Discussion Paper No. 17-052

Incumbents' Responses to Innovative Entrants – A Multi-Country Dynamic Analysis

Josefine Diekhof and Uwe Cantner

ZEW

Zentrum für Europäische
Wirtschaftsforschung GmbH

Centre for European
Economic Research

Discussion Paper No. 17-052

Incumbents' Responses to Innovative Entrants – A Multi-Country Dynamic Analysis

Josefine Diekhof and Uwe Cantner

Incumbents’ Responses to Innovative Entrants – A Multi-Country Dynamic Analysis

Authors:

Josefine Diekhof, josefine.diekhof@zew.de, Economics of Innovation and Industrial Dynamics, Centre for European Economic Research

Prof. Dr. Uwe Cantner, uwe.cantner@uni-jena.de, Friedrich Schiller University Jena and University of Southern Denmark

Key Words: Environmental Economics, Sustainable Development, Technological Innovation, Firm Behavior: Empirical Analysis, Entrepreneurship, Industry Dynamics, Automobile Industry, Electric Vehicle

JEL Codes: Q01; Q55; D22; L26; L62; O31

Abstract

The influence of innovative entrants on incumbents is considered important for technological change. We analyze this influence for the global transition towards alternative technology vehicles (ATVs). Our results indicate that entrants’ ATV-related knowledge accumulation stimulates average incumbent’s ATV-related research. Regarding global entrants, incumbents with higher ATV patent stocks increased patenting stronger; supporting previous literature on competitive reactions to entry. Responding to domestic entrants, however, incumbents with low ATV patent stocks increased whereas incumbents with high stocks decreased patenting; suggesting that advanced incumbents outsource research or overtake entrants. Further, certain characteristics and not merely the quantity of entrants drive incumbents’ responses.

1 Introduction

The crucial role of innovative entrepreneurs in accelerating technological change is well known by Schumpeter’s (1911/34) early work. While increasing firm concentration has a hampering effect, entry stimulates innovations within an industry (Geroski, 1990). Especially new markets for radical innovations are often shaped by many new entrants (Markides and Geroski, 2005). Given their lack of competences in dominant designs, entrants barely face opportunities to exploit mature technologies but instead spark technological transitions by introducing disruptive innovations that reduce entry barriers (Tushman and Anderson, 1986; Utterback, 1994)[a]. Entrants are considered as intrinsically motivated and not purely profit driven, often intending to achieve social change. However, they are not strong enough to enforce transitions alone and often remain in niche markets (Markides and Geroski, 2005; Schaltegger and Wagner, 2011). Radical technologies cannibalize profit from incumbents’ existing products and disrupt the value of their present knowledge base. Consequently, incumbents tend to advance their existing products with incremental improvements and process innovations instead of propelling immature radical technologies in early transitional phases (Gort and Klepper, 1982; Henderson and Clark, 1990; Christensen, 1997).

We perceive these different innovation tendencies of entrants and incumbents as especially relevant for the transition from dirty towards environmentally friendly technologies. Many sectors in need for a change are characterized by an increasing incumbent concentration and locked-in dirty technologies; such as the energy and transport sector. As innovating is further a path-depending process, firms that previously invested strongly in dirty technologies tend to perceive it more profitable to continue innovating in dirty technologies (Aghion et al., 2012; Acemoglu et al., 2012). The incumbents' focus on dirty technologies and defensive behavior in substitutive, environmentally friendly innovations[b] impedes technological change and yields industries that innovate more in dirty technologies than desirable for the social optimum; thus requiring policy interventions (Aghion et al., 2012; Acemoglu et al., 2012).

In this regards, Hockerts and Wüstenhagen (2010) hypothesize that entrants' contribution to sustainable transitions goes beyond the introduction of innovations; more importantly, entrants encourage incumbents' sustainable actions.[c] They stress that incumbents' motivation in pursuing new technology is crucial, since only incumbents can achieve mass-market penetration; using their influential power, trustworthy reputation, financial resources, and ability to achieve process innovations that reduce costs. This is in line with Markides and Geroski's (2005) finding that firms who give birth to radically new markets are hardly ever those that develop the new technology up to mass-market adoption. They also argue that only young, small, and agile firms, such as entrants, have the right skills to launch radically new technologies that may create a new market niche. In contrast, established and old firms, such as incumbents, have the skills to scale up this new technology from niche to mass-market. Following their arguments, it seems highly relevant to gain a deeper understanding of entrants' indirect role in overcoming lock-in phenomena via stimulating incumbents. Hence, our main research question is whether entrants' accumulation of environmentally friendly knowledge positively influences incumbents' environmentally friendly research and development (R&D).

To test this effect of entry on incumbents, the automotive industry has been chosen for four reasons: First, this industry is currently facing the challenging emergence of alternative technology vehicles (ATVs)[1] that provide lower or zero-emission drive systems. Second, ATVs provide entry opportunities. Although this industry is characterized by high entry barriers, technologies that disrupt incumbents' knowledge provide entry opportunities (Tushman and Anderson, 1986). ATVs constitute a substituting technology reported to have potential to disrupt the technological and economic structure of the current vehicle system (Cowan and Hultén, 1996; Christensen, 1997; Aghion et al., 2012). Additionally, ATVs require components that draw on multiple competences new to the industry; e.g., electric motors and energy storage systems.[2] These new requirements provide additional lateral entry opportunities. Third, this industry exhibits an oligopolistic market structure and increasing consolidation. Obstacles like complex operations, low margins and high risks are expected to inhibit incumbents' commitment to ATVs (van den Hoed, 2007; Barkenbus, 2009). Those market characteristics will likely hamper technological change and thus calls to analyze potential driving forces, such as entry. Lastly, the transport sector is the second largest CO_2 contributor by taking up over 20% of global CO_2 emissions; which is even set to increase if ATV sales will not surge up strongly in subsequent periods (IEA, 2015). Given governments'

[1] Automobile firms currently focus on three different ATV vehicle types: battery, fuel cell, and hybrid electric vehicles.
[2] Examples of new components in ATVs include electric motors, batteries, energy-control systems, charging systems, voltage converters, electromechanical brakes, transmission and steering-systems (Wallentowitz et al., 2010).

ambitions to reduce global emissions, the present study focusing on dynamics that potentially propels the ATV momentum is highly relevant also from a policy perspective.

The present study considers all different types of entrants that begin to patent in the ATV trajectory. We thus take innovative entrants into account that invent in a relatively radical technology as it is described in Markides and Geroski (2005); also covering innovative entry in the Schumpeterian sense. We further adopt the definition of Helfat and Liebermann (2002) to classify different entry types: diversifying entrants (same legal entity from lateral industries but new product application) versus new establishments, such as parent-company ventures (joint venture or parent spin-off) and de novo entrants (start-up or entrepreneurial spin-off). Ordinarily, automotive incumbents consider only a small fraction of entrants as challenging. The considered entrants, however, are partially affiliated with lateral industries and can thus also equip automotive incumbents with new competences crucial to advance ATVs; such as experiences in battery technologies or electric drive trains. Entrants further stimulate the demand, enlarge the scope of niche markets, and signal to governments and incumbents the viability of the technology for mass-market adoption. We subsequently expect entrants to stimulate incumbents via three channels: directly, via competitive pressure and complementary knowledge, as well as indirectly, via market initialization. We discuss our results in light of these different entrant forces. Previous literature, in contrast, largely disregards this aspect and focuses exclusively on the competition effect (e.g., Aghion et al., 2009; Iacovone et al., 2011; Andersson et al., 2012).

Fundamental results on the effect of entry on incumbents are scarce. Recent studies found that entrants positively influence incumbents' general innovation activity while incumbents responded asymmetrically, depending on their competitive performance (Aghion and Bessonova, 2006; Aghion et al., 2009; Iacovone et al., 2011; Fritsch and Changoluisa, 2014). Such studies utilized quantitative entry measures (e.g., entry rates, import flows, or employment size) and focused on industry-level entry into incumbents' domestic markets. However, these procedures have several limitations. First, incumbents are likely to react only if entrants directly interfere with their business field, in terms of introducing substituting technologies or providing complementary knowledge, which is not necessarily the case for industry-level entry. Second, multinational incumbents operate globally and are thus not only influenced by domestic but also by foreign entrants (Diekhof, 2015). Third, incumbents may not perceive the number but rather qualitative characteristics of entrants as important. The present study addresses these limitations and focusses on: cross-country entry, a measure for entrants' qualitative forces, influential entrants' relevant characteristics, and a technology that is substitutive to the incumbents' design.

The present paper is an extension to the study of Diekhof (2015). She finds that the numbers of foreign entrants have a stronger positive influence on incumbents' ATV patenting as compared to domestic entrants. For this reason, we consider foreign entrants to be of high importance and investigate them in further detail. We further advance her methodology and implement global and individualized policy, market, and technology-specific controls. Most importantly, we take entry measures that indicate their qualitative forces and market activity by considering their technology-specific knowledge accumulation over time. Beyond this, we shed more light on the heterogeneous sample of entrants. We test for entrants' technological relevance and for characteristics that are typical for diversifying entrants versus new establishments. That is, we contrast different age groups and entrants with existing versus non-existing knowledge in other technological fields prior to their entry in ATV technologies. This is helpful in providing more detailed policy advice on how to target support towards influential entrants.

The remainder of the paper is structured as follows. The next section highlights previous work on entrants' relevance for transitions and their influence on incumbents. The hypotheses are derived in the third section. The data, model, and variables are described in Section 4. The results are presented in Section 5. Section 6 discusses limitations and Section 7 concludes.

2 Literature Review

In the light of accelerating the pace of sustainable industrial developments, Hockerts and Wüstenhagen (2010) are among the first scholars to highlight the complementary roles of entrants and incumbents. In early transitional phases, entrants are more likely than incumbents to introduce environmentally sound technologies. However, they mostly fail to reach mass-market acceptance since they are unable to compete with incumbents and thus remain in niche markets. Hockerts and Wüstenhagen (2010), though, consider the entrants' activity in niche markets as crucial as it stimulates incumbents. In niche markets, entrants steadily master the technology, increase the market scope, and initialize the market to adapt such new technologies (by changing consumption patterns and building institutions for standard settings and certification schemes). Eventually, entrants thereby increase the technology's profitability and signal to incumbents and governments its viability for mass-market adoption (Hall et al., 2010; Hockerts and Wüstenhagen; 2010; Klewitz and Hansen, 2014; Diekhof, 2015). Once motivated, incumbents initially react with environmentally friendly product line extensions but leverage the new technology from niche to mass-market in later transitional stages (Hockerts and Wüstenhagen, 2010). Incumbents can better succeed in this step by drawing on their power, trustworthy reputation, and ability to reduce costs via process innovations and economies of scale. They can also draw on their strong innovative power, as their extensive resources facilitate large and in-depth R&D projects (Hockerts and Wüstenhagen, 2010).

Nevertheless, those firm dynamics described above do not constitute a new theory particular for sustainable innovations but find their roots in the literature of economics of innovation. The role of innovative entrepreneurs in accelerating technological change was firstly highlighted by Schumpeter (1911/34). Thereafter, also studies on incumbents' preference for incremental but reluctance for radical innovations followed (e.g., Nelson and Winter, 1982; Gort and Klepper, 1982; Henderson and Clark, 1990; Teece et al., 1997; Christensen, 1997). Geroski (1995) highlighted some cases in which entrants propelled incumbents to introduce innovations which incumbents had been holding back. Such different roles of both actors during technological change were later described comprehensively by Markides and Geroski (2005). They also emphasize that new markets for radical innovations are driven by entrants in early transitional stages whereas the power of incumbents, not of early pioneers, drive such innovations towards mass-market adoption. If we consider environmentally sound innovations to be in an emerging stage and of radical manner, it is not surprising that researchers from a rather specific environmental economic strand detect similar patterns. They not only observe an increasing number of new and small entities engaging in sustainable innovation but also observe that these firms tend to be more innovative than incumbents when such inventions are concerned

(Hockerts and Wüstenhagen, 2010; Schaltegger and Wagner, 2011; Klewitz and Hansen, 2014).[3] However, defining the key role of entrants in sustainable transitions not purely by introducing innovations but by their stimuli on incumbents' sustainable actions was discussed primarily in Hockerts and Wüstenhagen (2010).

Given that it is an emerging field of research, most empirical studies investigate more generally the influence of entrants on incumbents without focusing on certain technologies. On the other hand, though, most studies are country-level studies. They focus on incumbents' responses to entry within certain countries because of data limitations regarding global entry measures. The most important studies are highlighted below.

