2011). Sustainable entrepreneurship and sustainability innovation: categories and interactions. *Business Strategy and the Environment*, *20*(4), 222–237.

Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, *41*(6), 1025–1036.

Snow, D. (2010). Extraordinary Efficiency Growth in Response to New Technology Entry: The Carburetor's' Last Gasp'. *Available at SSRN 1668643*.

Van Bree, B., Verbong, G., & Kramer, G. (2010). A multi-level perspective on the introduction of hydrogen and battery-electric vehicles. *Technological Forecasting and Social Change*, *77*(4), 529–540.

Wesseling, J. H., Faber, J., & Hekkert, M. P. (2013). How competitive forces sustain electric vehicle development. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2013.02.005

Whitmarsh, L. (2012). How useful is the Multi-Level Perspective for transport and sustainability research? *Journal of Transport Geography*, *24*, 483–487.

Yin, R. K. (2009). *Case study research: Design and methods* (2nd ed.). Newbury Park, CA: Sage.

Zapata, C., & Nieuwenhuis, P. (2010). Exploring innovation in the automotive industry: new technologies for cleaner cars. *Journal of Cleaner Production*, *18*(1), 14–20.

Zott, C., & Amit, R. (2007). Business Model Design and the Performance of Entrepreneurial Firms. *Organization Science*, *18*(2), 181–199.

9 English summary

Global challenges such as climate change, resource depletion and energy security, as well as local challenges including air pollution and congestion, have led governments around the world to require the car industry to become more sustainable and to invest in more environmentally-friendly products, especially low-emission vehicles (LEVs). While cars with an internal combustion engine have been made more efficient by incumbents to defend its dominance, car firms have also increasingly engaged in various low-emission vehicle technologies, namely hybrid, electric and fuel-cell vehicles. This dissertation studied the car industry and the evolution of low-emission vehicles under the influence of policy interventions. It explored how the interplay between policy interventions and car firms' strategies has evolved over time and how firms have adapted their innovation strategies and business practices.

To shed light on the interplay between firm innovation and policy interventions, this dissertation studied international LEV developments from 1997 until 2010. It sought to answer four research questions: 1) How have low-emission vehicles evolved internationally over the years, and in what way have government policies influenced firm innovation?, 2) in the trajectory of low-emission vehicles, what has been the influence of protection mechanisms of governments and incumbents, respectively?, 3) in designing business models, how have incumbents dealt with the tension of the disruptive character of electric vehicles and the influence of government intervention?, and 4) considering the disruptiveness of low-emission vehicles, what have been the strategic motivations of car firms to engage in electric vehicles?

Four empirical chapters shed light on the factors central to this development. The empirical chapters were based on a large dataset of multiple industry and newspaper sources from 1997 until 2010. Performing a keyword search of the most important LEV technologies a dataset was compiled that included 9,908 articles from two trade magazines (Automotive News and WardsAuto World), a car magazine (Autoweek) and a daily newspaper (Financial Times). The dataset was carefully analyzed using the qualitative data analysis software Atlas.ti 6.2.

The first empirical chapter (Chapter 4) gave an overview of developments throughout the whole period. It enabled an understanding of the major international players in the industry over several years in light of technological, market and policy developments. Based

on the empirical analysis of the international LEV development, the chapter proposed mechanisms which explain why and how technological trajectories occur internationally.

Next, in describing how LEVs emerged, explanations commonly refer to government regulation, incentives or public-private projects. The analysis in Chapter 5 showed that in addition to such 'protected spaces' provided by governments, incumbents also 'protected' the development and commercialization of green cars themselves by supporting 'unprofitable' activities. Chapter 5 puts forward a framework that allows us to distinguish the type of protection and for whom it is most suitable, depending on the type of innovation—disruptive, systemic, or socially embedded. The analysis of the LEV trajectory shows that both governments and incumbents protected the LEVs. The interplay was illustrated in two trajectories, and this study found that although private protection was more effective, government support was necessary to trigger the trajectory.

The third empirical chapter (Chapter 6) studied business models for the commercialization of electric vehicles (EVs) in more detail. The commercialization of EVs has been a struggle for car manufacturers, as EVs are expensive, require a new recharging infrastructure, and have a shorter driving range than 'current' cars (with customers thus having to change their driving and recharging patterns). Besides barriers inherent to the technology, the empirical results implied that, in addition to the 'incumbents' curse due to a firm's history—i.e., path dependence—surprisingly, government support also impeded the successful diffusion of EVs through what is, for now, coined the 'incentive curse.' Firms face the incentive curse when government incentives foster counter-economic choices.

