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Incumbents? incentive and opportunity to innovate: Large car manufacturers in the market for electric vehicles

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Abstract

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commercialization period (2007-2011), large car manufacturers with both a strong incentive and a strong opportunity to innovate, i.e. firms that sold little ICEVs and had a strong EV asset position, sold significantly more EVs. On the basis of these quantitative analyses of asset positions and EV sales, this paper offers a typology of market strategies.

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Abstract

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1. Introduction

Electric Vehicles (EVs) provide zero tailpipe emissions and are an important technological solution to our unsustainable mobility system, in particular to the problem of smog formation that affects many large cities. The EV constitutes a radical innovation that completely differs from the established Internal Combustion Engine Vehicle (ICEV) (Bakker et al., 2012a). Such radical innovations build on a completely new technology (Tushman and Anderson, 1986) and tend to be competence-destroying for incumbents, because these innovations require radically different skills than the established technology (Henderson and Clark, 1990). Different literatures have argued that this competence-destroying nature inhibits incumbents to radically innovate (Christensen, 1997, Nelson and Winter, 1982, Ahuja and Lampert, 2001, Henderson, 1993). The tendency of incumbents to pursue little or no radical innovation has been challenged by Chandy and Tellis (2000). As the automotive industry is dominated by a small number of large incumbent car manufacturers, the commercial success of the EV may be codependent on the decision of large car manufacturers to radically innovate. In this study we aim to determine why some incumbent car manufacturers do radically innovate in the field of EVs, and others do not. By studying this divide between incumbents in their decision to radically innovate, we add to the literature on incumbents' tendencies to radically innovate, which has generally focused on incumbents as a homogeneous group.

For a large car manufacturer to exploit an innovation as the EV, it requires both incentive and opportunity to innovate (Swann, 2009). The *incentive* to innovate refers to the incentive of firms to enhance their competitiveness and increase their market share by introducing innovations (Swann, 2009: 218). The *opportunity* to innovate refers to the investments a firm can make to support innovation (Swann, 2009). Firms reveal their opportunity to innovate by the amount of assets they have built up in a particular technology (Lieberman and Montgomery, 1998, Silverman, 1999). Firms will be able to market greater amounts of a new technology when they have invested in R&D and have built up a substantial amount of assets. The literature suggests that incumbents may have the opportunity to innovate (Chandy and Tellis, 2000), i.e. the assets necessary to exploit an innovation, but not the incentive because they do not want to cannibalize

on their own profitable products built on the existing technology (Chandy and Tellis, 1998, Ali, 1994, Reinganum, 1983).

These findings can also be applied to the case of EVs. Previous research has demonstrated that large car manufacturers account for a large part of the technological EV development (Wesseling et al., 2013, Oltra and Saint Jean, 2009, Frenken et al., 2004), suggesting that these firms indeed have the opportunity to radically innovate. Moreover, many large car manufacturers have a very profitable competitive position that relies on the current ICEV technology. There appears to be little incentive for these firms to commercially exploit a radical and competence-destroying innovation such as the EV, as it would undermine their existing profitable position. On the other hand, the recent financial crisis strained the profitability of several large car manufacturers (Wells and Nieuwenhuis, 2012), which may provide them with an incentive to challenge the competitive position of their more profitable rivals by exploiting radically innovative EVs. In conclusion, some large car manufacturers may have both the incentive and opportunity to exploit EVs, whereas others may lack the incentive to innovate. We add to the literature on incentive and opportunity to innovate, by comparing these concepts between incumbents and relate them to the sales of EVs.

In recent history, the EV experienced several periods of increased interest by large car manufacturers (Wesseling et al., 2013, Mom, 2004). These periods of interest may have been triggered by different factors. For example, in the 1990s regulations were implemented that pressured large car manufacturers to develop more sustainable vehicles. The Californian Air Resources Board's (CARB's) introduction of the Zero Emission Vehicle (ZEV) mandate in 1990 is often perceived as the most important piece of legislation in this regard (Hoogma et al., 2002, Kemp, 2005, Collantes and Sperling, 2008). A recent period of EV interest started in 2007 (Wesseling et al., 2013) that may have been triggered by emerging commercial opportunities for EV technology (Magnusson and Berggren, 2011). Such commercial opportunities may provide incentive for less profitable large car manufacturers to commercially exploit EVs on a mass-market scale.

In this study we aim to gain more insight in what drives large car manufacturers to exploit radical and competence-destroying innovations such as the EV. With this goal in mind, we pose the following research question: *'How did the incentive and opportunity to innovate affect large car manufacturers' decision to mass market EVs over the period 1990-2011?'*

We focus our study on the timeframe 1990-2011, to take into account the effect of strong regulatory pressures emerging in the 1990s that coincide with increased interest of large car manufacturers in developing EV technology. This timeframe also allows us to compare the effect of regulatory pressures with the incentive and opportunity to innovate in the more contemporary period of EV interest that is characterized by better commercial opportunities for the EV. On the basis of our analyses and using this timeframe, we identify three different types of market strategies of the large car manufacturers, i.e. the first mover, quick follower and laggard strategies. In our typology of market strategies, we show how these strategies are determined by the firms' incentive and opportunity to innovate.

Our paper also makes a contribution in terms of the type of data that is used to study the incentive and opportunity to innovate. Previous research has used different indicators to study technological development, such as patents, prototypes and partnerships (Bakker, 2010, Sierzchula et al., 2012a, Frenken et al., 2004). In this paper, we make a contribution by combining these different types of data in one study, which allows us to more comprehensively study the differences between the EV asset position and market strategies of incumbents.

The remainder of this paper is structured as follows. In Section 2, the Theoretical Framework, we formulate hypotheses regarding the effect of regulatory pressures and the incentive and opportunity to innovate on large car manufacturers' EV sales. We also discuss the literature on market strategies. In the subsequent section on Methods, we discuss the operationalization of the concepts used and the data collection and analysis. Section 4 displays the results, containing our findings on the basis of a series of nonparametric tests to study our hypotheses; and a more qualitative analysis of large car manufacturers' market strategies. Finally, the Conclusions and Discussion section summarizes our findings and its limitations and suggests some directions for further research.

2 Theoretical framework

In Section 2.1 of this theoretical framework we follow Swann (2009), in arguing that for a firm to radically innovate, it requires both incentive and opportunity to do so. This incentive and opportunity, we argue in Section 2.2, determines the market strategy of the firm, be it a first mover, quick follower or laggard strategy (Lieberman and Montgomery, 1998, Freeman and Soete, 1997). Moreover, these incentives and opportunities to innovate change as the radical innovation matures and regulatory and market developments take place over time. Because such changes took place in the field of EVs during our period of study, Section 2.3 argues how car manufacturers' market strategies are likely to have been affected differently by the market and regulatory developments.