Czarnitzki et al. (2008, 2011) examine the German manufacturing sector. They test whether incumbents show different innovative behaviors when being faced with the threat of entry as opposed to situations when there is no entry threat. In case of a subjectively perceived entry threat, the authors found that the average firm showed a lower R&D intensity than when there was no such perceived threat. In addition, only when the incumbent leaders perceived a subjective entry threat did they exhibit a higher R&D intensity than the average firms. The competitive entry pressure consequently encouraged average firms to invest less and leading firms (in terms of size) to invest more in R&D.

Fritsch and Changoluisa (2014, 2017) investigate the response of German manufacturing incumbents to regional entrants within the same industry. They find a positive entry effect on incumbents' productivity. Incumbents with state of the art machinery responded strongest to entry. Though, the effect was limited to entry within incumbents' regions. Aggregated entry in all German regions did not show a significant effect. Also in case of Sweden, Andersson et al. (2012) found a positive effect of entrants on incumbents' productivity. They observed a different effect of entry over time; starting with initial negative up to later emerging positive impacts of entry. They thus termed it the delayed entry effect. Additionally, manufacturing incumbents appeared less responsive to regional entrants as compared to incumbents operating in service sectors. Both studies used country-level data of truly new establishments. As in our study, also their data did not allow to distinguish new establishments farther into de novo entrants and parent-company ventures. However, in contrast to those patenting entrants considered in our study, they cannot assure to deal with innovative entrants; the characteristic that is crucial for technological change in the Schumpeterian sense.

Other economists have explored trade liberalization and the effect of foreign firm entry into domestic markets on domestic incumbents. Iacovone et al. (2011) observed Mexican manufacturing firms' innovative internal changes, in areas such as job rotation or quality control, in response to new import competition by Chinese entrants. They also found asymmetric responses across firms. Entry induced productive incumbents to innovate more and less productive incumbents to innovative less. They argue that this competitive pressure reinforces the differences between strongly and weakly performing firms; causing heterogeneous responses to entry. Aghion et al. (2004) conducted a study on trade liberalization within the United Kingdom. The authors conclude that entry has a positive effect on incumbents' total factor productivity growth. Aghion and Bessonova (2006) investigated the effect of foreign firms' entry on Russian incumbents' total factor productivity growth.

[3] Hall et al. (2010), Levinsohn and Brundin (2011), and Klewitz and Hansen (2014) provide an overview on the nexus of sustainability and entrepreneurship.

Their results also indicate an asymmetric response across incumbents: those ones operating closer to their industry frontier responded stronger as compared to incumbents located further away from the technological frontier in their industry. The effect was robust merely for the sample restricted to manufacturing firms. In another study, Aghion et al. (2009) found that foreign firm entry into the United Kingdom had a positive influence on domestic incumbents' productivity and patenting. This effect, however, was only found for incumbents that operate in technologically advanced industries.

We close this section by highlighting a more descriptive but highly relevant empirical case study that also investigates the ATV transition. Based on patent-count analyses, Wesseling et al. (2014) investigated the continuation of ATV research within 15 original equipment manufacturers (OEMs) that lead the automotive market in terms of sales. The OEMs' ATV-related patenting is descriptively compared over time with the co-occurrence of three different competitive forces: rivalry, patent dispersion, and the presence of new entrants. The development of rivalry yielded ambiguous results, but seems to have a positive relationship to these OEMs' continuous patenting in hybrid vehicle technology. Regarding patent dispersion, the authors found that although the share of incumbents' individual battery electric vehicle patents to their total patents increased from 2006 to 2010, the proportion of their patents from the total patenting pool in this technology decreased. The authors stress that this finding suggests that incumbents struggle to keep pace with technological progress in this field. Their data were not comprehensive enough to show that the existence of entrants enhances ATV research in general. The authors nevertheless found that five entrants, four diversifying firms, but only two incumbents were placed among the firms that contributed most strongly to the overall patent increase in battery electric vehicle technology (from the period 2003–2006 towards the period 2007–2010). They thus argue that de novo entrants and diversifying entrants are important for the development of this technology.

3 Hypotheses

Our hypotheses build on previous findings and attempt to disentangle global industry dynamics that have not yet been addressed: the effect of cross-country entrants' technology-specific knowledge accumulation as a measure of their market activity and qualitative forces, incumbents' technology-specific responses in dependence on their technology-specific knowledge, and the role of entrants' characteristics when influencing incumbents. Three main sets of hypotheses are derived.

The different channels through which entrants influence incumbents have yet not been elaborated intensively in the literature. This could rest on the different angle of previous studies, directed at industry-level foreign firm entry into domestic markets or new domestic establishments. It seems an appropriate framework to study the competitive force of entry and also incumbents' overall productivity changes. The present study, in contrast, considers purely innovative entrants that undertake research in immature, radical technologies for which adoption is considered challenging (Markides and Geroski, 2005). We do not address general responses but automotive incumbents' innovative responses within a technology that challenges their profitable design. In our framework, it seems appropriate to consider beyond the competition effect also other channels through which entrants influence incumbents. In particular, we expect entrants to stimulate incumbents' ATV-related patenting via three forces:

directly, via competitive pressure and complementary knowledge, as well as indirectly, via market initialization. Although we cannot test directly for those different channels, we believe that they are crucial and helpful to interpret results.

Competitive entrants represent firms that target to sell ATVs. We use patent entry and thus innovative entry in the Schumpeterian sense. Theoretically, this would support entrants' challenging potential. In the automotive industry, however, the effect of competitive entry is likely to be limited as being strongly consolidated by powerful incumbent OEMs. Automotive OEMs are assumed to perceive, at most, a small fraction of competitive entrants as challenging. Despite the limited attention these entrants attract from OEMs, they are expected to influence OEMs rather indirectly by their niche market activity. They steadily acquire more early ATV adopters and thereby enlarge the market scope for ATVs. They spark not only the development of charging infrastructures but also standardization (e.g., for charging plugs). Competitive entrants eventually penetrate the market; thereby gradually increasing ATVs' profitability and thus the incumbents' commitment. Regarding entrants that supply complementary knowledge, we follow Wesseling et al.'s (2014) conclusion that not only de novo but also diversifying entrants are crucial to advance ATV technologies. There is a high likelihood that suppliers from lateral industries enter ATV niche markets to benefit from new profit opportunities; such as battery or electric motor manufacturers. These diversifying firms can draw on long-term experience and likely achieve rapid technological advances. Eventually, these firms can provide OEMs with crucial knowledge spillovers or superior components. Diversifying entrants that start ATV-related research were therefore also considered a potential influence on incumbents.[4]

First Hypotheses Set

A first set of hypotheses addresses the questions whether incumbents react on entrants' technology-specific knowledge accumulation and whether the entrants' origin plays a role. Previous findings suggest that quantitative entry forces impose an overall positive effect—on incumbents' general innovative activity (Iacovone et al. 2011), on incumbents' general patenting (Aghion et al., 2009) and on incumbents' technology-specific patenting (Diekhof, 2015). Instead of entrants' quantitative forces (e.g., entry rates or employment sizes) we utilize an indicator that rather reflects technology-specific qualitative entry forces; namely, entrants' ATV-related knowledge accumulation. We believe that this measure is more meaningful because the entrants' effect on incumbents is unlikely to increase merely with entry rates but rather with their qualitative performance. Taking the three channels through which we expect entrants to influence incumbents, we assume the following: the greater entrants' ATV knowledge the stronger is not only their competitive power and capacity for market penetration (competitive entry) but also the more supportive are their spillovers towards incumbents (complementary entrants).

In accordance to the finding of Fritsch and Changoluisa (2017) we expect an effect of domestic entrants on incumbents. However, we do not assume the effect of entry to be limited to country boundaries. The automotive industry is not restricted to national markets but is instead characterized by globally operating incumbents. Building on the findings of Diekhof (2015), the role of entrants in foreign countries is perceived important and investigated in detail.

[4] An example for diversifying incumbent entrants in the ATV research regime is Bosch who started research on electric drive systems.

Aghion et al. (2012) suggests that the extent to which OEMs consider a certain country's market conditions can be approximated with their relative number of patents filed in that country. This assumption is based on their finding that OEMs' patent distribution across countries is highly correlated to their relative sales figures in respective countries. We therefore assume foreign entrants to be influential if they origin from relevant countries in which the incumbent is patenting but not influential if they originate from irrelevant countries in which the incumbent is not patenting. We thus hypothesize that domestic (Hypothesis H1.1) and foreign entrants from relevant countries (Hypothesis H1.2) stimulate incumbents' ATV-related patenting. In contrast, entrants that originate from irrelevant countries are expected to have no influence on incumbents' innovative activities (Hypothesis H1.3).

H1.1 The ATV-related knowledge accumulation of domestic entrants has a positive effect on incumbents' ATV-related patenting.

H1.2 The ATV-related knowledge accumulation of foreign entrants from relevant countries abroad has a positive effect on incumbents' ATV-related patenting.

H1.3 The ATV-related knowledge accumulation of foreign entrants from irrelevant countries abroad has no effect on incumbents' ATV-related patenting.

Second Hypotheses Set

The second set of hypotheses investigates incumbents' asymmetric responses to entry. Aghion and Bessonova (2006), Czarnitzki et al. (2011), Iacovone et al. (2011), and Fritsch and Changoluisa (2014) find stronger responses to entry for leading incumbents in terms of sales, productivity, and distance to the technological frontier. Their studies, however, are based on a different framework. They investigate changes in incumbents' general firm-level performances and general industry-level entry. The present study, in contrast, takes another perspective. We investigate asymmetric responses to entry in dependence on incumbents' technology-specific performance (Hypothesis H2.1) while considering innovative and technology-specific entrants. We assume decreasing incumbent patent responses to entry with increasing incumbent ATV-related patent stocks (Hypothesis H2.2). This assumption is based on the findings of Diekhof (2015) who conducted a study on the same technology-specific framework though using other indicators for entrants and for incumbents' technology-specific performance. She explains this specific incumbent response pattern as follows:

Automotive incumbents that filed many ATV-related patents are likely to be too advanced in this technology to be challenged by competitive entrants. However, when the incumbent has reached a sufficiently high knowledge stock it becomes likely that the option of outsourcing R&D or the acquisition of new establishments becomes profitable when being faced with new and superior component suppliers. This suggests a substituting effect of entrants for the R&D activity of highly advanced incumbents and thus a decreasing patent response with increasing ATV-related knowledge stocks. To the contrary, OEMs that yet filed few ATV-related patents are likely to be challenged by competitive entrants and likely to seek research support from complementary entrants. Such automotive incumbents are therefore expected to increase ATV-related patenting more strongly than their well-experienced counterparts. This assertion is supported by the fact that those OEMs with few ATV-related patents also have a greater scope to increase ATV-related patenting because their baseline patenting has been so minimal. Note that based on the outcome in Diekhof (2015), we expect the overall effect of entry to be nevertheless positive. In her study, there was only a small minority of less than 1% firm observations estimated to react negatively to entry. As we build on a very similar firm sample, we do not expect this finding to change drastically.

H2.1 Incumbent responses to entrants are asymmetric and dependent on their ATV-related patent stocks.

H2.2 With incumbents' increasing levels of ATV-related patent stocks, their responses decrease in magnitude.

Although similar hypotheses to this second set of hypotheses were already raised in Diekhof (2015), we are nevertheless interested in this effect as we focus on different entry effects. We do not approximate quantitative entry but rather qualitative forces by entrants' technology-specific research activity over time. This measure also gives respect to indirect effects that entrants may spark with their market activity; likely to be crucial in our framework. Asymmetric incumbent responses to entry are relatively newly debated in the literature and have not yet been addressed from different perspectives. This new technology-specific perspective of Diekhof (2015) and the present study open up an opportunity to extend current literature and investigate incumbents' responses in detail; beyond country- and industry-level entry phenomena. We believe that this is relevant to understand the role of entrants in stimulating technological change via their influence on incumbents.

Third Hypotheses Set

From a policy perspective, it is important to identify the characteristics of influential entrants. Our considered entrant pool is heterogeneous, containing different types of entrants that begin ATV research. The third set of hypotheses intends to disentangle the effect of entrants with different, contrasting characteristics: high versus low technological relevance, young versus old, and existing versus non-existing pre-entry patent experience in other fields.