The last empirical chapter (Chapter 7) subsequently explored incumbents' motivations to engage in sustainable innovations such as EVs and contributed to the sustainable innovation debate. The chapter revealed that one of the benefits of engaging in sustainable innovations—in addition to first-mover advantages, CSR activities and policy pre-emption—is the possibility to facilitate strategic turnarounds. These motivations provide insights as to why and when firms invest in sustainable innovation which is valuable for analyzing and differentiating reasons for firms' engagement in, for example, environmentally-friendly technologies.

10 Nederlandse samenvatting [Summary in Dutch]

Mondiale ontwikkelingen, zoals klimaatverandering en uitputting van grondstoffen, en lokale ontwikkelingen, zoals luchtvervuiling en filevorming, hebben geleid tot druk vanuit nationale overheden op de auto-industrie om te verduurzamen en meer te investeren in milieuvriendelijke producten. Als een reactie hierop zijn autofabrikanten auto's met een efficiëntere verbrandingsmotor gaan maken en begonnen met het ontwikkelen van emissiearme voertuigen (LEV's), zoals hybride, elektrische en brandstofcel voertuigen. Met dit als achtergrond, richt dit proefschrift zich op de auto-industrie en de invloed van overheidsingrijpen op de ontwikkeling van emissiearme voertuigen . De focus van de studie ligt op het onderzoeken hoe de wisselwerking tussen beleidsmaatregelen en de strategieën van autofabrikanten zich heeft ontwikkeld en de wijze waarop fabrikanten hun innovatiestrategieën en bedrijfsvoering hebben aangepast.

Om te onderzoeken hoe de wisselwerking tussen innovatie en overheidsingrijpen zich heeft ontwikkeld, bestudeert deze studie internationale LEV ontwikkelingen in de periode van 1997 tot 2010. Meer specifiek probeert dit proefschrift een antwoord te vinden op de volgende vier onderzoeksvragen: 1) Hoe zijn emissiearme voertuigen internationaal geëvolueerd en op welke wijze heeft overheidsbeleid innovatie van autofabrikanten beïnvloed?; 2) Wat is de invloed van beschermingmechanismes, die zowel overheden en autofabrikanten hebben geïmplementeerd ter bescherming van nieuwe technologieën, op de evolutie van emissiearme voertuigen?; 3) Hoe zijn bestaande autofabrikanten in het ontwikkelen van nieuwe bedrijfsmodellen omgegaan met de mogelijke verstorende concurrentie-effecten van elektrische voertuigen op het succes van traditionele auto's en van overheidsingrijpen?; 4) Met betrekking tot de verstorende werking van emissiearme voertuigen, wat zijn de strategische beweegredenen geweest van autofabrikanten om deel te nemen aan de ontwikkeling van elektrische voertuigen?

De resultaten van dit proefschrift zijn verdeeld in vier empirische hoofdstukken, die elk verschillende factoren bespreken die centraal staan in de ontwikkeling van emissiearme voertuigen. De resultaten zijn gebaseerd op een analyse van een dataset van 9.908 artikelen uit twee vakbladen (Automotive News en Wards Auto World), een automagazine (Autoweek) en een financieel dagblad (Financial Times). De dataset is geanalyseerd met behulp van de kwalitatieve data analyse software Atlas.ti 6.2.

Het eerste empirische hoofdstuk (Hoofdstuk 4) geeft een overzicht van de ontwikkelingen gedurende de periode van 1997 tot 2010. Het hoofdstuk geeft een overzicht van de belangrijkste internationale actoren in de auto-industrie, daarbij rekening houdend met de ontwikkelingen in de technologie, de markt en het overheidsbeleid. Op basis van de empirische analyse van de internationale ontwikkeling van emissiearme voertuigen worden een aantal mechanismes gepresenteerd die de technologische evolutie verklaren.

In het beschrijven hoe LEV's zijn ontstaan, verwijzen verklaringen in de academische literatuur vaak naar algemeen overheidsbeleid, specifieke beleidsprikkels of publiek-private projecten. De analyse in hoofdstuk 5 laat echter zien dat in aanvulling op dergelijke 'beschermingsconstructies' die overheden creëeren, bestaande autofabrikanten zelf ook de ontwikkeling en commercialisatie van milieuvriendelijke auto's beschermen door het ondersteunen van 'niet-winstgevende' activiteiten. Hoofdstuk 5 presenteert een raamwerk dat het mogelijk maakt om het type bescherming en de actoren voor wie dit het meest geschikt is te onderscheiden op basis van het type innovatie – ontwrichtend, systematisch of sociaal ingebed. Uit de analyse van de evolutie van LEV's blijkt dat zowel overheden als bestaande fabrikanten LEV's beschermen. Het samenspel tussen deze actoren wordt geïllustreerd in twee trajecten. De analyse in dit hoofdstuk toont aan dat hoewel private bescherming veelal effectiever was, overheidssteun desalniettemin noodzakelijk was om de evolutie in gang te zetten.