2.1 The incentive and opportunity to radically innovate

In the economics of innovation, the relation between innovation and market structure has been studied extensively to understand the prevalence of innovations at the industry level. Swann (2009) summarizes the debate and makes a distinction between an incentive to innovate and an opportunity to innovate as two important factors influencing innovative output. We will describe these two factors in the following sections, and illustrate how these are relevant in an industry in which car manufacturers are becoming increasingly more innovative in the field of the EV, a radical and competence-destroying innovation with respect to the established ICEV.

2.1.1 The incentive to radically innovate

The incentive to innovate refers to the incentive of firms to enhance their competitiveness and market share by introducing innovations (Swann, 2009: 218). Radical and competence-destroying innovations, like the EV, undermine the competitive position of incumbents, as previous technology-specific competences are rendered obsolete by such innovations (Tushman and Anderson, 1986). In a review on incumbents' tendencies to radically innovate, Chandy and Tellis (2000) stress that incumbents that have a profitable competitive position in the existing technological regime have less incentive to radically innovate because they do not want to endanger their position, which draws from the existing technology and protects them from rivals and the threat of new entrants. However, this argument does not hold for firms that are less profitable and find it hard to compete with other firms in the industry. For these firms, radical innovation may be a means to escape the income-restraining situation in the existing market that results from their inferior competitive positions (Swann, 2009, Mensch, 1979, Barley, 1986). Instances in which incumbents challenge each other in new technological fields, causing incumbent losers to exit the industry, have been identified by Bergek et al. (Bergek et al., 2008) in the gas turbine industry and are labeled late industry shake-outs (Klepper and Simons, 2005). The automotive industry can be characterized as a differentiated oligopoly (Plourde and Bardis, 1999, Kwoka, 1992) that has different levels of competition in different product segments; some car manufacturers are making significant profits and others heavy losses (Wells and Nieuwenhuis, 2012). In line with Swann (2009), we assume that the radical and competence-destroying innovation of the EV constitutes a means for less profitable incumbent car manufacturers to undermine the existing competitive positions of its rivals and potentially establish a new market that is more profitable to the innovators. However, some car manufacturers are already making tremendous profits based on the existing technology of ICEVs, creating vested interests and a lack of incentive to radically innovate (Chandy and Tellis, 2000). In this study we will explore whether both types of incumbents are present: profitable large car manufacturers that aim to defend their competitive position and market share in the ICEV regime, and less-profitable large car manufacturers that aim to gain market share in the EV regime.

2.1.2 The opportunity to innovate

In addition to an incentive to innovate, firms must also have an opportunity to innovate when they wish to introduce new technologies into the market (Swann, 2009). According to Swann (2009), an opportunity to innovate depends on the financial possibilities of a firm to invest in innovation, and can be measured by a firm's capital available for investments in R&D. However, before firms are able to introduce an innovation into the market, they need to invest their capital in assets that facilitate the development of an innovative technology. In line with the resource-based view of the firm, we therefore consider the assets of a firm as a more direct measure of the firm's opportunity to innovate (e.g. Silverman, 1999), and thus as a good indicator of the firm's ability to introduce a viable new product into the market. Assets are the result of investments in financial and human capital that firms have made in a particular technological direction, and determine the firm's actual opportunity to innovate in this direction.

A firm's opportunity to radically innovate is determined by its unique and difficult to imitate resources, i.e. its assets that are necessary for the exploitation of the radical innovation (Teece et al., 1997). The aggregate of a firm's assets is referred to as its asset position. These assets may be technology-specific (Teece et al., 1997), implying that assets that support the exploitation of ICEVs may not support the exploitation of EVs. Different types of firm-specific assets can be distinguished, including technological, infrastructural, complementary and reputational assets. *Technological assets* entail protected knowledge necessary for the development and application of an innovation (Pavitt, 1998), in this case the EV. *Infrastructural assets* refer to the technologies necessary for infrastructure-dependent innovations to operate profitably (Teece, 2006). The success of the EV is, for example, codetermined by the presence of a charging infrastructure (Egbue and Long, 2012). *Complementary assets* are crucial to profit from innovations and include, for example, distribution channels, marketing and manufacturing facilities (Rothaermel, 2001). Finally, *reputational assets* result from the company's alignment with existing norms and values, which forms customers' perception of the company, especially their brand experience (Teece et al., 1997). The strategic importance of these four assets has been acknowledged in the field of EVs for technological assets (Wesseling et al., 2013, Van Den Hoed, 2005), infrastructural assets (Egbue and Long, 2012, Pohl and Yarime, 2012), complementary assets (Dyerson and Pilkington, 2005) and reputational assets (Bakker, 2010). We expect that firms with a stronger opportunity to innovate, (i.e. firms with a greater EV-related asset position), will introduce more EVs into the market.

2.2 Market strategies

In the previous sections, we argued that the more incentive and opportunity to innovate a firm has, the more likely it is to introduce a radical innovation. In this section we focus on the market strategies through which a firm can introduce an innovation into the market, and argue how such strategies are related to the concepts of incentive and opportunity to innovate.

The market strategy of a firm dictates how the firm intends to introduce a radical innovation; a firm may employ different market strategies for different innovations (Lieberman and Montgomery, 1998, Freeman and Soete, 1997, Teece et al., 1997). Within the strategic management literature, three strategies can be distinguished: first movers, quick followers and laggards¹ (Lieberman and Montgomery, 1998, Freeman and Soete, 1997, Lieberman and Montgomery, 1988, Robinson and

¹ We acknowledge that some articles only distinguish between two strategies, i.e. early and late movers (Lieberman and Montgomery, 1998), and that the nomenclature of the three related exploitation strategies differs in the literature e.g. Freeman and Soete (Freeman and Soete, 1997) talk about offensive, defensive and imitative strategies, whereas Robinson and Chiang (Robinson and Chiang, 2002) refer to market pioneers, early followers and late entrants. We find entrants a confusing term in the context of the incumbent firms we research; therefore, we use laggards instead.

Chiang, 2002). First movers intend to become mass-market pioneers and subsequently stay ahead of competitors through technological lead-time (Freeman and Soete, 1997, Golder and Tellis, 1993). Firms with a quick follower strategy leave the decision of exploiting a radical innovation open, until a first mover goes to the market. Quick followers attempt to avoid the costly mistakes made by first movers and quickly follow them onto the market (Lieberman and Montgomery, 1998, Freeman and Soete, 1997). Laggards are less engaged in innovative activities and attempt to acquire rents from reducing overall costs by minimizing R&D. They are the last to enter the market (Freeman and Soete, 1997, Jovanovic and MacDonald, 1994).