In investigating the first characteristic, technological relevance, we intend to shed more light on the importance of entrants' qualitative expertise associated to the technology in question. Incumbents are unlikely to perceive an entrant follower with minor technological relevance as important. Instead, leading entrants that give birth to major advances are expected to have greater challenging and supportive potential with which they influence incumbents and are thus likely to attract more attention. We hence hypothesize that the magnitude of incumbents' responses on entry is dependent on the entrants' level of technological relevance (Hypotheses H3.1).

H3.1 The effect of entrants with high technological relevance is stronger than the effect of entrants with low technological relevance.

H3.2 The effect of older entrants is stronger than the effect of younger entrants.

H3.3 The effect of entrants with pre-entry patent experience in other fields beside ATVs is stronger than the effect of entrants without pre-entry patent experience.

We further test for entrants' characteristics that are typical for diversifying entrants versus characteristics typical for new establishments (de novo entrants and parent-company ventures). That is, high versus low age and none versus pre-entry patent experience in other fields beside ATVs. This is expected to help distinguishing to some extent the influence of such different entrant types. Following Helfat and Lieberman (2002), general organizational and pre-entry complementary capabilities influence how successful entrants proceed in new markets. Other studies reveal that any type of experience regarding an industry, a product, or a market provides diversifying entrants competitive advantages over de novo entrants when entering new markets (King and Tucci, 2002). We adopt these findings of entrants' relevant success characteristics for our framework. Diversifying entrants can take advantage of their pre-entry experience from lateral markets and are thus likely to be more successful compared to new establishments that are expected to suffer from lability of newness. The more successful an entrant prospers and initializes the market, the rather incumbents perceive it as challenging or supportive. For these reasons, diversifying entrants that are older and have pre-entry patent experience are assumed to be more influential than young entrants without experience (H3.2 and H3.3).

4 Methodology

Patent Database Construction

Patent data were used to gather information about innovative activities on technologies related to ATVs. Patents have been proven to be appropriate indicators to analyze inventive technical activities (Griliches et al., 1988; OECD, 1994). However, patents also bear drawbacks. First, innovative efforts do not necessarily result in successful inventions and even if it does, firms may prefer secrecy. Second, not all patents require the same R&D investments. Lastly, individual firms and countries show different patent propensities (Archibugi and Pianta, 1996).

Despite these limitations, using patent data was deemed the best option for analyzing inventive activity within the automotive industry. While some manufacturing sectors do not perceive patents as effective to prevent imitation, OEMs and their suppliers are reported to rely heavily on patents to protect their inventions (Cohen et al., 2000). Patents also allow for an objective evaluation of R&D activity. In contrast, OEMs' publications about environmentally friendly achievements are influenced by strategic intentions, making them an unreliable source (McGrath, 1999; van den Hoed, 2005; Wesseling et al., 2014). Since firms ordinarily patent before launching products, patents have been instrumental in prior research for identifying firms' innovative strategies in early R&D stages even before market entry occurred (Archibugi and Pianta, 1996). This aspect is important for the present study as many entrants have undertaken ATV-related R&D but did not yet (or never will) launch ATVs or components. Furthermore, while firms' R&D expenditures are usually not made available to researchers, patent data are publicly available, offer a large dataset with long time periods (Archibugi and Pianta, 1996). Most importantly, although patents do not reveal actual innovative output, they are strong indicators of firms' input to their innovation process and thus rather associated with R&D expenditures and innovative effort. Patent data were therefore determined to be indicative for analyzing long-term differences between firms' technology-specific inventive strategies (Griliches et al., 1988; Trajtenberg, 1990). Those arguments support our choice to analyze incumbents' ATV-related effort by their yearly patent numbers and entrants' ATV-related activities and knowledge stock by accumulating their patents over time.

We make use of the 2013 fall edition of the Worldwide Patent Statistical Database (PATSTAT), provided by the European Patent Office (EPO). This database allows extracting comprehensive information on key characteristics of patents: the applicant's name and nationality, the date of priority application, the inventions' technological field as well as patent family links. More than 80 different national patent offices are covered by the dataset. Due to firms' higher propensity to patent through their domestic patent office than through foreign ones (especially for initial patent filings), national patent data are crucial for emerging technologies and cross-country analyses (OECD, 1994; Archibugi and Pianta, 1996).

Patent data provide three options to count; via application, publication, or granting date. Patent queries based on application and publication dates yield patent pools that include all patents, regardless of whether they were later granted.[5] This better represents firms' overall innovative effort as all patent applications—not just successful ones—are included in the count. Further, the data on application and publication dates are available about 18 months after the first priority application whereas granting dates may take up to five years to be published due to time-consuming review processes (OECD, 1994; Harhoff and Wagner, 2009). Our patent query is based on application and publication dates since it allows us to better capture incumbents' overall willingness to allocate innovative effort towards ATVs. By the same token, it also allows us to constitute more precisely the point in time when entrants began ATV-related research. Application and publication dates were used for different purposes, as discussed further below.

In the present study, the global search query of patent applications and publications exclusively consider patent documents assigned to specific International Patent Classifications (IPCs) and Cooperative Patent Classifications (CPCs) for ATVs.[6] An overview of considered IPCs and CPCs is provided in the Appendix (Table 6 and 7). Restricting the patent request to these classifications allows the construction of a rich data pool of all firms who were ever involved in ATV-related patenting. All relevant incumbents and entrants considered were extracted from this firm pool.

In line with similar patent studies on ATVs (e.g., Wesseling et al., 2014), w defined the group of relevant incumbents as the 20 most successful OEMs in terms of worldwide production in 2012; published by the International Organization of Motor Vehicles (OICA, 2013). Many OEMs were previously independent but in the course of time acquired by one of these 20 most successful OEMs; such firms were also categorized as individual firms. For example, Porsche AG and Audi AG were previously independent but belong presently to the Volkswagen group. Furthermore, OEMs' foreign establishments that also conduct R&D often develop country-specific innovation strategies to satisfy local needs; different from those of their parent firms. For this reason, foreign establishments that are associated to the 20 most successful OEMs but patent under autonomous names were also categorized as individual firms and included in the incumbent firm sample.[7]

Application dates were used to retrieve the number of patents filed by incumbents. As the application is the point in time when firms firstly file a patent, this is the date most closely related to their hypothesized innovative responses to entrants. Using applications also holds another advantage. After the initial application is made, the existence of the patent is kept confidential at least 18 months until the patent office publishes the patent document.[8] For this

[5] This holds for most countries' patent offices, e.g., U.S., Japan, China, and Europe (OECD, 1994; USPTO, 2000; Hu, 2010; EPO, 2011).
[6] The IPC scheme is provided by the World Intellectual Property Organization and the OECD Environment Directorate (WIPO, 2011; OECD, 2011) and the CPC scheme is provided by the EPO and the United States Patent and Trademark Office (USPTO) (CPC, 2014).
[7] An overview of considered incumbent firms is provided in the Appendix, Table 8.
[8] An overview of this procedure can be found in OECD (1994) and in Harhoff and Wagner (2009).

reason, entrants in any period t in the analysis are not aware of the incumbents' patent claims at that point in time. To accurately represent incumbents' innovation activities, it is important to count their inventions only once. Commonly, however, a group of patents refer to the same invention; known as the patent family. Only the first priority application was therefore included in the patent count.[9] The individual incumbents' yearly numbers of ATV-related patents is tracked from t=1980 to t=2009, serving as the observation period in the analysis.

The date at which new entrants start ATV-related research is estimated by their first patent in this field. This research entry date is expected to be more informative than e.g. the date of product launch. Automotive firms ordinarily start patenting long before market entry occurs. Incumbents monitor carefully patent activities within their competitive environment and are hence likely to take strategic actions already in response to other actors' patenting. As explained above, applications are kept confidential for 18 months; making publication dates the earliest point at which incumbents could be aware of entrants' patenting. Hence, publication dates were used to indicate the year of entrants' entry into the ATV research regime. If their first ATV-related patent publication occurred between t=1975 and t=2008, they were classified as relevant entrants, extracted from the firm pool, and their ATV-related patent publications were taken to construct the variable of entrants' ATV knowledge stocks. This procedure allows us to capture all different types of entrants that begin ATV-related research: diversifying entrants and new establishments (parent-company ventures and de novo entrants).[10]

The 2013 fall edition of the PATSTAT database contains accurate patent data from 1970 to 2011.[11] The period from 1970 to 1974 was excluded for constructing entry variables. For example, if a firm patented in 1969 (which could not be determined using these data) and again in 1972, it would be wrong to categorize this firm as an entrant from 1972 onwards. To rule out this misclassification, only those firms that started ATV-related patenting from 1975 onwards were considered entrants.[12] The observation period of the analysis, however, was restricted from t=1980 to t=2009 because of limitations of other data sources and because the construction of variables required accurate patent data from earlier and later periods.

Country codes provided by the PATSTAT database were used to infer incumbents' and entrants' national affiliations.[13] With this procedure, the analysis accounts for all countries affiliated with the relevant incumbents and entrants. The former group originates from 15 and the latter from 92 different countries, respectively.

Variable Specification[14]

Firm-level patent count data served to construct the ***dependent variable*** ($IPA_{i,t}$) which represents incumbent i's number of ATV-related patent applications in year t.[15] Due to highly skewed and over dispersed data distribution, a negative binomial model (NB) for count data

[9] To further prevent double counts, the data was reviewed to ensure that each DOCDB patent family is counted only once per firm.

[10] Note that all remaining firms who were neither classified as incumbent nor as entrant were excluded from the sample.

[11] Due to the updating process of the PATSTAT database and the time frame of 18 months until patent applications are disclosed, the last two years (2012 and 2013) of the database do not accurately represent firm patenting and were therefore excluded.

[12] A lead-time of five years without any ATV-related patents was deemed sufficient as this industry is characterized by frequent patenting.

[13] Firms for which no country affiliation was available in the PATSTAT database were excluded from the sample.

[14] Descriptive statistics, the correlation matrix, and collinearity diagnostics of all variables are provided in the Appendix, Table 9 to 11.

[15] We use simple patent counts instead of citation weighted patents (see Trajtenberg (1990)) as we are interested in incumbents' willingness to put effort in ATV-related technological advances, independent from the output value of their innovative effort.

was utilized, which controls for within-group correlations among multiple firm observations over time.[16] [d]

Some researchers have shown that the effect of entry differs over time (e.g., Fritsch and Mueller, 2004; Andersson et al., 2012), causing difficulties when intending to capture the incumbents' reactions in the dependent variable. In our case, incumbents may differ in the time needed to respond: some may invest in R&D directly after observing entrants' patent activities while others may invest after two years. Further, the time interval from investing in R&D until the patent application may differ; not only by firm (given different innovative capabilities) but also among R&D projects (depending on its nature, difficulty, and likelihood of success). These sources of distortion yield that neither one nor multiple single entry lag variables are sufficient to determine the effect; instead, wide-ranging time horizons seem sensible for observing incumbents' responses in the dependent variable.

The main ***explanatory variables*** of interest account for this imperfection. To create each entrant's knowledge stock ($\mathrm{EKS}_{\mathrm{j,t},z_j}$), we considered its research activity from its first ATV-related patent until the time at hand in the analysis (t). This variable is constructed by applying Griliches' (1979) perpetual inventory method that is used in many innovation studies.

$$\mathrm{EKS}_{\mathrm{j,t},z_j} = \mathrm{EPP}_{\mathrm{j,t},z_j} + (1-\delta)\,\mathrm{EKS}_{\mathrm{j,t-1},z_j} \tag{1}$$

where: entrant j = 1,..., J; observation period t = 1979,...,2008, j's home country z_j = 1,...,Z_j.

The variable $\mathrm{EKS}_{\mathrm{j,t},z_j}$ is calculated by summing up entrant j's ATV-related patent publications ($\mathrm{EPP}_{\mathrm{j,t},z_j}$) in period t and the depreciated knowledge stock from the prior period (t-1).[17] The depreciation rate (δ) is set to the commonly used 20% in innovation studies. Hence, this variable contains in each period also information about entrants' patenting in previous periods; to which incumbents can react individually. Depending on the hypotheses in question, entrants' knowledge stocks were aggregated to different entrant groups referring to their country origins (first and second hypotheses set) or characteristics (third hypotheses set); described further below.