Het derde empirische hoofdstuk (Hoofdstuk 6) onderzoekt bedrijfsmodellen voor de commercialisatie van elektrische voertuigen (EV's) in meer detail. De commercialisatie van EV's was een strijd voor autofabrikanten, gezien de hoge productiekosten, de vereiste nieuwe oplaadinfrastructuur, en de kortere actieradius in vergelijking met bestaande auto's (wat inhoudt dat consumenten hun gebruikspatroon moeten aanpassen). Naast de belemmeringen die inherent zijn aan de EV technologie, tonen de resultaten aan dat in aanvulling op de 'incumbent's curse' – hetgeen refereert aan de moeilijkheid voor bestaande organisaties om innovatieve, nieuwe producten op de markt te brengen – steun van de overheid ook de succesvolle verspreiding van EV's heeft belemmerd als gevolg van de zogenaamde 'incentive curse'. Deze vloek houdt in dat hoewel overheidsprikkels in de vorm van subsidie- of belastingvoordeel op de korte termijn voordelig kunnen zijn, deze prikkels niet-economische keuzes stimuleren die op de langere termijn nadelig kunnen zijn voor een organisatie.

Het laatste empirische hoofdstuk (Hoofdstuk 7) onderzoekt de motivaties van bestaande fabrikanten om deel te nemen aan duurzame innovaties zoals EV's en draagt bij aan discussies op het gebied van duurzame innovatie. Naast mogeleijke voordelen zoals het behalen van 'first mover' voordelen, maatschappelijk verantwoord ondernemen en het anticiperen van toekomstig overheidsbeleid, tonen de resultaten aan dat de wens om een strategische ommekeer teweeg te brengen ook één van de factoren is die van invloed is op deelname aan duurzame innovatie. De resultaten geven inzicht in de redenen waarom en wanneer organisaties waarschijnlijk zullen investeren in duurzame innovatie en wat zij proberen te bereiken met het ontwikkelen van milieuvriendelijke technologieën.

11 Deutsche Zusammenfassung [Summary in German]

Das Automobil hatte im Verlauf des 20. Jahrhunderts bedeutende Auswirkungen auf unsere Gesellschaft. Während zu Beginn des Jahrhunderts Autos noch hauptsächlich von wohlhabenden Menschen genutzt wurden, so wurden sie bald zum Standardfortbewegungsmittel für jedermann. Autos haben seitdem unsere soziale Interaktion, die Arbeitswelt und den Transport von Gütern verändert. Sie bieten heute Mobilität und Freiheit in der Fortbewegung. Da das Automobil für viele Menschen ein Instrument zum Ausdruck von Gefühlen, Leidenschaft und Fahrerlebnis darstellte, entstanden gar kollektive Kulturen rund um das Automobil.

Jedoch sind Autos auch die Ursache gravierender Probleme. Bei der Produktion von Pkws werden beispielsweise große Mengen an Energie eingesetzt und die benötigte Verkehrsinfrastruktur für die stetig steigende Anzahl an Kraftfahrzeugen (Pkws) verursacht häufig einschneidende Veränderungen im Landschaftsbild. Zudem erfordert die Nutzung von Pkws hohe Mengen an Kraftstoff, ein Problem, dem erst in den letzten Jahren, in Zusammenhang mit einer Verknappung fossiler Rohstoffreserven, größere Aufmerksamkeit geschenkt worden ist. Erschwerend wirkt sich dabei der Umstand aus, dass sich ein Großteil der weltweit verbliebenen Erdölvorkommen in politisch instabilen Regionen dieser Welt befindet, was eine zuverlässige Versorgung mit Öl bzw. Treibstoff durch unzuverlässige Lieferwege gefährdet. Zudem tragen Autos zum Klimawandel bei. In Europa, beispielsweise, werden 20 Prozent aller CO_2 Emissionen allein durch Kraftfahrzeuge verursacht. Weiterhin haben Abgase, insbesondere in urbanen Gegenden, negative gesundheitliche Auswirkungen und erhöhen die Mortalität der von Umweltverschmutzung dieser Art betroffenen Bevölkerung.