Relating these three market strategies to the concepts of incentive and opportunity to innovate and to the case of EVs, we expect firms with a strong incentive and a strong opportunity to radically innovate to adopt a first mover EV market strategy as these firms are most willing and able to bear the costs and risks of pioneering the radical innovation and its necessary infrastructure. Firms with some incentive and opportunity to innovate are likely to employ a quick follower strategy, as they may not be willing or able to pioneer the innovation, but do not want to fall behind on their more innovative rivals. Firms with either little incentive or little opportunity to innovate are expected to employ a laggard strategy, as they are either not willing or not able to introduce the radical innovation into the market.

2.3 External impacts on strategies

The incentives and opportunities of firms to innovate, and their market strategies, may be influenced by factors external to the firm (North, 1990). Firms operate in a system of regulatory, market and technological components that changes over time and influences the market strategies of firms (Hekkert et al., 2007). Especially in the field of EVs significant regulatory, market and technological developments have taken place over the period 1990-2011 (Wesseling et al., 2013, Wells and Nieuwenhuis, 2012, Magnusson and Berggren, 2011, Hoogma, 2000). During the 1990s, EV developments were especially stimulated by regulatory developments, as substantial consumer demand for EVs was lacking (Collantes and Sperling, 2008) and technological hurdles like battery costs, driving range and a recharging infrastructure needed to be overcome (Dyerson and Pilkington, 2005). The most influential policy was a technology-forcing regulation called the ZEV (Zero Emission Vehicle) mandate, introduced by the Californian Air Resources Board (CARB) in 1990 (Kemp, 2005, Collantes and Sperling, 2008, Dyerson and Pilkington, 2005, Hoogma, 2000). The ZEV mandate stated that "While meeting the fleet average requirement, each manufacturer's sales fleet of passenger cars and light-duty trucks from 0 to 3750 lbs LVW [Loaded Vehicle Weight], shall be composed of at least 2% ZEVs each model year from 1998 through 2000, 5% ZEVs in 2001 and 2002, and 10% ZEVs in 2003 and subsequent model years" (CARB, 1990: 22). This mandate applied to car manufacturers that sold more than 35,000 vehicles in California per year and included Chrysler, Ford, General Motors, Honda, Mazda, Nissan, and Toyota (Collantes and Sperling, 2008). However, in 1996 oil companies (Grant, 1995) and car manufacturers (Kemp, 2005) lobbied against the continuation of this mandate, resulting in relaxation and extension of the mandated targets (Hoogma, 2000). The relaxation of the ZEV mandate constituted a decrease in regulatory pressures, after which car manufacturers lost interest in EVs and started to refocus on HEVs and HFCVs (Wesseling et al., 2013, Dijk and Yarime, 2010). Technological uncertainty and market uncertainty prevented car manufacturers from exploiting EVs more extensively during the 1990s (Dyerson and Pilkington, 2005). Because EV developments during the 1990s were primarily triggered by the CARB's technology-push mandate, we formulate the following hypothesis:

Hypothesis 1: Large car manufacturers that fell under the CARB's 2% ZEV mandate will have a) developed a stronger opportunity to innovate and b) will have marketed more EVs during the 1990s than large car manufacturers that did not fall under this mandate.

In the late 2000s, car manufacturers regained interest in the EV (Wesseling et al., 2013). During this period car manufacturers were not triggered by stringent technology-push regulation. Instead,

car manufacturers saw market opportunities emerge for the EV (Magnusson and Berggren, 2011). These opportunities emerged because technological hurdles like battery costs were partly overcome due to developments in other sectors focusing on mobile phones and laptops (Magnusson and Berggren, 2011). Furthermore, increasing regulatory support such as tax rebates supported the adoption of EVs by consumers (Magnusson and Berggren, 2011, Sierzchula et al., 2012b). The fact that EVs became an emerging market opportunity in the late 2000s implies that less profitable large car manufacturers may now attempt to exploit the commercialization of EVs. Hence, as of the late 2000s, large car manufacturers that are less profitable in the ICEV regime may attempt to exploit EVs to undermine the asset positions of their more profitable rivals and by doing so establish a more profitable market position for themselves. They require not only a strong incentive to innovate, but also the opportunity to do so. We therefore formulate a second hypothesis as follows:

Hypothesis 2: Large car manufacturers that have a stronger incentive and opportunity to innovate will have marketed more EVs than their competitors during the early stage of EV commercialization.

3. Methods

3.1 Research design and operationalization

A considerable body of literature has used different indicators to study the technological development of low emission vehicles. These indicators include patent applications, prototypes, production models and partnerships (Wesseling et al., 2013, Bakker, 2010, Bakker et al., 2012b, Sierzchula et al., 2012a, Frenken et al., 2004). So far however, no research has yet attempted to combine these different indicators. In this paper we contribute to this literature on technological developments by incorporating the different types of data (see Table 3.1).

Our combined analysis of patent applications, prototypes, production models, partnerships, EV sales and income in the ICEV regime, enabled us to study more comprehensively the differences between different groups of large car manufacturers in building their EV asset position and in their EV market strategies, over the period 1990-2011. Our analysis focuses on the period 1990-2011, because 1990 marks the start of a period of renewed interest in the EV, caused by the CARB's ZEV mandate (Hoogma, 2000). Large car manufacturers are defined in this study as car manufacturers producing more than a million cars in the year 2011. According to the 2011 personal vehicle sales figures from the International Organization of Motor Vehicle Manufacturers, fifteen car manufacturers comply with this definition (OICA, 2012); based on the 2010 vehicle production data, the same fifteen car manufacturers would be selected (OICA, 2011). We study each of these large car manufacturers, meaning that our research sample matches our research population. The companies included accounted for 84.4% of all personal vehicle sales in 2011 and include Toyota, Volkswagen, General Motors, Hyundai, Honda, PSA, Nissan, Ford, Suzuki, Renault, Fiat, BMW, Daimler AG, Mazda and Mitsubishi (OICA, 2012).

Table 3.1 displays how each of the concepts discussed in the Theoretical framework, is operationalized into their respective indicators and what sources are employed to retrieve data on these indicators. First, whether a firm was subject to technology forcing policy was measured by whether it fell under the 2% ZEV restriction of the CARB's mandate. Six firms of the population of fifteen large car manufacturers fell under this restriction.

Second, the incentive to innovate, approached by a firm's profitability in the ICEV regime was measured by the firm's net income. ICEVs account for more than 95% of vehicles sales² and hence

² Although no specific data of Low Emission Vehicle sales are available, Pohl and Yarime (2012) find that over the period 1997-2008 2.14 million hybrids have been sold; we find that over the EV models introduced over the period 1990-2011 sold approximately 105 thousand times; the number of Hydrogen Fuel Cell Vehicles and Plug-in Hybrid Vehicles sold over this period is negligible. This aggregated amount of LEV sales over these respective periods comprises only 3.6% of 2011's total cars sales.

account for most of the firm's net income. Net income is therefore a good indicator for profitability in the ICEV regime.