Several ***control variables*** were computed. Similar to Diekhof (2015), we control for incumbents' patent propensities ($\mathrm{PP}_{\mathrm{i,t}}$), and age ($\mathrm{A}_{\mathrm{i,t}}$). Instead of ATV-related patent productivity, we control for a more acknowledged indicator, ATV-related knowledge stocks ($\mathrm{IKS}_{\mathrm{i,t}}$), deemed relevant in previous studies (Aghion et al., 2012). We omit the global oil prices because it was found redundant in her estimates. Instead, we implement new vehicle registrations ($\mathrm{VR}_{\mathrm{i,t}}$) as a more specific indicator for rival technology demand. Diekhof's (2015) model is further extended by implementing individualized policy, market, and technology-specific controls; such as R&D subsidies ($\mathrm{SubRD}_{\mathrm{i,t}}$), advances in charging stations ($\mathrm{ACS}_{\mathrm{i,t}}$), and ATV patent growth rates ($\mathrm{PGR}_{\mathrm{i,t}}$).[18] The construction and reason to add each control variable is briefly described below.

The present analysis aims at mitigating the noise of different firm-specific patent propensities, which are not necessarily constant but may vary over time with firms' financial situations,

[16] We preferred the NB model over a poisson as the mean of the dependent variable (12.35) is very different from its variance (3991.63).
[17] Note that we made sure to have sufficient data to calculate for all considered operating entrants in the first period t=1980 their knowledge stock from their first ATV-related patent onwards.
[18] The R&D experience and the autoregressive term of the dependent variable were also omitted as being critically correlated to other variables. As a robustness check, however,we tested the influence of the latter (explained further in Section 6; see also Appendix, Table 19).

leadership changes or different reactions to trends. To control for individual patent propensities ($PP_{i,t}$), we calculated i's share from all considered incumbents' total patent applications in all technologies. The age ($A_{i,t}$) was included to control for distortion by older firms that may face fewer barriers to patent. Older firms have gained more experience in patenting procedures and are likely to have established large R&D facilities and contacts to venture capital providers. This control seems relevant to account for our incumbent firm pool with great age differences; such as incumbents' younger subsidies versus older incumbents' establishments. An incumbent's age was approximated by subtracting the year of its first patent application from the year t in question.

Based on Aghion et al. (2012), we also control for i's ATV-specific knowledge stock ($IKS_{i,t}$). They constructed a similar variable and found it to be relevant for a similar dependent variable (automotive firms' yearly ATV-related triadic patent grants). Like the entrants' knowledge stocks, we also build this variable on Griliches' (1979) perpetual inventory method but instead of publications, it rests on the number of patent applications ($IPA_{i,t}$) (see Equation 2).

$$IKS_{i,t} = IPA_{i,t} + (1 - \delta)IKS_{i,t-1} \quad (2)$$

where: incumbent $i = 1,\dots, I$; observation period $t = 1979,\dots,2008$.

Incumbents' ATV-related R&D strategies are further likely to depend on policy, market, and technology-specific factors. First, governments' R&D subsidies are likely to stimulate incumbents' ATV-related patenting. Data for public R&D expenditures in energy efficiency for transportation were taken from the International Energy Agency; provided by the OECD Statistical Service (2014a).[e] Second, incumbents' expected profits from selling combustion engine vehicles is likely to negatively influence their ATV-related patenting. From the OECD Statistical Service (2014b) we take annual, country-level new vehicle registrations as a proxy for incumbents' profit expectations for the dominant vehicle design. Third, a sufficient charging station infrastructure is not only likely to ease ATV adoption but also claimed to increase incumbents' motivation to undertake ATV-related research (Aghion et al., 2014). We take yearly filed country-level patents on charging stations from PASTAT to proxy a country's effort to advance the charging stations technology (respective IPC and CPC codes are provided in the Appendix, Table 7). Lastly, it seems sensible to control for ATV-specific research trends; such as global patent hypes due to emerging technological opportunities or global patent decreases due to appearing technological bottle-necks. Further, incumbents' ATV-related patents may also increase steadily over time because ATVs are new technologies and hence provide patent opportunities. To infer about ATV patent trends, we compute yearly country-level growth rates of all ATV-related patent applications.

These four control variables (new vehicle registrations ($VR_{t,d}$), R&D subsidies ($SubRD_{t,d}$), advances in charging stations ($ACS_{t,d}$), and ATV growth rate ($PGR_{t,d}$)) are originally provided at the country-level. The dependent variable, however, varies on the firm level which is beneficial to exploit. Following Aghion et al. (2012), it is reasonable to assume that the extent to which an OEM considers a certain country's market conditions can be approximated with the OEM's relative number of patents filed in that country. This assumption is based on their finding that OEMs' patenting across countries is highly correlated to their country-level sales. Taking their approach, Equation 3 shows the construction of firm-specific country weights ($w_{i,t,d}$) by accumulating the share of i's patent filings in country d over its total patent filings in all countries (D) from i's first year of observation ($t_{1st\,Obs}$) until the time at hand (t). The final weighted control variables were constructed by multiplying these firm-specific country weights[19] with our country-level variables and summing up the products over all countries (Equations 4 to 7).

$$w_{i,t,d} = \sum_{t_{1st\,Obs}}^{t} \frac{number\ of\ i's\ patents\ in\ country\ d}{total\ number\ of\ i's\ patents\ in\ all\ countries\ D} \quad (3)$$

$$SubRD_{i,t} = \sum_{d=1}^{D} w_{i,t,d} \text{ x } SubRD_{t,d} \qquad VR_{i,t} = \sum_{d=1}^{D} w_{i,t,d} \text{ x } VR_{t,d} \quad (4, 5)$$

$$ACS_{i,t} = \sum_{d=1}^{D} w_{i,t,d} \text{ x } ACS_{t,d} \qquad PGR_{i,t} = \sum_{d=1}^{D} w_{i,t,d} \text{ x } PGR_{t,d} \quad (6, 7)$$

where: incumbent i = 1,...,I; observation period t = 1979,...,2008, country d = 1,..., D.

Model Specification

Incumbents are likely to have established over time stable individual characteristics; such as firm-specific cultures, habits, or attitudes, which could bias the predictor variables. Fixed effects models remove these time-invariant characteristics of variables to ensure the unbiased consideration of the predictors' net effects. As we analyze the change over time in incumbent patenting, time-invariant characteristics must be controlled for as they cannot determine the corresponding changes in patenting. However, the applicability of the conditional fixed effects negative binomial model (FENB) (introduced by Hausman et al. (1984)) has been debated recently. The model might not fully control for individual fixed effects in longitudinal count data as fixed effects are implemented in the model via the dispersion parameter rather than via the conditional mean function; the model may hence exhibit an incidental parameter problem (Allison and Waterman, 2002; Guimarães, 2008).[20] As the conditional FENB model is potentially problematic, our analysis rests on a hybrid NB model in following the method in Allison (2005).

This hybrid NB model builds on a random effects model in which firm fixed effects are constructed manually by splitting firm-specific time-varying covariates in two parts: the firm-specific mean and the deviations from this mean. The coefficients of the latter variable represent the corrected fixed effects estimates, while the former variable controls for stable effects (indicated by FFE for the set of all mean variables, Equation 8). This procedure was undertaken for all seven control variables. A set of time dummies (YFE) were also included to control for macro shocks as the Wald test indicated that time fixed effects are present.[21]

Each set of our hypotheses relates to a certain model setting; Table 1 displays an overview. We test the first hypotheses set with three separate models containing differently aggregated entrants to country groups. The second hypotheses set is addressed by implementing interaction terms of incumbents' knowledge stock with the variables for domestic and foreign entrants. Lastly, for the third hypotheses set we separately test six models containing differently aggregated entrants to certain characteristic groups. For all estimations, we apply

[19] The difference of Aghion et al.'s (2012) and our country weights is that we allow them to be time variant as a firm's perception of a country's relevance is likely to changes over time. E.g., China gained importance from the 90's onwards when its car market started to increase rapidly.

[20] Greene (2007) states that this model may not have an incidental parameter problem but may suffer from an omitted variable bias. Further, the FENB model provides a sufficient statistic for fixed effects while the size of the potential bias still remains to be investigated in future research.

[21] Beyond firm and time fixed effects, the necessity to control for other observational levels was rejected. For the country and subsidiary levels, Anova results indicate a significantly stronger within-group than between-group variation and negligible values of intra-class correlations.

the hybrid NB model and additionally estimate Model 4 with the conditional FENB model to validate robustness.

Table 1: Relation of Hypotheses and Model Settings

Hypotheses	Model & Content
1st Set H1.1 – H1.3	***First Model Setting*** Hybrid NB Model (1) – (3): Entrants' country origins
2nd Set H2.1 & H2.2	***Second Model Setting*** Hybrid NB Model (4.1) & FENB Model (4.2): Incumbents' asymmetric responses
3rd Set H3.1 – H3.3	***Third Model Setting*** Hybrid NB Model (5) & (6): Leading versus following entrants Hybrid NB Model (7) & (8): Old versus young entrants Hybrid NB Model (9) & (10): Pre-entry patent experienced versus inexperienced entrants

The ***first model setting*** regards the first set of hypotheses (H1.1 – H1.3): whether entrants' different country origins (z_j) play a role for their influence on incumbents. For this purpose, the entrants' knowledge stocks were aggregated on the country-level, assigned to different country groups and tested separately in three models. In Model 1, two country groups of entrants were included: domestic entrants that originated from incumbents' home countries ($z_j=h_i$) as well as foreign entrants that originated from all foreign countries considered ($z_j \in afc_i$). In Model 2, the variable of foreign entrants is further split up into two new country groups. Based on each incumbent's global patent portfolio, entrants that originated from foreign countries in which incumbent i patented were aggregated to a variable associated with relevant foreign countries ($z_j \in rfc_i$). All other entrants that originated from countries in which incumbent i did not patent were aggregated to another variable associated with irrelevant foreign countries ($z_j \in ifc_i$). For example, Model 2 can be expressed by Equation 8:

$$\mathrm{IPA}_{i,t} = \exp\Bigg[\beta_0 + \beta_1 \sum_{j=1}^{J} \mathrm{EKS}_{j,t-1,z_j=h_i} + \beta_2 \sum_{j=1}^{J} \sum_{z_j \in rfc_i} \mathrm{EKS}_{j,t-1,z_j} + \beta_3 \sum_{j=1}^{J} \sum_{z_j \in ifc_i} \mathrm{EKS}_{j,t-1,z_j}$$
$$+ \beta_4 \mathrm{IKS}_{i,t-1} + \beta_5 \mathrm{PP}_{i,t-1} + \beta_6 \mathrm{A}_{i,t-1} + \beta_7 \mathrm{SubRD}_{i,t-1} + \beta_8 \mathrm{VR}_{i,t-1} + \beta_9 \mathrm{ACS}_{i,t-1}$$
$$+ \beta_{10} \mathrm{PGR}_{i,t-1} + \mathrm{YFE} + \mathrm{FFE} + \epsilon_{i,t}\ \Bigg] \tag{8}$$

where: incumbent $i = 1,...,I$; observation period $t = 1980,...,2009$; entrant $j = 1,...,J$;
i's home country: h_i; j's home country $z_j = 1,...,h_i,...,Z_j$;
i's relevant foreign countries: $rfc_i = \{1,Z_j\}\backslash h_i+ifc_i$;
i's irrelevant foreign countries $ifc_i = \{1,Z_j\}\backslash h_i+rfc_i$.

Turning to Model 3, the prior variable of entrants from relevant foreign countries ($z_j \in rfc_i$) was also split up into two new country groups. Firstly, entrants that originated from the three most relevant foreign countries in which i filed most of its international patents ($z_j \in mrfc_i$). Secondly, entrants from all other remaining relevant foreign countries in which i patented ($z_j \in rrfc_i$).