Ein bedeutender Fortschritt, um diesen Herausforderungen zu begegnen, stellen heute sogenannte „emissionsarme Fahrzeuge“ dar (abgekürzt LEV, engl. Low-emission vehicles), wie zum Beispiel „Hybridfahrzeuge“, „elektrische Fahrzeuge“ oder „Brennstoff-zellenfahrzeuge“. Unglücklicherweise bedeuten LEVs jedoch nach wie vor eine Herausforderung für alle etablierten Automobilhersteller, indem sie beispielsweise die Vorherrschaft des Verbrennungsmotors bedrohen und die Kompetenzen, welche sich die Automobilhersteller im Verlaufe eines ganzen Jahrhunderts aufgebaut haben, in Frage stellen. Zudem ist die Produktion von LEVs ein „Henne-Ei-Problem“: LEVs werden nicht im größeren Stil hergestellt solange nicht eine ausreichende Auflade- und Auftankinfrastruktur

zur Verfügung steht. Andererseits wird diese Infrastruktur allerdings auch häufig nicht weiter ausgebaut solange keine hinreichende Nachfrage nach LEVs besteht.

In den vergangenen 20 Jahren haben Regierungen verschiedener Staaten verstärkt in die Entwicklung von LEVs durch staatliche Fördermaßnahmen eingegriffen, um eine weitere Verbreitung von LEVs zu ermöglichen. So wurden beispielsweise neue Plattformen zur Entwicklung von LEVs zur Verfügung gestellt, Gesetze erlassen, die zu Kraftstoffeffizienz und geringeren Emissionen verpflichten und weitere monetäre bzw. steuerliche Anreize für Käufer von LEVs in Aussicht gestellt. Bedenkt man die internationalen Aktivitäten von Automobilherstellern, stellen diese politischen Entwicklungen signifikante Herausforderungen dar, welche in der Industrie kritisch beobachtet werden.

Die verschiedenen Interventionen seitens der Politik haben einen Anreiz für die weltweit operierenden Automobilfirmen geliefert, in die Entwicklung von LEVs zu investieren. In den späten 1990ern wurden LEVs schließlich zum ersten Mal in größerem Umfang produziert. Das Interesse an saubereren, klimafreundlicheren Technologien stieg in diesem Zeitraum zudem rapide, so dass neue Produkte und Märkte erschlossen werden konnten. Dennoch führten verschiedene Interventionen der Politik, eine schnelle technologische Weiterentwicklung der LEVs, eine unsichere Marktlage und nicht zuletzt strategische Handlungen des Wettbewerbs zu erheblichen Unsicherheiten bei den großen internationalen Automobilherstellern.

Drei Probleme kamen insbesondere zum Tragen. Erstens veränderte sich die Marktsituation der Automobilfirmen. Hatten sie zuvor ein relativ stabiles legislatives Umfeld mit wenig gesetzlichen Vorgaben, mussten sie sich im Verlauf der Jahre vermehrt nun an viele verschiedene und sich kontinuierlich ändernde Auflagen der Politik halten. Durch ihre Internationalität waren die Automobilhersteller zudem nicht nur in ihrem Herkunftsland, sondern auch in vielen weiteren Ländern unterschiedlichen gesetzlichen Vorgaben verpflichtet. Diese Umstände bedeuteten eine erhebliche Herausforderungen. Es stellte sich z.B. die Frage, in welche Technologien die Firmen investieren sollten, weil verschiedene Länder unterschiedliche Technologie förderten. Allerdings bot dieses regulative Umfeld auch eine Chance, in der alle Automobilfirmen auch einen Wettbewerbsvorteil hätten erzielen können, indem sie vorausschauend Technologien entwickelten. Obwohl Chancen meist ungenutzt blieben, konnte beispielsweise Toyota einen Vorteil aus der Entwicklung des Modells „Prius“ ziehen. Die Firma wird heute als innovativ und nachhaltig angesehen.

Zweitens waren LEVs in der Produktion stets deutlich kostenintensiver als Fahrzeuge mit einem Verbrennungsmotor. Um jedoch für den Massenmarkt attraktiv zu sein, sollten

LEVs nicht mehr kosten als konventionelle Fahrzeuge. Daher erwies es sich als notwendig, LEVs vor Marktselektionsmechanismen zu schützen , zum Beispiel durch Subventionen von Regierungen oder Firmen bis sie mit konventionellen Fahrzeugen konkurrieren konnten. Um mehr über Brennstoffzellen-Fahrzeuge erfahren und sie verbessern zu können, haben manche Regierungen beispielsweise Projekte initiiert, welche die Testung der neuen Fahrzeuge unter lebensnahen Bedingungen ermöglichten. Ferner wurde in eine bessere Infrastruktur investiert und wurden die Konsumenten über Vorteile der neuen Technologien aufgeklärt. Daneben haben die Automobilfirmen die Entwicklung kostenintensiver Technologien zu signifikanten Teilen auch selbst finanziert, wie z.B. Daimler, das eine der größten Brennstoffzellen Testflotten weltweit aufgebaut hat. Kürzlich entschieden sich schließlich immer mehr Hersteller zur Produktion von elektrischen Fahrzeugen (abgekürzt EV, engl. electric vehicle).