Third, the opportunity to innovate, or asset position, is comprised of several types of assets, each with its specific indicators. Technological assets were measured by patent applications and by partnerships that are aimed at developing or exchanging knowledge or components regarding the EV, like the battery or the electric drivetrain. Despite the drawbacks of using patents or patent applications, i.e. the tendencies to patent might differ between companies (Van Den Hoed, 2005, Archibugi and Pianta, 1996), patent applications still provide a good indicator for the technological know-how developed by a firm (Archibugi and Pianta, 1996, Griliches, 1998). Besides developing know-how internally, firms may also co-develop knowledge with external organizations, e.g. through R&D alliances. Firms may also acquire knowledge from external organizations (e.g. through licensing), or firms may acquire knowledge integrated in components (e.g. through supply contracts). Partnerships, which include any type of alliance or contract with the goal to co-develop or acquire EV-related knowledge, are therefore a useful complement to the patent data³.

Similar to technological assets, infrastructural assets were measured by patent applications and partnerships aimed at developing or exchanging knowledge or components. For the infrastructural assets, the components or knowledge did not concern the EV itself, but its charging infrastructure and compatibility with this infrastructure. Complementary assets were measured by partnerships geared towards acquiring production facilities and distribution channels, and thus concern assets that are necessary to exploit an innovation.

Reputational assets are measured by prototypes, which are models presented at auto-shows that, at the time of presentation, were not (yet) in production. However, the interpretation of this indicator remains debated (Bakker et al., 2012b). In general, researchers stress that prototypes are used for testing and to demonstrate technological progress (Suarez, 2004), or that they are part of a trial and error learning process (Clark et al., 1987, Thomke et al., 1998, Thomke, 1998). However, in the case of the automotive industry prototypes also have an important signaling role, especially in the case of Low Emission Vehicles (Bakker et al., 2012b). Bakker *et al.* (2012b) underline that car manufacturers use such prototypes to boost their reputation and influence actors outside the company, like policymakers and consumers. In several interviews that we conducted with car manufacturer executives and an editor-in-chief of an automobile magazine, interviewees mentioned that reasons for developing prototypes include testing, shaping and even claiming future markets, as well as testing technological performance. All interviewees stressed that creating an innovative and sustainable company image was key to promoting prototypes. Such an image would not only benefit LEV sales but also sales of the ICEVs produced by those companies. Moreover, the interviewees pointed out that most prototypes cannot even drive, and their technological performance is often an estimate instead of a real-world test record. Hence, prototypes are primarily used to acquire reputational assets.

Fourth, the firm's EV market strategy was measured by its EV sales volume. Complementary information, including the moment the vehicle was first commercially available, the number of models introduced into the market, and whether the EVs sold are purpose-built EVs or based on an ICEV model, will be used to classify the exact EV market strategies of large car manufacturers.

³ Because co-developed knowledge may also be patented by the alliance partners, we checked for overlap between the patent and partnership data by determining if any patents included both the participating firms on a patent during the alliance and several years after because of possible delays in the patent process. However, no such overlap was found, suggesting the patent and alliance data are suitable complements.

Table 3.1, Concepts, indicators and data sources.

Concepts:		Indicators:	Data sources:
Subject to technology forcing policy		Falling under the CARB's 2% ZEV restriction	(CARB, 1990)
Incentive to innovate / profitability in the ICEV regime		Net income in dollars	Datastream
Opportunity to innovate / Asset position	Technological assets	Patent applications and partnerships oriented at developing or exchanging EV knowledge or EV components	IPO patent database and media statements; company websites
	Infrastructural assets	Patent applications and partnerships oriented at developing or exchanging EV-infrastructure knowledge or EV-infrastructure components	IPO patent database and media statements; company websites
	Complementary assets	Partnerships geared towards acquiring production facilities and distribution channels	Media statements; company websites
	Reputational assets	Prototypes, i.e. models presented at auto shows that are not (yet) in production	Annual reports, websites, documents
EV market strategy		EV sales volume	Annual reports, websites, documents
		Complementary information, including timing to market; number of models introduced on the market; purpose-built EV or not	Interviews, Annual reports, websites, documents

3.2 Data collection

Data on the car manufacturers' annual net income in dollars were obtained from Datastream, a global financial database (Thomson Reuters, 2013) that contains the data of all fifteen car manufacturers over our study period.

Patent data were collected using the International Patent Office's (IPO) Global Patent Index program (International Patent Office, 2013), because this program contains worldwide patent data, and thus better represents technological developments worldwide. We used patent applications instead of patent grants, because a significant amount of patent documents do not provide information on patent grants at the time of indexing (European Patent Office, 2013). Moreover, we applied a publication level filter to exclude patent applications that were withdrawn during the period. To select patent applications related to technological assets, we used a search query based on EVs; to acquire patent applications related to infrastructural assets, we employed a search query related to EV infrastructure. The queries used resemble those constructed by Wesseling et al. (2013); see their paper for more information on the queries' construction. Due to the 18-month period of secrecy and processing time of patent applications, the database does not include all patent applications of recent years. We controlled for the decreasing trend in patent applications by dividing the number of EV and infrastructure related patent applications of each large car manufacturer in every year by the total amount of patent applications of the fifteen car manufacturers in the same year. Our patent study resulted in 7611 relevant patent applications.

Based on the work of Sierzchula et al. (2012b), prototype data were collected using different sources, including government reports, annual reports, websites, auto-shows, newspaper articles, company press releases or personal contacts with the manufacturer. Combining these sources allows for a broader coverage of prototype models and the triangulation that is needed to pinpoint the exact date of each prototype's release. A total of 126 prototypes were collected.

Partnership data were collected from the LexisNexis database that includes numerous large newspapers, business magazines and automotive magazines. Schilling (2009) points out that such media-oriented data collection approaches have been applied to construct various professional

databases and have yielded reliable results for inter-firm analyses (Hagedoorn, 2002, Rice and Galvin, 2006). To acquire relevant data we used the Power Search function, and applied a search query that contains any combination of words that include 1) any term synonymous with or comparable to 'partnership'; and 2) any term synonymous with or comparable to 'electric vehicle'; and 3) to further narrow down the results and improve relevance the articles should include the term 'battery or batteries'⁴. This query provided 6151 articles that were published in the period 1990-2011. Each article was scanned for relevant partnerships. For each partnership, data were collected on the actors involved, the goal of the partnership, i.e. developing technological or complementary assets, and the year of formation. Company websites and annual reports were consulted for additional information. We included only reports of partnerships that had already been formed, but not the announcements of future formations. Additionally, double counts of partnerships were excluded and endings of partnerships were omitted from the analysis. This resulted in 171 relevant partnerships.