The ***second model setting*** regards the second set of hypotheses (H2.1 and H2.2): whether incumbent responses to entrants differ with their level of ATV-related knowledge stocks. For this purpose, in Model 4 we interacted incumbents' ATV-related knowledge stocks ($\mathrm{IKS}_{i,t}$) with the variables for domestic and relevant foreign entrants ($\mathrm{EKS}_{j,t,z_j=h_i}$ and $\mathrm{EKS}_{j,t,z_j \in rfc_i}$).[22]

The ***third model setting*** regards the third set of hypotheses (H3.1 – H3.3) in which we are interested in the effects of entrants that exhibit certain characteristics (technological relevance,

[22] We test Model 4 with the hybrid NB model (Model 4.1) and with the FENB model (Model 4.2) to verify robustness as the IKS variable is constructed differently in both models. The difference of both IKS variables is explained and depicted graphically in the Appendix, Figure 2.

age, pre-entry knowledge). We consider all domestic and relevant foreign entrants and split them in two contrasting groups in accordance to a certain criterion of each characteristic.[23]

With hypothesis H3.1 we examine whether entrants with more relevant patents have a stronger influence on incumbents than entrants with less relevant patents. The technological relevance of patents is measured by forward citations. Taking citations as an indicator of the patent's technological importance or value is an acknowledged procedure. It rests on the argument that if a patent was cited, it was probably valuable for the citing patent by opening up a new or useful technological path or perceived important in a lawful manner (Trajtenberg, 1990).[24] We presume that a cited patent is more relevant than a non-cited patent while the holder of such a relevant patent is likely to receive more attention from incumbents.[f] Considering entrants' citation stock, they split up almost naturally into two groups: leading entrants that received at least one citation and following entrants that did not receive any citations on their ATV-related patents.[g] An equal three-year citation window for each patent accounts for the bias that earlier applied patents would have otherwise been endowed with a higher likelihood to be cited than recently applied patents.[25] Interestingly, leading entrants are less but file more patents than their following counterparts: leaders represent 13% and followers 87% of all entrant observations whereas leaders account for 64% and followers for 36% of respective entrants' total patent stocks. These two groups of entrants were tested separately in Model 5 and 6 due to high correlation among their variables.

The hypotheses H3.2 and H3.3 regard potential different effects of diversifying entrants versus new establishments and test characteristics typical for either entrant type. For testing hypothesis H3.2, entrants were classified into old entrants from their age of five years onwards versus young entrants with the maximum age of four years. The threshold of four years was chosen because it was found that more than 60% of entrants exit already within the first five years after entry (Geroski, 1995) and we are exactly interested in the effect of these very young and fragile entrants in contrast to older ones. An entrant's age was approximated by subtracting the year of its first patent publication in any field from the year t in question.[26] The resulting two variables are relatively balanced regarding the proportion of young and old entrants (54% and 46%, respectively) and also their contribution to entrants' total ATV patenting (44% rest on young and 56% rest on old entrants). These two groups of entrants were tested separately in Model 7 and 8 due to high correlation among their variables.

For testing hypothesis H3.3, we constructed groups of entrants with pre-entry patent experience versus entrants without pre-entry patent experience. The former entrants already filed patents in other fields besides ATVs before filing their first ATV-related patent. The latter entrants never filed any patent before their first ATV-related patent and thus before their entry into the ATV-research regime. Following this concept, we classified 74% of entrants into the group of patent-experienced and 26% into the group of non-experienced entrants. As one would expect, experienced entrants contributed with more patents than inexperienced ones to

[23] In order to prevent noise in our estimations, in those variables that refer to entrants with different characteristics, we excluded entrants from irrelevant foreign countries as they were found to have no effect on incumbents in all preceding models (see Model 1-4).

[24] For an accurate measurement, it is important to capture all citations associated to one invention. We thus consider citations on the DOCDB patent family level which links together all patents belonging directly to the same invention (e.g., the first priority application and its subsequent applications in other countries). Needlessly to say, we excluded citations within a patent family.

[25] The citation window is set to three years as it is a common citation interval (Harhoff and Wagner, 2009) and as citations per patent decreases strongly over time (Trajtenberg, 1990).

[26] An entrant's first patent publication in any field may be dated many years before its first patent publication on ATVs (their entry into the ATV research regime); this holds especially for diversifying entrants that operated before in lateral industries.

entrants' total ATV patenting (61% and 39%, respectively). These two groups of entrants were tested separately in Model 9 and 10 due to high correlation among their variables.

5 Results

In this section, we introduce and discuss the outcome of our analysis. As described in the preceding section, for all estimations we apply the hybrid NB model to robustly estimate firm fixed effects. In the present section, we present all results apart from Model 4.1 as incident rate ratios (IRRs)[27] and show reduced results containing only the fixed effects corrected estimates. The full results are provided in the Appendix, Table 12 to 19, including mean variable estimates, t-statistics, and the results as original coefficients.

First Hypotheses Set: Results for entrants' country of origins

Table 2 displays the results for the first set of hypotheses regarded to the question whether entrants' different countries of origin (z_j) play a role for their effect on incumbents' ATV-related patenting. For this purpose, entrants were aggregated into different country groups and tested separately in three models. In all three models, entrants from incumbents' home countries ($z_j=h_i$) show a positive and significant effect which supports hypothesis H1.1, see Section 3. The effects of all variables containing entrants that originate from relevant foreign countries ($z_j \in afc_i, rfc_i, mrfc_i, rrfc_i$), in which incumbents are patenting, are also positive and significant (Model 1, 2, and 3). In contrast, entrants originating from irrelevant foreign countries ($z_j \in ifc_i$) appear to be unrelated to incumbents' patenting as their estimated effects are insignificant (Model 2 and 3). These findings validate hypothesis H1.2 and H1.3.

Table 2: Incumbents' Responses to Entrants from Different Countries

Dependent Variable: Incumbents' Number of ATV Patents

	(1)	(2)	(3)
EKS (home) $_{t-1}$	1.157**	1.186**	1.186**
EKS (all foreign) $_{t-1}$	1.421**		
EKS (relevant foreign) $_{t-1}$		1.572***	
EKS (3 most relevant foreign) $_{t-1}$			1.246***
EKS (remaining relevant foreign) $_{t-1}$			1.367***
EKS (irrelevant foreign) $_{t-1}$		1.077	1.078
ATV Knowledge Stock $_{t-1}$	1.017	1.028*	1.028*
Patent Propensity $_{t-1}$	1.089***	1.081***	1.081***
Age $_{t-1}$	0.981	0.796	0.797
R&D Subsidies $_{t-1}$	1.001	1.007	1.008
Vehicle Registration $_{t-1}$	1.039	1.034	1.034
Charging Station Advances $_{t-1}$	1.133***	1.132***	1.133***
ATV Patent Growth $_{t-1}$	0.953	0.956	0.955
Constant	0.432***	0.384***	0.383***
Firm FE	yes	yes	yes
Year FE	yes	yes	yes
R2 Mc Fadden (adjusted)	0.050	0.052	0.051
N	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; the table above shows the FEs corrected estimates as IRRs; mean variable estimates are omitted; the IRRs for the full models and the original coefficients are provided in the Appendix (Table 12 and 13).

[27] The NB model is a non-linear model in which the IRRs are commonly reported. The original coefficients in the NB model refer to the differences in the logs of expected counts and are thus difficult to interpret. Instead, the IRRs refer to the factorial change of expected counts. Take for example the effect of domestic entry in Model 1: if the EKS variable were to increases by one percent, the incumbents' rate for yearly patents would be expected to increase by a factor of 1.157 (15.7%) while holding all other variables constant. Hence, the IRR shows an increase (a decrease) in case the coefficient is >1 (<1).

A more detailed separation of entrants from relevant foreign countries ($z_j=rfc_i$) into three most relevant foreign countries ($z_j=mrfc_i$) and remaining relevant foreign countries ($z_j=rrfc_i$) does not seem to be sensible (Model 3). Although both variables yield positive effects, they show relatively similar magnitudes whereas we would have expected the effect of entrants from the three most relevant countries to be stronger. The number of OEMs' patents by country does not seem to indicate different magnitudes in OEMs' attention they put on foreign entrants. In contrast, the existence or non-existence of OEMs' patent activity in a certain country seems to represent very well whether the OEM is putting attention to that country's entrants. Hence, we only consider this separation as meaningful (Model 2) and rely on this classification when testing the remaining hypotheses.

Lastly, the effect of foreign entrants was in all cases (Model 1, 2, and 3) higher than the effect of domestic entrants; underlining that the consideration of cross-country entrants is crucial to determine correctly the overall effect of entrants on global incumbents. Knowing the importance of foreign entrants would further be helpful for international negotiations of policy makers that target to stimulate advancements of certain technologies via stimulating entrants.

Second Hypotheses Set: Results for incumbents' asymmetric responses

The second set of hypotheses (H2.1 and H2.2) concerns incumbent responses that are expected to depend on their levels of ATV-related knowledge stocks (IKS) and expected to decrease as this level increases. The corresponding results are presented in Table 3. The interaction term and its individual parts are all significant in case of domestic entrants but the interaction term of relevant foreign entrants with the IKS variable is not significant (see first five coefficients in Model 4.1).

Table 3: Incumbents' Responses to Entrants Depending on their ATV Knowledge Stocks

Dependent Variable: Incumbents' Number of ATV Patents

	(4.1)
Entrants' ATV Knowledge Stock (home) $_{t-1}$	0.154**
Entrants' ATV Knowledge Stock (home) x IKS $_{t-1}$	-0.100***
Entrants' ATV Knowledge Stock (relevant foreign) $_{t-1}$	0.470***
Entrants' ATV Knowledge Stock (relevant foreign) x IKS $_{t-1}$	0.0327
ATV Knowledge Stock (IKS) $_{t-1}$	0.303***
Entrants' ATV Knowledge Stock (irrelevant foreign) $_{t-1}$	0.120
Patent Propensity $_{t-1}$	0.0497**
Age $_{t-1}$	-0.293*
R&D Subsidies $_{t-1}$	0.0798**
Vehicle Registration $_{t-1}$	0.0539
Charging Station Advances $_{t-1}$	0.114***
ATV Patent Growth $_{t-1}$	0.00380
Constant	-0.720***
Firm FE	yes
Year FE	yes
R2 Mc Fadden (adjusted)	0.069
N	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; the table above shows FEs corrected estimates as original coefficients; mean variable estimates are omitted; results for the full Model 4.1, the FENB Model 4.2, and the IRRs are provided in the Appendix (Table 14 and 15); we present original coefficients as they show signs which better demonstrate the direction of the interaction effects.

Before interpreting this result, we present the incumbents' asymmetric responses in further detail. Based on Model 4.1, the effects of both entry groups were calculated for all different levels of the incumbents' IKS variable, holding other explanatory variables constant at their mean values. In Table 4 we illustrate the effects of domestic and foreign entrants in the second and third column, respectively. The first column shows the bandwidth of the IKS variable, ranging from -5 to 18.2. As this variable is standardized, the initial negative values refer to incumbents that file a below-average number of ATV-related patents. A small step length of 0.8 was chosen in order to compare the effects for detailed IKS levels; especially as most observations cluster at small IKS levels. Figure 2 in the Appendix provides a histogram that shows for each IKS level the corresponding number of incumbent firm observations in the underlying sample.

Table 4: Effect of Entrants for Different Levels of Incumbents' ATV Knowledge Stocks

Level of Incumbents' ATV Knowledge Stock	**Effects of Entrants' ATV Knowledge Stock** based on Hybrid NB Estimates (4.1)	
	Home Country	Relevant Foreign Countries
-5	0.656***	0.306
-4.2	0.576***	0.332
-3.4	0.496***	0.359*
-2.6	0.415***	0.385**
-1.8	0.335***	0.411***
-1	0.254***	0.437***
-0.2	0.174**	0.463***
0.6	0.0937	0.489***
1.4	0.0133	0.516***
2.2	-0.0670	0.542***
3	-0.147*	0.568***
3.8	-0.228**	0.594***
4.6	-0.308***	0.620***
5.4	-0.389***	0.646***
6.2	-0.469***	0.672***
7	-0.549***	0.699***
7.8	-0.630***	0.725***
8.6	-0.710***	0.751**
9.4	-0.790***	0.777**
10.2	-0.871***	0.803**
11	-0.951***	0.829**
11.8	-1.032***	0.856**
12.6	-1.112***	0.882**
13.4	-1.192***	0.908**
14.2	-1.273***	0.934**
15	-1.353***	0.960**
15.8	-1.433***	0.986*
16.6	-1.514***	1.012*
17.4	-1.594***	1.039*
18.2	-1.675***	1.065*

Note: * p<0.10, ** p<0.05, *** p<0.01; the results are based on Model 4.1, Table 3; all other variables besides IKS were held constant at their mean values; results of the FENB Model 4.2 are reported in the Appendix (Table 16).

In case of foreign entrants, it is evident from Table 4 that many low and high IKS levels do not yield significant effects. As interaction terms have very high requirements on data, these insignificant results for some IKS levels are likely to be the reason for the insignificant interaction term in Table 3. Hence, we are not distracted by this finding and will continue interpreting the results of Table 3 in combination with Table 4.