Drittens unterschieden sich LEVs erheblich von Autos mit Verbrennungsmotoren (z.B. hinsichtlich Reichweite, Wartungsintensität, Fahrerlebnis) und machten Veränderungen in den Geschäftsmodellen der Autohersteller notwendig, z.B. in den Bereichen Preis, Wertschöpfungskette oder der benötigten Infrastruktur. Erschwerender Weise haben die Hersteller leider bestehende rigide Routinen, Ressourcen und Kompetenzen, welche selbst relativ einfache Veränderungen in ihren Geschäftsmodellen erschweren. Ein Weg dieses zu umgehen ist durch Kollaborationen mit Start-Ups oder durch die Unterstützung von Regierungen. Beispielsweise ist die Firma Nissan mit dem Start-Up Projekt „Better Place“ eine strategische Partnerschaft eingegangen, um handy-ähnliche Zahlungspläne für EVs anbieten zu können. Zusätzlich hat das Unternehmen großzügige Zuschüsse seitens der Regierung verschiedener Ländern erhalten, um Betriebsstätten für Komponenten einrichten zu können. Diese Umstände führten zu einem Abweichen von bis dato üblichen Geschäftspraktiken. Beispielsweise vergrößerte sich die Entfernung zwischen dem Ort der Montage und der Produktion der Kernkomponenten. Ungeklärt bleibt jedoch, inwieweit die historische Entwicklung (Pfadabhängigkeit) der Unternehmen und die Unterstützung der Regierung die neuen Geschäftsmodelle für LEVs beeinflusst haben.

Die oben dargestellten Probleme waren Forschungsgegenstand dieser Dissertation. Es wurde untersucht, wie sich das Zusammenspiel von politischen Interventionen und den Innovationsstrategien der Automobilhersteller im Laufe der Zeit entwickelt und wie dieses Zusammenspiel die Entwicklung von LEVs beeinflußt hat. Zudem hatte diese Dissertation eine Verbesserung des Verständnisses der Entwicklungen in der internationalen Automobilindustrie der letzten 15 Jahren im Hinblick auf emissionsarme Fahrzeuge zum

Ziel. Ein besonderes Augenmerk wurde auf elektrische Fahrzeuge gelegt. Zu diesem Zweck fokussierte sich die Dissertation auf die folgenden vier Kernfragen:

1. Wie haben sich emissionsarme Fahrzeuge international im Laufe der Zeit entwickelt und in welcher Weise haben *politische Interventionen die Innovationsstrategie von Firmen beeinflusst*?

2. *Welchen Einfluss hatten Schutzmechanismen* wie Subventionen von Regierungen und Firmen auf die Entwicklung von emissionsarmen Fahrzeugen?

3. Wie sind Firmen bei der Gestaltung von Geschäftsmodellen mit der Spannung des *disruptiven Charakters von elektrischen Fahrzeugen und dem Einfluss von politischen Interventionen* umgegangen?

4. Im Angesicht der Herausforderungen von emissionsarmen Fahrzeugen, welches waren die *strategischen Motivationen* der Automobilhersteller, dennoch intensiv in elektrische Fahrzeuge zu investieren?

Jede Frage wurde in einem empirischen Kapitel dieser Dissertation erörtert. Die empirischen Kapitel basieren auf einem umfangreichen Datensatz von verschiedenen Industrie- und Zeitungsquellen von 1997 bis 2010. Nach Durchführung einer Stichwortsuche mit den wichtigsten LEV Technologien wurde ein Datensatz erstellt, welcher 9.908 Artikel von zwei Handelszeitschriften (*Automotive News* und *WardsAuto World*), einem Automagazin (*Autoweek*) und einer Tageszeitung (*Financial Times*) beinhaltet. Der Datensatz wurde mithilfe der Datenanalyse Software Atlas.ti 6.2 analysiert.