EV sales data were based on websites, documents and car companies' annual reports. These sales data were collected in 2012 and attributed to each production model's year of market introduction. A total of 37 commercialized EV production models were included in our database.

To get more information on car manufacturers' market strategies, besides consulting websites, documents and annual reports, we conducted three complementary interviews, one with the head of future powertrains department of Volkswagen and one with a previous Acting Chief Executive Officer of General Motors. A third interview was conducted with an editor-in-chief of an automobile magazine to get more insight in the role of prototypes.

3.3 Methods of data analysis

To test our hypotheses, we took several interrelated steps. As a first step in the analysis, we plotted our R&D and commercialization trends over the study period to see if we could distinguish unique periods in the development of EVs. We measured R&D trends by our indicators for technological assets, including both patent applications and partnerships. The additional trend in commercialization was measured by EV sales per production model year. Well-defined periods allow us to better contextualize recent EV developments, to highlight significant changes in EV strategies over time and to focus our analysis on periods of interest.

Second, we wanted to see if the concept of asset position could be represented by a single component that explains the variance of its underlying technological, infrastructural, complementary and reputational assets. For this purpose, we conducted a Principal Component Analysis (PCA). One premise for PCA is that the indicators correlate with each other. Preliminary research using correlation matrices suggested that all indicators that made up the asset position indeed correlated well with each other ($p < 0.05$). Consequently, we conducted a PCA on the four indicators that comprised a company's asset position. The Scree-plot's inflexion point suggested the use of only one component, which validates aggregation of the different indicators to one score that represents a firm's asset position. The Kaiser-Meyer-Olkin measure showed a good score of $KMO = 0.711$, which according to Hutcheson and Sofroniou (1999) yields a reliable factor. Bartlett's test of sphericity confirmed that correlations between the indicators were sufficiently large for PCA ($p < 0.001$). The component explained 61.5% of the indicators' total variance.

In the third step of the analysis we tested our hypotheses using nonparametric Mann-Whitney tests, because our data are not normally distributed and the Mann-Whitney test is, for our purposes, the most powerful nonparametric test for smaller samples. Moreover, Levene's tests show that for each between groups comparison the requirement of homogeneity was met, as the variances between groups were not significantly different. We used the 'exact test method' because it is more precise for small sample sizes. Because we tested predefined hypotheses, the 1-tailed exact significance values could be used to determine the significance levels of the between group differences. Our low sample size ($n=15$) is not a problem for conducting Mann-Whitney tests, because no generalizations will be made to a larger population of large car manufacturers, as this population equals our sample.

⁴ 'Battery OR batteries' was added to refine our search results. These search terms refer to the most important component of the EV. Additionally, these terms often form the basis in patent analyses to acquire EV related patents (Oltra and Saint Jean, 2009).

To test Hypothesis 1, we created a group of firms that fell under the CARB's 2% ZEV restriction and a group of firms that did not fall under the restriction and compared them in terms of asset position and EV sales. To test Hypothesis 2, whether firms with a strong incentive and opportunity to innovate will have commercialized more EVs during the period of commercialization, we first created two groups based on the population's average score for the variables 'asset position' and 'profitability in the ICEV regime'. Different groups of firms resulted with either an above or a below average asset position and net income. Finally, a group of firms was created that have an above average asset position and a below average net income. The EV sales of this group are compared to those of a group that comprises the remainder of the population of large car manufacturers.

Fourth, to analyze how different car manufacturers' market strategies relate to their incentive and opportunity to innovate, we plot each firm's asset position, profitability in the ICEV regime, and EV sales to identify clusters of firms. To gain more in-depth insight in the market strategies, we connect our quantitative data to more qualitative data on individual firms' EV market strategies.

4. Results

Section 4.1 presents the periods of EV development in terms of trends in R&D and commercialization. Section 4.2 discusses the results of the Mann-Whitney tests that were used to test our hypotheses. Section 4.3 categorizes the market strategies of large car manufacturers.

4.1 Periods of R&D and commercialization

Figure 4.1 displays the trends in the aggregated R&D and commercialization endeavors of the population of large car manufacturers over the period 1990-2011. Displayed on the left-hand y-axis, large car manufacturers' R&D trends, measured by their technological assets, are presented in broken, blue lines. The dark blue line represents technological assets measured by large car manufacturers' total number of EV related patent applications, divided by 25 to fit the graph. The light blue line represents technological assets measured by large car manufacturers' EV related alliances. The commercialization trend is presented in green with EV sales volume per model year⁵, depicted on the right hand y-axis.

Based on these trends we can identify three distinctive periods: the R&D period, the period of inactivity and the commercialization period. The first period started in 1990 and is characterized by a strong initial increase in R&D (blue lines), followed by the introduction of some production models that were restrictively sold on the market until 1999 (green line). Accumulated EV sales reached approximately 10.6 thousand vehicles this period. Because of its strong focus on R&D, we label this period the *R&D period*.

Over the timeframe 2000-2006, relatively little EV related activities took place compared to the previous period. Car manufacturers continued only to file a low and steady number of patent applications (dark blue line). Because of the low R&D activity and the lack of commercial activities during this period, we label it the *period of inactivity*.

As of 2007, a third period can be distinguished that started with a strong increase in EV related technological assets (blue lines). This increase in R&D is followed by an unprecedented increase in EV sales (green line), reaching approximately 93.7 thousand EVs over the entire period. Nine times as many vehicles were introduced into the market when compared to the longer R&D period. This relatively high EV sales volume supports the finding by Magnusson and Berggren (2011) that some car manufacturers perceived EVs as a commercially viable opportunity during this period. Because of its unprecedented increase in EV sales we label this *period the commercialization period*.

The remainder of this Results section focuses on the differences between the R&D period and the commercialization period, in terms of the car manufacturers' incentive and opportunity to innovate and market strategies. The period of inactivity has been omitted from further analysis, because it is relatively insignificant in terms of EV developments.

⁵ The model year refers to the year an EV production model was introduced into the market.