In support of Hypothesis H2.1, we find asymmetric incumbent responses with their ATV knowledge stock levels. The second column in Table 4 shows a decreasing effect of domestic entrants along increasing IKS levels; also indicated by the negative coefficient sign of the respective interaction term (second coefficient in Table 3). In regard to foreign entrants, the third column shows the opposite pattern: an increasing effect along increasing IKS levels.

Hypothesis H2.2 finds hence support only for the effect of domestic entrants. In the followings, we interpret these findings separately for each entrant group.

As to ***domestic entrants***, incumbents' reactions decreased from positive to negative responses as their IKS levels increased. The more knowledge incumbents accumulated, the lower was the ATV-patent-increase effect of domestic entrants on incumbents. The overall positive effect of domestic entrants on the average incumbent (see Table 2 and 3) can be explained by that a vast majority (about 97%) of the observed incumbents exhibit very low IKS levels; which are those firms estimated to increase their patenting (seen in the first seven rows of column two in Table 4). The estimated negative effects for higher IKS levels (seen in the last 20 rows of column two) hold only for very few observations (about 1%). Considering the technology- and firm-specific characteristics, the two different response patterns of incumbents can be explained as follows.

First, incumbents with relatively low IKS levels might have been estimated to respond with an increase in ATV-related patenting for various reasons: One possible explanation is that complementary entrants provide crucial capabilities from lateral industries that support innovation advances in these incumbents, e.g., by releasing knowledge spillovers during collaborations or by selling superior R&D equipment. Other possible explanations derive from direct and indirect stimuli of competitive entrants. Given that these incumbents filed a small number of ATV-related patents, they are likely to perceive competitive entrants as challenging and may increase their innovation effort to keep up with the ATV technology frontier. Additionally, competitive entrants can also indirectly stimulate these incumbents. Over time, such entrants pioneer the market: they set up the initial demand, advance the technology, and increase the scope of ATV niche markets. Once these entrants managed to initialize the necessary condition for incumbents to perceive ATVs as profitable, incumbents realize the potential and may accelerate their ATV-related R&D.

Second, incumbents with relatively high IKS levels might have been estimated to respond to entrants with a decrease in ATV-related patenting for the following reasons: Given that these incumbents already filed many ATV-related patents, they are unlikely to perceive new competitive entrants as challenging. Instead, OEMs are likely to acquire these entrants and to reduce their in-house patenting in accordance to the newly acquired knowledge. When considering complementary entrants, R&D outsourcing becomes another likely explanation for negative incumbent responses. In the initial phase of research projects on ATV development, OEMs ordinarily use self-constructed prototypes. This entails producing small quantities of new components, R&D testing equipment, and laboratory devices, which are used predominantly to optimize the electrical powertrain.[28] This R&D effort, if successful, may result in more and more patents over time. Before incumbents start to source new components and R&D equipment from suppliers, however, they need to reach a certain stage of development, characterized by a sufficient knowledge threshold and long-term management targets for ATV production. As these incumbents have already filed many ATV-related patents, they are likely to have reached this stage. When new superior suppliers enter, these incumbents are therefore likely to begin to source components or licenses from those suppliers, thereby partially replacing their previous in-house R&D. These two scenarios (firm acquisition

[28] The behaviour of automotive incumbents in their initial phase of ATV-related research was discussed in an interview in October 2014 with an expert who worked in a company supplying R&D equipment to automotive OEMs.

and R&D outsourcing) would explain the decrease in incumbents' patenting as a response to domestic entrants.

This behavior would indicate dynamics that are commonly observed in the shake-out phase in early industry developments. This phase indicates the beginning of growth within new industries and is characterized by early pioneers, firm turnovers, and the distribution of core tasks related to the new technology across new supply chains (Markides and Geroski, 2005). Wesseling et al. (2014) found that although incumbents increase their electric vehicle patents, their share on the global patent stock of electric vehicles has been decreasing over time. The authors conclude that incumbents cannot keep pace with the progress achieved in this technology. The acquisition of entrants and R&D outsourcing constitute alternative explanations for their observation. Given that OEMs tend to source predominantly from domestic suppliers, this explanation is even more likely as the negative effect holds only for domestic entrants. Some researchers even identified that sustainable small firms have the strategic objective to become the acquisition target of incumbents (Moore and Manring, 2009).

As to ***entrants from relevant foreign countries***, incumbents' responses increased along increasing IKS levels. The more ATV knowledge incumbents accumulated, the higher was the ATV-patent-increase effect of foreign entrants on incumbents. Given that more advanced incumbents responded more strongly, their responses seem to be of competitive nature which was found also in previous studies (e.g., Czarnitzki et al., 2011; Iacovone et al., 2011; Fritsch and Changoluisa, 2014). One explanation is that incumbents increased patenting in response to foreign entrants that are exceptionally challenging (e.g., Tesla Motors or BYD). However, embodying a challenge for automotive incumbents is likely to hold for very few entrants only and can thus not explain the whole effect. Based on the effect found for domestic entrants and the expectation that foreign entrants originate from countries in which incumbent i is operating, the effect is rather likely to be driven indirectly by foreign entrants. We may not measure i's response to foreign entrants but (partially) its competitive response to improving foreign incumbent competitors which were, in turn, stimulated by their own domestic entrants. For example, in case the German OEM Volkswagen reacts with increased patenting to improving Chinese OEMs (e.g., Chang'an Automobile, Dongfeng Motor, or SAIC) who improved their ATV competitiveness as receiving valuable knowledge spillovers by domestic entrants (e.g., BYD or Wanxiang).

In contrast to our results, Diekhof (2015) finds that also foreign entrants yield decreasing incumbent responses. She explains this finding similar to the effect of domestic entrants and notes that for certain new technologies in which key components were already mastered by foreign firms, incumbents might be in need to also source from foreign suppliers. Only few countries in the world are for example already specialized in battery technologies for ATV applications, most from Asia. Nevertheless, both findings are meaningful while it appears very difficult to explain such contrasting results purely by that she uses many different indicators[29] (e.g., the number of entrants from all foreign countries in contrast to our indicator for the research activity of entrants from relevant foreign countries). More research is needed to disentangle the effect of foreign entry on incumbents in global innovation systems.

[29] Diekhof (2015) uses the number of entrants, all foreign entrants, incumbents' ATV productivities beyond different control variables.

Third Hypotheses Set: Results for entrants' different characteristics

As our sample of entrants is very heterogeneous, the third set of hypotheses investigates certain characteristics of influential entrants. In Table 5 we present results as IRRs of six model estimations: We address technological relevance by contrasting the effect of entrants with and without patent citations (Model 5 and 6). In addition, we test for characteristics that are associated with diversifying entrants versus new establishments. That is, old versus young entrants (Model 7 and 8) and existing versus non-existing pre-entry patent experience in other fields besides ATVs (Model 9 and 10). The results are to be interpreted pairwise as the contrasting counterparts are each tested in a separate model.

Table 5: Incumbents' Responses to Entrants with Different Characteristics

Dependent Variable: Incumbents' Number of ATV-related Patents

	Entrants' Characteristics					
	Technological Relevancy		Age		Pre-Entry Patent Experience	
	Leader	Follower	Old	Young	Yes	No
Parameter	(5)	(6)	(7)	(8)	(9)	(10)
Entrants' ATV Knowledge Stock (t-1)	1.552***	1.467***	1.520***	1.764***	1.542***	1.771***
ATV Knowledge Stock (t-1)	1.033**	1.031**	1.030*	1.037**	1.031**	1.036**
Patent Propensity (t-1)	1.074***	1.074***	1.075***	1.066**	1.075***	1.064**
Age (t-1)	0.788	0.763*	0.772*	0.669***	0.768*	0.647***
R&D Subsidies (t-1)	1.012	0.993	1.000	0.993	0.999	0.994
Vehicle Registration (t-1)	1.031	1.025	1.033	1.028	1.033	1.027
Charging Station Advances (t-1)	1.133***	1.127***	1.130***	1.133***	1.132***	1.127***
ATV Patent Growth (t-1)	0.955	0.952	0.954	0.955	0.954	0.954
Constant	0.575***	0.564***	0.571***	0.579***	0.578***	0.556***
Firm FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
R2 Mc Fadden (adjusted)	0.053	0.053	0.053	0.055	0.053	0.056
N	1655	1655	1655	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; the table above shows the FEs corrected estimates as IRRs; mean variable estimates are omitted; the IRRs for the full models and the original coefficients are provided in the Appendix (Table 17 and 18).

Regarding technological relevance, incumbents were estimated to respond more strongly to leading entrants whose inventions exhibit patent citations with which they are assumed to be better off in penetrating the ATV market and in supporting or challenging incumbents. This result is in support of Hypotheses H3.1. Nevertheless, we would have expected the difference between their effects to be of greater size (see coefficients in Model 5 and 6). The difference appears more pronounced, however, if we consider the underlying entrants' quantities. The leading 13% of entrants bring about a slightly higher effect than the 87% following entrants altogether.

Addressing the characteristics associated to different entrant types, our Hypotheses H3.2 and H3.3 are both rejected: entrants that share characteristics of diversifying firms (older, pre-entry patent experienced) were estimated to yield lower effects on incumbents than entrants with characteristics of new establishments (younger, pre-entry patent inexperienced) (compare Model 7 with 8 and Model 9 with 10). It is surprising that young entrants show a stronger effect than older ones because they are not even patenting for more than five years and are thus not expected to have gained great market experience. The proportion and patent contribution of young and old entrants is relatively balanced and should thus not affect the estimates greatly. It is even more surprising that entrants without pre-entry patent experience in other fields were more influential because their effect rests on fewer numbers and fewer patents compared to their experienced counterparts (inexperienced entrants take up only 26% of all entrant observations and account for only 39% of entrants' total ATV patent stocks).

These findings indicate that not only experienced diversifying entrants but also new establishments influence automotive incumbents. While this result contrasts Bergek et al. (2013), who generally question the power of new establishments, it underlines Schumpeter's (1911/34) idea on the importance of innovative entrepreneurs for technological change. It remains an open question, though, what exactly young and inexperienced entrants embody that affects incumbents. Two explanations cross our minds: First, following Markides and Geroski (2005), young and inexperienced entrants bring birth to radical innovations. We hence assume that this group might be more explorative and radical than older and experienced entrants; and therewith stronger threaten or support incumbents. Second, given that these entrants are relatively inexperienced, they are probably more open for R&D collaborations with incumbents, more vulnerable for undesired knowledge leakages, or even favor knowledge exchange. Take for example the new automotive player Tesla Motors who disclosed their ATV patents to speed up other OEMs' R&D advances and therewith the ATVs' transition (Musk, 2014).

Our results on influential entrants' relevant characteristics for their effect on incumbents open up some new insights, yet not been addressed. Previous studies focused mainly on relevant characteristics for survival. For success and survival, they found inter alia the accumulation of general organizational skills and competitive knowledge to be essential. This comes with experience and learning during market activities and increasing ages; thus, providing diversifying entrants an advantage over de novo entrants (Geroski, 1995; Helfat and Lieberman, 2002; King and Tucci, 2002). However, for imposing an effect on incumbents, these characteristics seem of minor importance. Instead, entrants' technology-specific expertise seems crucial; while being young and pre-entry research inexperienced also complements their influence.

Having yet discussed the effects of the explanatory variables of interest, we will next provide comments to more general findings. The global ATV patent growth rate did not lead to significant effects (see Appendix, Model 1-18). It hence seems that incumbents drive their ATV-related R&D strategies independently from a global research trend. This finding supports that rather entrants equip incumbents with technological opportunities to exploit; for instance, in battery technology as it was already argued in Diekhof (2015). Furthermore, R&D subsidies are in all but Model 4.1 insignificant. Aghion et al. (2012) used the same data to construct this indicator, tested it for a similar dependent variable, and neither found a significant effect. They explain the absent effect by that the majority of these public R&D expenditures apply to fuel and energy efficiency technologies rather than to clean technologies such as ATVs.[h] Lastly, vehicle registration also appear insignificant. This is not disturbing to us as it seems that the effect is vanished by its firm fixed effects; estimated to be significant and negative (see Appendix, Model 1-18). It is likely that OEMs, once set their R&D strategy for a new technology, have standardized their R&D responses to changes in profits from the rival technology and always react with the same variation, independently from the magnitude of those changes.