Das erste empirische Kapitel (Kapitel 4) gab einen Überblick der Entwicklungen über die gesamte Zeitspanne. Es ermöglichte ein Verständnis der großen internationalen Akteure in der Industrie über mehrere Jahre angesichts technologischer, politischer und Markt-Entwicklungen. Die Ergebnisse zeigen, dass die Entwicklung von LEVs drei Perioden mit sich ändernden technologischen Schwerpunkten durchlaufen hat: *Erforschen von Batterien* (bis 1998), *Aufstieg von Brennstoffzellenfahrzeugen* (1999 bis 2005) und die *Wiederauferstehung von Elektrofahrzeugen* (2006 bis 2010).

Ferner wurden LEVs von Regierungen und Automobilherstellern in verschiedenen geographischen Regionen und auf verschiedenen politischen Ebenen beeinflusst. Zu Beginn der untersuchten Periode waren besonders US amerikanische und japanische Automobilhersteller mit der Forschung an von EVs beschäftigt. Diese Bestrebungen wurden besonders von der jeweiligen Regierungspolitik in Kalifornien und Japan angeregt.

Anschließend, verschob sich in den Jahren 1998 bis 2005 der Fokus verstärkt auf Hybrid Fahrzeuge (abgekürzt HVs, englisch: hybrid vehicles) und Brennstoffzellenfahrzeuge (abgekürzt FCs, englisch: fuel-cell vehicles), da die Leistung der EVs hinter den Erwartungen zurückblieben. Im Jahre 2006 schließlich bewirkte die Unterstützung der Regierung für umweltfreundliche Technologien und verbesserte Batterie-Technologien einen Aufschwung der EV Technologie. Europäische Automobilhersteller begannen aufgrund strikterer Richtlinien in Europa mehr LEVs zu produzieren und HVs behielten ihre Position in den Produktportfolios der meisten Automobilhersteller.

Bislang hatten die meisten Studien die Entwicklung der LEVs nur im Hinblick auf einzelne Länder betrachtet und die Tatsache vernachlässigt, dass ein technologischer Wandel immer international stattfindet. Basierend auf der empirischen Analyse der internationalen LEV Entwicklung, führt dieses Kapitel drei Mechanismen an, die erklären warum und wie ein technologischer Wandel international stattfindet: (1) Verbreitung von Best-Practice Gesetzen und internationale Richtlinien, (2) Internationalität von Firmen und (3) das Zusammenpassen der gesetzlichen Forderungen mit den Kompetenzen von Firmen.

Die Popularisierung von LEVs wird häufig mit dem Erlassen von Gesetzen, finanziellen Anreizen für Verbraucher oder öffentlich-privaten Projekte erklärt. Die Analyse in Kapitel 5 zeigte auf, dass zusätzlich zu derart „geschützten Räumen“, die von Regierungen gestellt werden, auch die Firmen selbst die Entwicklung und Kommerzialisierung von umweltfreundlichen Fahrzeugen „schützten“ indem sie „unrentable“ Aktivitäten unterstützen. Zur Untersuchung dieser „Schutzmechanismen“ – das heißt Innovationen werden vor den Kräften des Marktes in der Entwicklungs- und Kommerzialisierungsphase durch Anreize oder Niedrigpreise geschützt – setzt sich Kapitel 5 mit der Literatur sozio-technischer Systeme und der Innovations-Management Literatur auseinander. Aus einer Untersuchung von Daimler, General Motors und Toyota ging hervor, dass der Schutz der Firmen im europäischen, US-amerikanischen und japanischen Kontext erfolgreicher bei der Vermarktung von Hybrid- und elektrischen Fahrzeugen zu sein schien. Diese Firmen – während sie den öffentlich Schutz zu ihrem Vorteil nutzten – schützten die Technologien, z.B. durch finanzielle Förderung , zielgruppenspezifische Lösungen (z.B. für Flottenmanager) oder Zusammenarbeit mit anderen Stakeholdern (z.B. neuen Mitbewerbern).

Kapitel 5 verknüpfte die Innovations-Management Literatur mit der sozio-technologischen Literatur. Auf Basis wichtiger Ergebnisse dieser Forschungsrichtungen werden verschiedene Schutzmechanismen der Automobilwirtschaft systematisiert. Anschließend analysiert dieses Kapitel empirisch, welche Strategien am geeignetsten waren,

Innovationen, beispielweise vor mangelnde Nachfrage aufgrund ihrer Preisineffizienz, zu schützen. Die Analyse der LEV Entwicklung zeigt, dass Regierungen und Firmen gleichermaßen LEVs geschützt haben. Dabei war der Schutz durch Firmen grundsätzlich effektiver, allerdings stellte die Unterstützung durch Regierungen eine notwendige Voraussetzung dar, um technologische Entwicklungen weiter voran zu treiben.