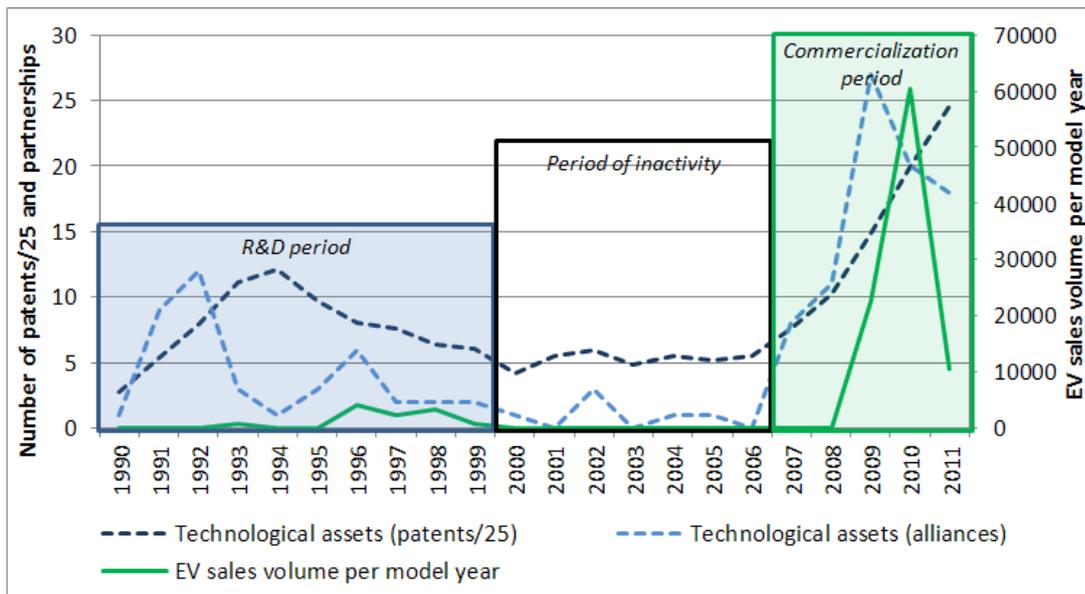


Figure 4.1, Trends in R&D and commercialization over the period 1990-2011

4.2 Statistical analyses: Hypotheses 1 and 2

Table 4.1 displays the results of our nonparametric Mann-Whitney tests that tested the differences between groups as formulated in our hypotheses. The first two rows of results relate to the R&D period; the third row to the commercialization period. With regard to hypothesis 1, *Large car manufacturers that fell under the CARB's 2% ZEV mandate will have a) developed a stronger opportunity to innovate and b) will have marketed more EVs during the 1990s than large car manufacturers that did not fall under this mandate*, Table 4.1 shows that there is a significant difference between the groups in terms of the asset position during the R&D period ($p < 0.05$). No similar differences in asset position were found during the commercialization period. Therefore, hypothesis 1a can be confirmed, indicating that the CARB succeeded in stimulating firms falling under the 2% ZEV restriction to develop EV technology, and thus to increase their EV asset position. Moreover, the positive effect of the 2% ZEV mandate on the asset position of these firms did not continue in the commercialization period. Hypothesis 1b is rejected, as no significant difference between groups could be identified in terms of EV sales. This suggests that although the CARB succeeded in temporarily triggering EV asset position development by the firms that fell under its 2% ZEV mandate, it was not able to increase the firms' EV sales in the R&D period.

With regard to hypothesis 2, *Large car manufacturers that have a stronger incentive and opportunity to innovate, will have marketed more EVs than their competitors during the early stage of EV commercialization*, Table 4.1 shows that indeed a significant difference ($p < 0.01$; Mann-Whitney $U = 11.00$) was found in EV sales volume during the commercialization period between, on the one hand, firms with above average asset position and below average net income and, on the other hand, the firms with below average asset position and/or above average net income. No significant difference was found during the R&D period. Moreover, at no time do groups, distinguished in terms of asset position or in net income alone, show any significant difference in EV sales. This confirms hypothesis 2 and suggests that large car manufacturers indeed are more inclined to move first in mass marketing EVs when they *both* have the incentive, i.e. they are less profitable in the ICEV regime, *and* the opportunity, i.e. they have a high asset position. Lack of profitability in the ICEV regime or a strong asset position alone do not suffice to trigger a large car manufacturer to move first in mass marketing EVs.

Table 4.1, Group statistics of the nonparametric Mann-Whitney tests, including significance levels.

Significant differences between groups for R&D period						
Dependent Variable:	Group variable:	N	Mean	Mann-Whitney U	Z score	Exact sig. (1-tailed)
Asset Position	Falling Under CARB's 2%	6	.7621	11.00	-1.886	0.033
	ZEV Restriction	9	-.5080			
EV Sales Volume	Falling Under CARB's 2%	6	94.62	17.00	-1.205	0.129
	ZEV Restriction	9	66.11			
Significant differences between groups for the commercialization period						
Dependent Variable:	Group variable:	N	Mean	Mann-Whitney U	Z score	Exact sig. (1-tailed)
EV Sales Volume	High Asset Position and	3	4168	2.00	-2.505	0.009
	Low Net Income	12	519.4			

4.3 Clustering of market strategies

Figures 4.2a and 4.2b provide a firm level overview of the data, along the dimensions of incentive to innovate, measured by net income (y-axis); opportunity to innovate, measured by EV asset position (x-axis); and market strategy, measured by EV sales volume (bubble size, with empty bubbles if no EVs were sold). The bold lines represent the averages in terms of net income and asset position, over the population of large car manufacturers. Based on these averages, the data have been clustered into four quadrants. We discuss every cluster and focus on the commercialization period, because this is when large car manufacturers started to mass market their EVs and their exploitation strategies can thus be studied.