We would like to highlight that the variable for global research advances on charging stations shows a significant and positive effect on incumbents' ATV-related patenting (see Model 1-

18). This finding supports Aghion et al.'s (2014) argument that infrastructure is one of the key aspects which needs to be improved rapidly. The development of a sufficient ATV infrastructure will reduce the risk for investments and thus stimulates OEMs' ATV research. Without rapid improvement, though, the existing infrastructure for combustion engine vehicles will further lock in conventional vehicles and makes a transition more difficult in future periods.

The present study finds a significant, positive effect of incumbents' ATV knowledge stock on their ATV patenting (see Model 2-10). Hence, a firms' tendency to invent in ATV technologies is positively influenced by its previously compiled knowledge in ATVs. This is consistent with similar findings on path-dependency for this technology by Aghion et al. (2012). However, we extend their results as we find a decreasing and eventually negative reaction along increasing ATV knowledge levels in case of domestic entrants. This indicates that during the evolution of new technologies there might exist certain development stages at which highly experienced firms prefer replacing their in-house research by R&D outsourcing or strategic acquisition. Throughout technological change, the influence of technology-specific knowledge on firms' corresponding innovation activity might thus be non-linear and rather inverse u-shaped; where the turning point appears when they start outsourcing R&D. Hence, path-dependency plays an important role but seems more complex as yet considered. Further research is needed to determine whether our observed patterns of incumbent responses also hold for other technologies or is driven by peculiarities of ATVs. For example, the technological evolution of smart-phones, electric bicycles, and digital cameras are likely to show a similar development in which entrants stimulate incumbents to shift their research towards those new technologies.

6 Limitations & Future Research Avenues

Our results support the assumption that it is not only important how many establishments enter but also with which characteristics they oppose incumbents. We find that some entry groups that share certain characteristics can be less in quantity but yield stronger effects on incumbents; as it was the case for entrants with technological-relevant patents and without pre-entry patent experience. This is an essential finding. Studies that focus on indicators of entrants' quantitative forces are likely to suffer from distortions as assuming a linear relationship in the entrant quantity and their effect on incumbents whereas not all entrants may have the same effect on incumbents. Our results, however, also indicate that it is neither the accumulation of technology-specific patents that linearly drive the effect on incumbents (as inexperienced entrants also filed for less patents but yield stronger effects on incumbents than experienced entrants). The relationship between entrants and their influence on incumbents seems hence complex and non-linear; which should be treated as such in future studies.

Although our results support the hypotheses in many aspects, some qualifications are appropriate. Our study is limited in its ability to provide insights on the consequences of incumbent patent growths. According to Gilbert and Newbery (1982), firms with monopoly power have incentives to pursue pre-emptive R&D activities. They patent strategically on substitute technologies to deter entrants but do not take economic advantage of these patents on the market. These patents are known as sleeping patents. Following this line of thought, the possibility exists that OEMs merely patent to prevent competitive entrants from achieving technological advances but do not transform their ATV inventions into market applications. It thus remains an open question whether entrants stimulate also incumbents' innovative market output.

In addition, incumbent patent responses do not only miss the information on innovative market output. It is a proxy for in-house innovative effort and thus misses various other investments that are also relevant; e.g., acquisition of ATV-related licenses, ATV-related marketing investments, and ATV-related knowledge sourcing by strategic acquisitions. Those indicators would not only capture a bigger picture of incumbents' willingness to promote ATVs but would also simplify the interpretation of their asymmetric responses to entrants. Beyond these ATV-related measures, also responses within the existing vehicle design seem relevant. Following Howells (2002), incumbents' reactions to the introduction of substitutive technologies can be categorized into three strategies: switch to the new technology, exit from the market, and the improvement of the old technology. The latter one is known as the sailing ship effect which refers to incumbents' acceleration of innovations on the challenged, old technology to prevent the risk of replacement (Rothwell and Zegveld, 1985). However, it is a seldom strategy while it has yet not been empirically determined whether such responses are driven by the introduction of substituting technologies or instead by intra-industry competition (Howells, 2002). As such responses may inhibit the pace of the transition towards ATVs, also the sailing ship effect is important to be investigated. Testing other ATV-related output variables and contrasting them with incumbent responses in the existing vehicle design seems therefore highly relevant for future research.

We further addressed the potential bias that entrants' patenting is driven by incumbents' patenting. As explained in Section 4, application dates served to retrieve incumbents' patents as this date relates most closely to their potential response. This holds another advantage: after the initial application, patent offices wait 18 months to disclose the patent. Until this publication date, the patent's existence is kept confidential. Entrants are hence not aware of incumbent patenting in period t. Additionally, we used one year lag and publication dates to construct entrants' patent stocks. This provides the benefit that such variables in t refer to the earliest date from which incumbents could be aware of entrants' patenting but entrants' actual R&D activity (which could be influenced by incumbents) certainly took place many years before.[i] Though, a potential bias remains if entrants' R&D activity is driven by incumbents' patenting form many years before and if the latter is correlated to incumbents' patenting in t. We tested and mitigated the existence of this bias. Our robustness estimations indicate that all coefficients of the autoregressive terms of the dependent variable (t-1 to t-8) are zero and only the autoregressive term in t-1 is significantly correlated with the dependent variable. The effects of entrants remain the same across all additional models tested. The results thereof are provided in the Appendix, Table 19. With this procedure of taking application and publication dates for our different entities while showing that the dependent variable is not significantly correlated by incumbents' patenting many years before, we believe that we can sufficiently mitigate the potential noise of reverse causality.

7 Conclusion

This study examined the effect of innovative entrants on automotive incumbents' innovative activities related to alternative technology vehicles (ATVs); such as hybrid, electric, and fuel-cell vehicles. We extend current literature by focusing on cross-country entrants, a substitutive technology, incumbents' technology-specific responses, and entrants' relevant characteristics for their effect on incumbents. Our results indicate that entrants stimulate the average incumbents' ATV-related patenting.

Following Hockerts and Wüstenhagen (2010), we consider the stimuli of entrants on incumbents' sustainable activities as crucial for industries' sustainable development. Entrants are more likely than incumbents to launch ATV-related technologies and to initialize niche markets. Once motivated, incumbents are more likely than entrants to reach mass-market penetration of ATVs. We expect incumbents' innovative responses to entrants to accelerate technological change and thereby to provide opportunities to escape from the locked-in combustion engine trajectory.

Our findings affirm that entrants' country of origin is important for influencing incumbents. Entrants from relevant foreign countries (in which incumbents are expected to operate) showed a stronger influence on incumbents than domestic entrants. In contrast, entrants from any other foreign countries (in which incumbents are not expected to operate) were found to have no effect.

Incumbents' patent responses were further found to be asymmetric and dependent on their ATV-related knowledge stocks. Regarding domestic entrants, incumbents' responses decreased as their ATV knowledge increased. The majority of observed incumbents (about 97%) with low ATV patent stocks were estimated to increase ATV patenting. We assume that complementary entrants from lateral industries provide crucial knowledge whereas competitive entrants challenge these incumbents to keep up with the technology frontier or influence them indirectly via market penetration. In contrast, a small minority of incumbents with relatively high ATV-related patent stocks (about 1%) were estimated to decrease ATV patenting. We presume that their knowledge is too advanced as to be challenged by competitive entrants. Instead, such incumbents are likely to start replacing their in-house R&D by sourcing new components from entrants or by investing in acquisition of entrants. Regarding foreign entrants, in contrast, incumbents' responses increased with their increasing ATV knowledge. This is expected to be a sign of direct responses to outstanding competitive entrants or indirectly to competitive foreign automotive OEMs (that strengthened their ATV performance as being stimulated by their domestic entrants).

Our findings basically suggest that environmentally friendly entrants reinforce environmentally friendly innovation activities, especially in incumbents that previously had a relatively low R&D commitment to environmentally sound technologies. This effect of entrants might be key to encouraging a transition. However, the present study is merely able to conclude that entrants had an influence on incumbents' patenting. Given the possibility of strategic patenting, these incumbents do not necessarily immediately commercialize their technological advances on the market. This possibility limits conclusions regarding the impact of increased incumbent patenting for market-level technological change. Further research is required to determine whether entrants' not only increase incumbents' patenting but also influence their innovative market output.

Entrants are deterred by high entry barriers and survival challenges, especially in the energy and transport sector that show high firm concentrations. Their potential key role is therefore likely to be limited in such markets, suggesting that policy interventions may be supportive in reaping the full benefit of entrants' potential to catalyze transitions. Our findings are useful to derive policy implications for governments that intend to achieve environmental goals and target to increase R&D levels within a certain technological field. Possible implications include supporting an entrepreneurship-friendly environment and reducing entry barriers within corresponding industries by enabling sufficient access to entrepreneurial education and venture capital. Our results further suggest that policies directed at supporting entrants are likely to not only encourage entrants but also to stimulate innovative advances of incumbents; namely of those ones that have yet been relatively uncommitted to the new technology. Joint research projects could be funded to speed up the knowledge exchange between entrants and incumbents. In addition, the incumbents' strong responses to foreign entrants suggest that not only local but also transnational policy reforms are important and should be reconsidered to support the transition towards an environmentally friendly transport system.

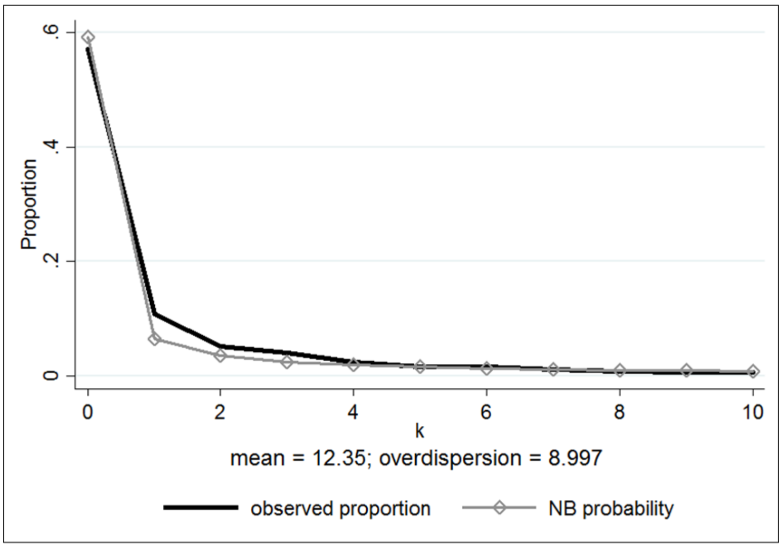
When it comes to the question of targeting policies to certain actors, one might want to know which actors are in need of support but simultaneously highly influential on incumbents. In this regard, we found that young and pre-entry patent-inexperienced entrants greater stimulated incumbents' R&D activities than their older and more experienced counterparts. We presume these young entrants to give birth to more radical solutions while being more open for collaboration and knowledge spillover. Given lability of newness, these young entrants are likely to be in need of greater support compared to their older and more experienced counterparts. Although it was previously found that basic organizational skills achieved by learning during market experience is essential for survival, higher ages and pre-entry patent experience in other fields turned out to be less important for entrants' influence on incumbents. Instead, it seems to be worthwhile to support entrants' technology-specific expertise as we found that a small group of technological leading entrants (13% of entrants' firm sample) had a stronger effect on incumbents than the remaining following entrants altogether (87% of entrants' firm sample). As the group of inexperienced and leading entrants were more influential but strongly outnumbered by their counterparts, this further suggests that it is not the number of entrants but the existence of some entrants with relevant characteristics that drive these effects on incumbents.

Acknowledgements

This work was funded by the German Science Foundation via the DFG-RTG-1411 'The Economics of Innovative Change'. For helpful comments, the authors thank Bernhard Truffer, Tobias Regner, Alexia Gaudeul, Javier Changoluisa as well as the audiences at the Dphil-days in Brighton (2014), at an internal seminar at the Federal Institute of Aquatic Science and Technology in Dübendorf (2014), at the ISS in Jena (2014), at the DRUID Academy in Aalborg (2015), and at an internal seminar at the Utrecht University (2015). The usual caveats apply.