Das dritte empirische Kapitel (Kapitel 6) setzte sich im Detail mit Geschäftsmodellen für die Kommerzialisierung von elektrischen Fahrzeugen (EVs) auseinander. Die Kommerzialisierung der EVs war für die Automobilhersteller eine schwierige Phase, da EVs stets kostenintensive Produkte darstellten, zum Aufladen eine neue Infrastruktur benötigten und eine kürzere Reichweite hatten als benzinbetriebene Pkws. Es wird allgemein angenommen, dass EVs nur durch disruptive Technologien oder radikale Veränderungen in den Geschäftsmodellen attraktiv gemacht werden können. Um zu verstehen, warum etablierte Firmen Schwierigkeiten dabei hatten, disruptive Innovationen wie EVs durch neue Geschäftsmodelle auf den Markt zu bringen, beschäftigt sich Kapitel 6 mit dem Konzept der Pfadabhänigkeit (d.h. dem Einfluss der historischen Entwicklung eines Unternehmens auf zukünftige Entwicklungen). Zusätzlich zu dem Kurs, den die „etablierten Firmen“ aufgrund ihrer Firmengeschichte einschlugen, hat die Unterstützung verschiedener Regierungen überraschenderweise eine erfolgreiche Verbreitung der EVs verhindert. Der Prozess, in dem dies geschah, wird als „Anreiz-Fluch“ bezeichnet, welche Firmen dann unterliegen, wenn Anreize welche von Regierungen gegeben werden, zu kontraproduktiven Entscheidungen führen. Dieser Fall tritt beispielweise ein, wenn eine Regierung den Verkauf eines Produktes auf einem Markt fördert, für den dieses Produkt schlecht geeignet ist. Dies ist geschehen in Fall des norwegischen Automobilhersteller Think. Großzügige Fördermittel in den U.S. veranlassten das Unternehmen ihre Elektrofahrzeuge der Größe eines Smarts in den USA zu produzieren und zu verkaufen. Neben anderen Gründen war das Fahrzeug nicht für den U.S.-amerikanischen Markt geeignet, fand keinen Absatz und die Firma meldete bald später Insolvenz an.

Das letzte empirische Kapitel (Kapitel 7) untersuchte schließlich die Motivationen von etablierten Automobilherstellern in nachhaltige Innovationen wie EVs zu investieren und trägt damit zum Diskurs über nachhaltige Innovationen in der Literatur bei. Nachhaltige Innovationen leiden oft unter dem Problem des „Entgleitens der Wertschöpfung“. Dies bedeutet, dass die Innovationen zwar einen ökologischen oder sozialen Wert haben, dieser jedoch für die Firmen nicht kommerzialisierbar ist da die meisten Kunden zum Beispiel nicht bereit sind, höhere Preise für Elektrofahrzeuge zu zahlen. Wie bereits erwähnt wurde, sind

EVs daher derzeit noch für die meisten Privatkunden unattraktiv. Und tatsächlich zeigt eine Analyse von Firmenmeinungen in diesem Kapitel, dass die meisten Automobilhersteller keinen Markt für EVs sehen. Das erklärt, warum die Mehrheit der etablierten Firmen nur Konzeptfahrzeuge oder Testreihen entwickelt haben. Nur einige wenige, darunter General Motors, Nissan und Mitsubishi, entschieden sich für die Massenproduktion von Elektrofahrzeugen. Neben der Tatsache, dass diese Firmen interessanterweise einen Markt für EVs sahen, betrachteten sie EVs – den Volt, den Leaf und den iMiev – als so genannte „Halo"-Vehikel („Heiligenschein-Fahrzeuge") um Technologieführer zu werden, als Mittel um Unterstützung vom Staat zu erhalten, um Bußgelder vom Staat zu verhindern oder als Mittel zum Zweck, um strategische Umschwünge leichter herbeiführen zu können. Diese Motivationen verdeutlichen, warum und wann Firmen in nachhaltige, umweltfreundliche Innovationen investieren. Der gesellschaftliche Nutzen tritt dabei gegenüber einer utilitaristisch-ökonomischen Motivation offenbar deutlich zurück.