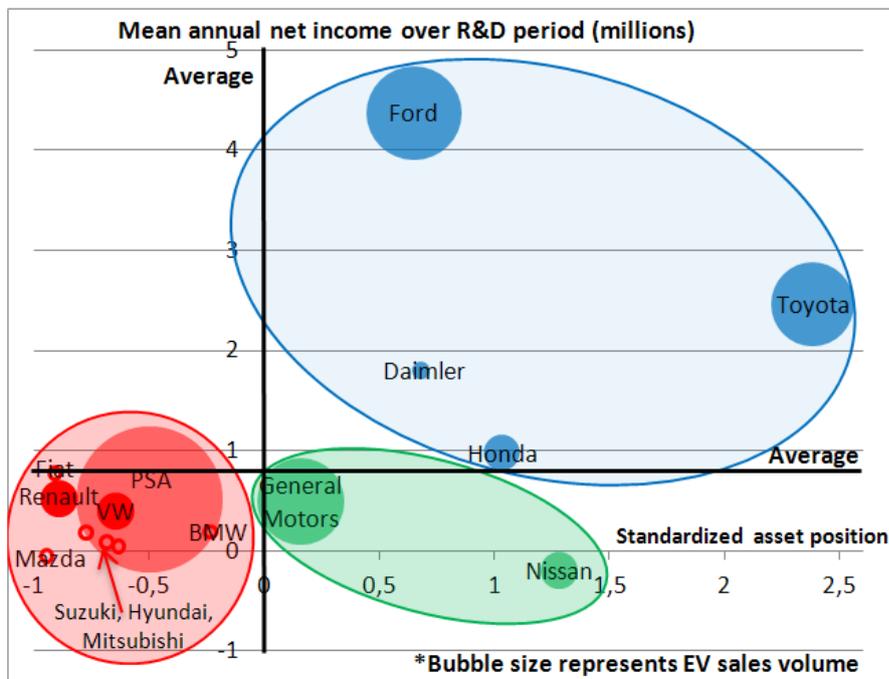


Figure 4.2a, the firm distribution during the R&D period

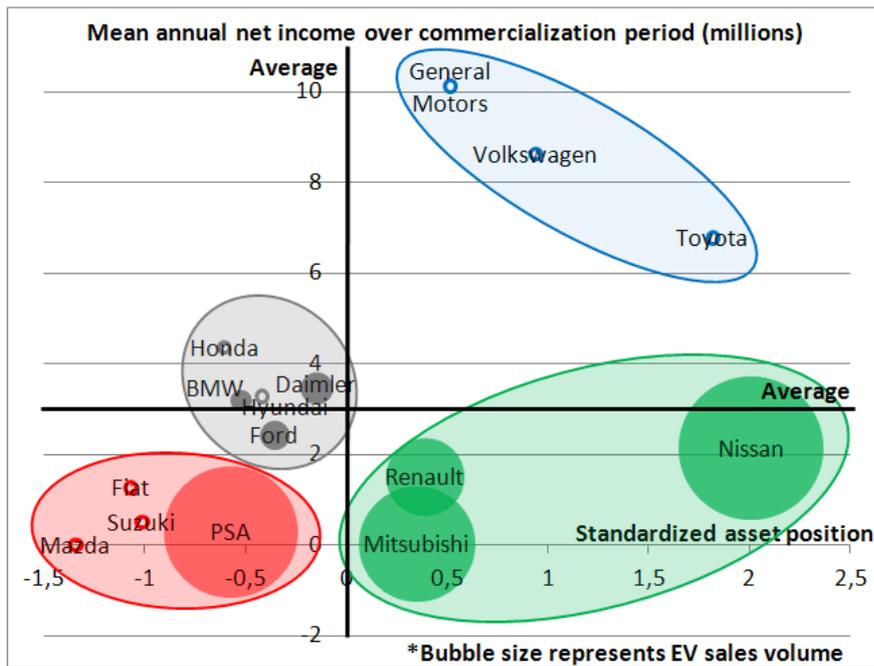


Figure 4.2b, firm level distribution during the commercialization period

The red clusters in Figures 4.2a and 4.2b comprise firms that have a high incentive to innovate, as they are below average profitable in the ICEV regime, but that have little opportunity to innovate, as they have a below average EV asset position. Half of the firms that were in this cluster during the R&D period continued to be in this cluster during the commercialization period, including Fiat, Mazda, Suzuki and PSA. Despite their similarities in net income and asset position, there are some differences in their EV market strategies. In general, these market strategies can be characterized as *laggard* strategies as most of these firms did not intend to commercialize EVs in the short term. As of late 2012, Suzuki has no plans whatsoever to exploit EVs, Mazda is postponing EV exploitation until 2018 (Newton, 2011) and Fiat has planned only a restricted market introduction of its EVs in California (Fiat, 2013). Peugeot on the other hand is a rare case; it introduced approximately 27,5 thousand EVs at the end of 2012 (PSA Peugeot Citroën, 2013, PSA Peugeot Citroën, 2012). Despite its low asset position, Peugeot managed to sell this relatively high amount of EVs by buying ready-made EVs from Mitsubishi, the i-MiEV, and rebranded them into Peugeot Ions and Citroën C-zeros. Moreover, using Venturi Automobiles' electric powertrain, PSA and Venturi were able to transform PSA's existing vans into EVs (PSA Peugeot Citroën, 2008). Peugeot was thus able to introduce EVs into the market by leveraging the asset positions of other car manufacturers.

The blue cluster consists of firms that have little incentive and a strong opportunity to exploit EVs, as they are relatively profitable in the ICEV regime and have a strong asset position. Of the firms that continued to be profitable in the ICEV regime, Toyota was the only one that retained its strong EV asset position. While during the R&D period Ford and Toyota introduced some EVs on the market as a response to the CARB's ZEV mandate, the blue cluster provided no EVs during the commercialization period, suggesting they employed a *laggard* strategy in this period. Toyota explained that it wants to exploit the gradual electrification of the ICEV, enjoying knowledge spillovers between each step (Toyota, 2012). Volkswagen executives told us that they adopt a 'slow follower strategy' when it comes to EVs, and wait for the system to materialize before they attempt to exploit EVs (Volkswagen, 2012). A former executive of General Motors told us that General Motors wanted to mimic the success of the Prius and that the best technology at hand was a Plug-In Hybrid Electric Vehicle. It leveraged its EV asset position to introduce this hybrid car to the market (General Motors, 2012). Overall, the EV market strategies of the car manufacturers in the blue cluster during the commercialization period can be classified as *laggards*, as none of them had introduced EVs into the market.

The grey cluster emerged during the commercialization period and comprises firms that have average profitability in the ICEV regime and thus average incentive to exploit EVs, and a just-below-average asset position, suggesting that they have some opportunity to innovate. The EV strategies of these firms are mixed. BMW, Ford, Honda and Daimler are all experimenting with or

starting the market introduction of their EVs (BMW, 2013, Ford, 2013, Honda, 2013, Daimler, 2013), suggesting they follow a *quick follower* strategy, whereas Hyundai solely focuses only on the introduction of Hydrogen Fuel Cell Vehicles (Hyundai Motors, 2011), another zero-emission and radically-innovative vehicle, suggesting it employs a laggard EV exploitation strategy. During the commercialization period, the grey cluster overall is closer to marketing their EVs than the firms in the blue and the red cluster (with the exception of PSA), while being less exploitative than the green cluster. We classify the firms in the grey cluster therefore as quick followers.

The firms in the green clusters have a high incentive to innovate as well as a strong asset position. In accordance with confirmed hypothesis 2, each of these firms has introduced a large number of EVs compared to other car manufacturers. Their market strategy is therefore classified as a *first mover* strategy. Mitsubishi had a weak asset position during the R&D period, but quickly developed a strong asset position during the commercialization period, which enabled it to pioneer in mass marketing EVs (Mitsubishi Corporation, 2011). In a contractual agreement PSA ordered 100.000 EVs from Mitsubishi (Roberts, 2012). Although this order was eventually delayed due to lack of demand (Roberts, 2012), it was a way for Mitsubishi to hedge against the risks of low EV demand. Renault employed a different strategy to develop a strong asset position during the commercialization period. It engaged in a partnership with Nissan, which already had a strong asset position during the R&D period, to jointly exploit the commercialization of EVs. Nissan used its strong asset position to commercially exploit the first purpose-built EV, the Leaf, selling approximately 32 thousand models by the end of 2012 (Nissan Global, 2013). Renault had a more diversified strategy towards marketing EVs and launched a number of models on the market between late 2010 and late 2012, including the Fluence, Twizy, Kongoo Z.E., Zoe Z.E. According to Swann (2009), a strategy of introducing multiple models at the same time increases both the costs of market introduction, as well as the revenues, because multiple models can target different market niches. Indeed each of Renault's models is very different from the other. In sum, the first movers Mitsubishi, Nissan and Renault all pioneered in different ways on the mass market of EVs.

In conclusion, we find that first movers (period of commercialization's green cluster) have a high incentive and opportunity to innovate, while quick followers (period of commercialization's grey cluster) have some incentive and some opportunity to innovate. Moreover, two types of laggards can be identified. The red cluster during the period of commercialization generally comprised laggards with high incentive to innovate, but with little opportunity. The period of commercialization's blue cluster comprised laggards with no incentive to innovate, but with sufficient opportunity.

Discussion

This paper contributes to the literature on innovation by incumbent firms, by taking into account both the incentive and the opportunity to innovate of different groups of incumbent firms to explain the introduction of a radical innovation into the market. Previous studies have used these two concepts, but only to explain differences in the tendency to radically innovate between incumbents and new entrants (Henderson, 1993; Chandy and Tellis, 2000). Others, such as Hill and Rothaermel (2003) focused on intra-firm processes of incumbents, such as the presence of an autonomous and loosely-coupled division, use of real options perspective, useful complementary assets and organizational slack, to establish propositions as to why some incumbents are better able to radically innovate. The analysis of these intra-firm processes can be considered as a refined approach of what we perceive as the opportunity to innovate, but this approach does not take into account the strong incentive to radically innovate for less profitable incumbents. In this sense, it would be useful for further research that aims to explain differences in tendencies to radically innovate between incumbents to incorporate the differences in incumbents' profitability under the existing regime in their studies, in combination with incumbents' opportunity to innovate.

Another contribution of this paper is that we interpret the opportunity to innovate in terms of firms' asset positions instead of their access to financial funds. The measure of asset position stands closer to the actual opportunity to innovate and has proven useful in our study to explain differences in EV sales of incumbents. This paper has analyzed the asset position of firms with an extensive set of data on patent applications, partnerships, and prototypes.

This paper also adds to the strategic management literature on market strategies (Lieberman and Montgomery, 1998, Freeman and Soete, 1997, Lieberman and Montgomery, 1988), by linking the

opportunity and incentive to innovate to market strategy. Further, we make a distinction between two types of laggards, i.e. laggards with incentive to innovate but no opportunity, and laggards with opportunity to innovate and no incentive.

In addition to these contributions, this paper also has several limitations that may highlight interesting areas for future research. First, firms may exhibit differences in their tendencies to patent and their willingness to publish strategic decisions. This could have affected our patent and our media statements database. Therefore, our findings must be carefully interpreted and should not be easily generalized to other industries. Future developments that account for these firm level differences would increase the validity of firm-level studies like this and provide a fruitful venue for further research. A related limitation concerns our identification of the quick follower and laggard strategies, which was based on car manufacturers' announcements regarding their forecasted mass market introduction of EVs. Because such announcements may be unreliable and car manufacturers' forecasts can be volatile, these conclusions need to be approached with care.

Third, we have labeled the period 2007-2011 a period of EV commercialization, but we do not imply that the EV has been successfully commercialized. We only argue that the commercialization of the EV has been initiated. To illustrate, the best-selling EV is the Nissan Leaf, which sold approximately 32.000 units, equaling 0,05% of 2011's annual personal vehicle sales (OICA, 2011). Moreover, none of the large car manufacturers that marketed EVs on a large scale have been able to meet their EV sales targets (Caradvice, 2012, Digital Trends, 2012, FVL magazine, 2012).

Fourth, future research could also focus on the impact of lobbying activities of incumbents on EV sales. Our hypothesis 1b was rejected, as firms falling under the 2% restriction did not have significantly higher EV sales than the other firms during this period. This is surprising as the explicit aim of the CARB mandate was to force large car manufacturers to sell more EVs. Placing these findings in the context of the lobby activities of the large car manufacturers falling under the 2% ZEV restriction may provide further insights. The main argument in the lobby against the ZEV mandate was that there would not be sufficient demand for EVs (Collantes and Sperling, 2008). Doyle (2000) suggests that, to support this argument of a lack of EV demand, General Motors invested minimally in the marketing of its EV1 and did not publicize the number of reservations for the EV1. Meanwhile their attorneys opposed the mandate based on a lack of consumer demand. We recommend further research to consider this context of lobbying activities while studying why large car manufacturers falling under the 2% ZEV restriction were not able to sell more EVs than other large car manufacturers, while they did have a better opportunity to do so.

Finally, future research could also address collaboration activities of incumbents. In our analysis, PSA, had unexpectedly high sales despite its relative low opportunity to innovate. These high sales can be explained by the fact that Peugeot added very little value to the EVs it marketed. During the commercialization period, it rebranded Mitsubishi's EV and collaborated with a new entrant to transform an existing van into an EV; it adopted a similar approach during the R&D period. Hence, Peugeot was consistently very externally oriented in obtaining the assets necessary for EV exploitation. We recommend further research to focus more explicitly on the decision to develop assets internally or externally and on how this affects the opportunity to innovate and the exploitation strategy of firms.

Conclusion

In this study, we analyzed the incentive and opportunity to innovate of large car manufacturers and their strategies to market EVs over the period 1990-2011. We proposed that firms with a stronger incentive and a stronger opportunity to innovate introduce more EVs into the market. The incentive to innovate is measured by a firm's income in the ICEV regime, and the opportunity to innovate by a firm's EV asset position. We find that during the R&D period in the 1990s, regulatory pressures triggered large car manufacturers to develop EV related assets. Although this constitutes an increase in their opportunity to innovate, it did not result in significantly higher EV sales. As of 2007, during the commercialization period, large car manufacturers with a strong opportunity and a strong incentive to innovate, i.e. firms with below average net income and an above average asset position, have significantly higher EV sales than firms with either a low incentive and/or a low opportunity to innovate. The firms with higher EV sales also adopted a first-mover market strategy. A strong incentive to innovate, i.e. being less profitable in the ICEV regime, or a strong opportunity to innovate, i.e. a strong asset position, alone does not suffice to trigger a large car manufacturer to mass market EVs at an early stage of EV commercialization. Large car

manufacturers with some incentive and opportunity to innovate tended to pursue a quick follower strategy, whereas firms with either little incentive or little opportunity followed a laggard strategy.

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