Abschließend ist festzuhalten, dass die Erkenntnisse dieser Dissertation besondere Implikationen für Unternehmen der Automobilwirtschaft haben. Ein zentrales Thema dieser Dissertation waren Geschäftsmodelle für LEVs und die Trägheit von etablierten Firmen in der Industrie, bestehende Geschäftspraktiken zu ändern. Die bestehende Literatur suggeriert, dass disruptive Geschäftsmodelle in neuen Organisationseinheiten außerhalb von Unternehmen entwickelt werden sollten, beispielsweise als Spin-Offs. Diese Praktiken sind in der Automobilindustrie jedoch schwer umsetzbar, da hohe Investitionen für die Produktentwicklung und Produktion notwendig eingesetzt werden müssen. General Motors hat eine separate Geschäftseinheit entwickelt – die Marke Saturn, die auch für den EV1 verantwortlich war. Nichtsdestotrotz ist dieser Versuch gescheitert und Saturn wurde geschlossen. Dennoch könnte im Falle von LEVs die Schaffung einer separaten Geschäftseinheit eine mögliche Lösung sein, denn LEVs benötigen andere Geschäftspraktiken, die am besten in separat organisierten Einheiten (siehe Kapitel 6) umgesetzt werden können. Interessanterweise hat BMW bereits eine neue Einheit für seine umweltfreundlichen Autos geplant, das sogenannte Projekt „i", und Toyota zieht bereits in Erwägung, den Prius als eigenständige Markezu kommerzialisieren.

Auch in Zukunft werden LEVs voraussichtlich eine bedeutende Rolle für Automobilfirmen spielen. Jedoch wird der Übergang zu der einen oder anderen Technologie nur schleichend vorangehen. Obwohl Hybridfahrzeuge bereits in den Produktportfolios der Autohersteller verankert sind, stellen sie möglicherweise nur eine Übergangstechnologie für elektrische oder Brennstoffzellen Fahrzeuge dar, die das Potenzial haben CO_2-emissionsfrei

zu sein (abhängig von der Energiequelle, die sie benutzen). Derzeit scheinen elektrische Fahrzeuge der Spitzenkandidat für die führende LEV Technologie zu sein (siehe Kapitel 4). Dennoch sollten optimistische Ausblicke, die eine schnelle Elektrifizierung von Fahrzeugen vorhersagen – wie beispielsweise in Reports von Beratungsunternehmen – mit Vorsicht interpretiert werden. Wie die Kapitel 5, 6 und 7 darlegen, entwickelt sich die Industrie langsam, nicht nur aufgrund ihrer Pfadabhängigkeit, sondern auch wegen der Trägheit, welche ein Resultat der sozialen Einbettung von Autos in der Gesellschaft ist. Die Mühlen der Fahrzeugindustrie mahlen langsamer als beispielsweise die der IT-Technologie, in der neue Technologien deutlich schneller auf den Markt gebracht werden. Das Fehlen einer geeigneten Infrastruktur und den großen Investitionen für Entwicklung und Produktion sind nur einige der vielen Hindernisse die einem Wandel zur breiteren Verbreitung von EVs im Weg stehen, denn auch die Konsumenten müssen für die neue Technologie begeistert werden. Hieraus ergibt sich die Notwendigkeit für Automobilhersteller innovative Wege zu finden, um Kosten zu drücken oder zu verhindern und offensichtliche Probleme und Herausforderungen der Infrastruktur zu meistern, bevor der Wandel an Geschwindigkeit zulegen kann. Autos sind häufig die zweit-teuerste Investition für Konsumenten (nach dem Kauf eines Eigenheims) und im Durschnitt fahren Vehikel etwa 17 Jahre lang. Innovative Geschäftsmodelle sollten sich durch eine Beschleunigung aller Prozesse auszeichnen. Wie auch immer die Reise weitergeht, sie wird auf jeden Fall mehr und mehr elektrifizierend sein.

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Prior to his PhD, René worked as a strategic controller for the GEA Group. He also co-founded an online platform which provides telemedicine. René's research and practical experience informs his teaching in International Business, Strategic Management, and Sustainability for Master, Bachelor and MBA students.

This dissertation explores the developments in the international car industry from 1997 to 2010 in relation to low-emission vehicles, with specific attention to electric vehicles. More specifically, the study seeks to better understand strategies of car manufacturers and the interplay of particularly incumbents with governments. In recent years, interest in cleaner, more climate-friendly technologies – such as those related to hybrid, fuel-cell and electric vehicles – has grown rapidly, and new products and markets are emerging, with governments often trying to stimulate such a move towards innovation and lower emissions. However, there is not much research that systematically investigates the drivers and implications for companies in the car industry to move in such directions. This dissertation aims to address this gap by shedding light on company-government interactions on the basis of an analysis of developments over time. In this way, this study provides input to a (re)consideration of government policy as well as of corporate strategy and sustainable business models.