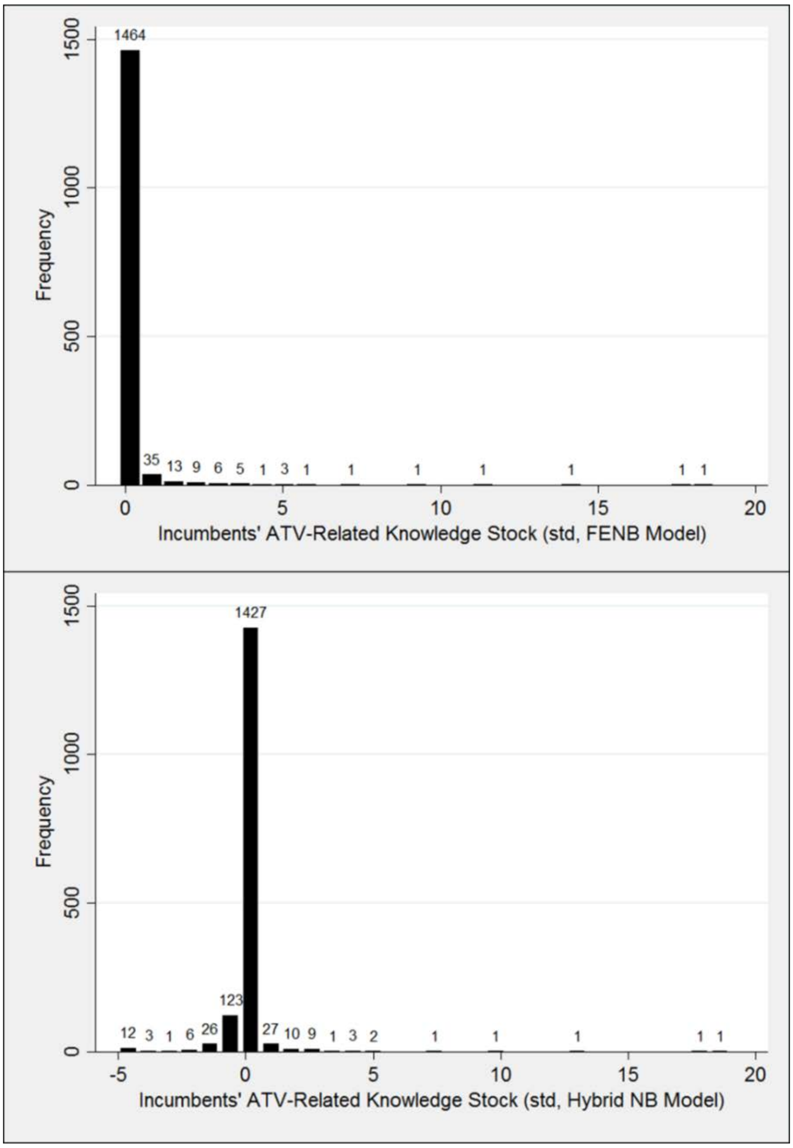
Appendix

Figure 1: Graphical Fit of Dependent Variable to Negative Binomial Distribution



Source: Authors' elaboration based on global patent query from PATSTAT database.

Figure 2: Histogram of the Variable Indicating Incumbents' ATV Knowledge Stocks



Source: Authors' elaboration based on global patent query from PATSTAT database.

Note: The first histogram depicts the incumbents' ATV-related knowledge stock (IKS) used in the conditional fixed effects negative binomial model (Model 4.2); and the second histogram depicts the IKS variable used in the hybrid negative binomial model (Model 1 to 18). The negative values in the first histogram rest on the standardization of the original variable and refer to firms that exhibit below mean values in the IKS variable. The variable used in the second histogram rests on both the transformation to fixed-effects corrected values (the deviation from the firm-specific mean) and on the standardization of this variable. Hence, negative values of this variable result when a firm's mean-deviation in the IKS variable is below the average of firms' mean-deviations in the IKS variable.

Table 6: Patent Classes and Description (1)

Description	International Patent Classification (IPC) & Cooperative Patent Classification (CPC)
Alternative Technology Vehicles	
Arrangement of mounting of plural diverse prime-movers for mutual or common propulsion, e.g. hybrid propulsion systems comprising electric motors and internal combustion engines	B60K 6
Control systems specially adapted for hybrid vehicles, i.e. vehicles having two or more prime movers of more than one type, e.g. electrical and internal combustion motors, all used for propulsion of the vehicle	B60W 20
Gearings therefore	F16H 3/00–3/78, 48/00–48/30
Brushless motors	H02K 29/08
Electromagnetic clutches	H02K 49/10
Dynamic electric regenerative braking systems for vehicles	B60L 7/10–7/22
Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L 8
Electric propulsion with power supply external to vehicle	B60L 9/00
Electric propulsion with power supplied within the vehicle	B60L 11
Methods, circuits, or devices for controlling the traction- motor speed of electrically-propelled vehicles	B60L15
Combustion engines operating on gaseous fuels, e.g. hydrogen	F02B 43/00, F02M 21/02, F02M27/02
Arrangements in connection with power supply from force of nature, e.g. sun, wind	B60K 16
Charging stations for electric vehicles	H02J 7/00
Arrangement or mounting of electrical propulsion units	B60K1
Electric circuits for supply of electrical power to vehicle subsystems characterized by the use of electrical cells or batteries	B60R16/033
Arrangement of batteries in vehicles	B60R16/04
Supplying batteries to, or removing batteries from, vehicles	B60S5/06
Conjoint control of vehicle sub-units of different type or different function; including control of electric propulsion units, e.g. motors or generators	B60W 10/08
Conjoint control of vehicle sub-units of different type or different function; including control of energy storage means for electrical energy, e.g. batteries or capacitors	B60W 10/26
Conjoint control of vehicle sub-units of different type or different function; incl. control of fuel cells	B60W 10/28
Technologies related to hybrid vehicles: using ICE and mechanical energy storage, e.g. flywheel; using ICE and fluidic energy storage, e.g. pressure accumulator; using ICE and electric energy storage, i.e. battery, capacitor (of the series type or range extenders, of the parallel type, of the series-parallel type, with motor integrated into gearbox, driving a plurality of axles, provided with means for plug-in); combining different types of energy storage (incl. battery and capacitor, battery and mechanical or fluidic energy storage); control systems for power distribution between ICE and other motors (incl. predicting future driving conditions), other types of combustion engine	Y02T 10/62, Y02T 10/6204, Y02T 10/6208, Y02T 10/6213, Y02T 10/6217, Y02T 10/6221, Y02T 10/6226, Y02T 10/623, Y02T 10/6234, Y02T 10/6239, Y02T 10/6243, Y02T 10/6247, Y02T 10/6252, Y02T 10/6256, Y02T 10/626, Y02T 10/6265, Y02T 10/6269, Y02T 10/6273, Y02T 10/6278, Y02T 10/6282, Y02T 10/6286, Y02T 10/6291, Y02T 10/6295
Electric machine technologies for applications in electromobilty: characterised by aspects of the electric machine; control strategies of electric machines for automotive applications (incl. vector control, control strategies for ac machines other than vector control, Control strategies for dc machines, number of electric drive machines)	Y02T 10/64, Y02T 10/641, Y02T 10/642, Y02T 10/643, Y02T 10/644, Y02T 10/645, Y02T 10/646, Y02T 10/647, Y02T 10/648, Y02T 10/649

Source: OECD (2011); WIPO (2011); CPC (2014).

Table 7: Patent Classes and Description (2)

Description	International Patent Classification (IPC) & Cooperative Patent Classification (CPC)
Alternative Technology Vehicles	
Energy storage for electromobility: batteries (incl. lithium ion battery, lead acid battery); capacitors, supercapacitors or ultracapacitors; mechanical energy storage devices (incl. fly wheels); energy storage management (incl. controlling the battery or capacitor state of charge, controlling vehicles with one battery or one capacitor only, controlling vehicles with more than one battery or more than one capacitor); electromobility specific charging systems or methods for batteries, ultracapacitors, supercapacitors or double-layer capacitors (incl. on board the vehicle, with the energy being of renewable origin)	Y02T 10/70, Y02T 10/7005, Y02T 10/7011, Y02T 10/7016, Y02T 10/7022, Y02T 10/7027, Y02T 10/7033, Y02T 10/7038, Y02T 10/7044, Y02T 10/705, Y02T 10/7055, Y02T 10/7061, Y02T 10/7066, Y02T 10/7072, Y02T 10/7077, Y02T 10/7083
Electric energy management in electromobility: electric power conversion within the vehicle (incl. DC to DC power conversion, DC to AC or AC to DC power conversion, AC to AC power conversion); optimisation of vehicle performance (incl. automated control, desired performance achievement, optimisation of energy management, route optimisation, transmission of mechanical)	Y02T 10/72, Y02T 10/7208, Y02T 10/7216, Y02T 10/7225, Y02T 10/7233, Y02T 10/7241, Y02T 10/725, Y02T 10/7258, Y02T 10/7266, Y02T 10/7275, Y02T 10/7283, Y02T 10/7291
Transmission of mechanical power	Y02T 10/76
Technologies related to electric vehicle charging: plug-in electric vehicles; information or communication technologies improving the operation of electric vehicles (incl. navigation, Information or communication technologies for charging station selection, systems integrating technologies related to power network operation and communication or information technologies for supporting the interoperability of electric or hybrid vehicles, i.e. smart grids as interface for battery charging of electric and hybrid vehicles)	Y02T 90/14, Y02T 90/16, Y02T 90/161, Y02T 90/162, Y02T 90/163, Y02T 90/164, Y02T 90/165, Y02T 90/166, Y02T 90/167
Application of fuel cell technology to transportation: fuel cells specially adapted to transport applications, e.g. automobile, bus, ship; fuel cell powered electric vehicles	Y02T 90/32, Y02T 90/34
Application of hydrogen technology to transportation: hydrogen as fuel for road transportation	Y02T 90/42
Charging Stations	
Charging stations for electric vehicles	H02J 7/00
Electromobility specific charging systems or methods for batteries, ultracapacitors, supercapacitors or double-layer capacitors: Charging stations; Charging stations with the energy being of renewable origin	Y02T 10/7088, Y02T 10/7094
Electric charging stations: by conductive energy transmission, by inductive energy transmission, by exchange of energy storage elements, Alignment between the vehicle and the charging station, Converters or inverters for charging, Energy exchange control or determination	Y02T 90/12, Y02T 90/121, Y02T 90/122, Y02T 90/124, Y02T 90/125, Y02T 90/127, Y02T 90/128

Source: OECD (2011); WIPO (2011); CPC (2014).

Table 8: Considered Incumbents

Individual Firm Name in PATSTAT Data Base		
ABB DAIMLER BENZ TRANSP	GEN MOTORS LLC	PEUGEOT CYCLES
AUDI HUNGARIA MOTOR KFT	GERTRAG FORD TRANSMISSIONS GMB	PEUGEOT MOTOCYCLES
AUDI NSU AUTO UNION AG	GETRAG FORD TRANSMISSIONS GMBH	PEUGEOT MOTOCYCLES SA
BAYERISCHE MOTOREN WERKE AG	GIE PSA PEUGEOT CITROEN	PORSCHE AG
CHONGQING CHANGAN AUTOMOBILE	GM DAEWOO AUTO & TECHNOLOGY	RENAULT AGRICULTURE SA
CHRYSLER CORP	GM GLOBAL TECH OPERATIONS INC	RENAULT SA
CHRYSLER FRANCE	GM SOC	RENAULT SAS
CHRYSLER GROUP LLC	HONDA AMERICA MFG	RENAULT SOC PAR ACTIONS SIMPLI
CHRYSLER LLC	HONDA LOCK MFG CO LTD	RENAULT TRUCKS
CHRYSLER MOTORS	HONDA MITSUO	RENAULT VEHICULES IND
DAIMLER AG	HONDA MOTOR CO LTD	SAAB SCANIA AB
DAIMLER BENZ AEROSPACE AG	HYUNDAI AUTONET CO LTD	SCANIA CV AB
DAIMLER BENZ AG	HYUNDAI MOBIS CO LTD	SCANIA CV ABP
DAIMLER CHRYSLER AG	HYUNDAI MOTOR CO LTD	SEAT SA
DAIMLER CHRYSLER CORP	HYUNDAI MOTOR JAPAN R&D CT	SUZUKI CO LTD
DAIMLERCHRYSLER RAIL SYSTEMS	IVECO FIAT	SUZUKI YASUO
FERRARI S P A ESERCIZIO FABBRI	IVECO FRANCE SA	SUZUKI YUUJI
FERRARI SPA	IVECO SPA	TOYOTA AUTO BODY CO LTD
FIAT AUTO SPA	JAGUAR CARS	TOYOTA CENTRAL RES & DEV
FIAT FERROVIARIA SPA	LINCOLN GLOBAL INC	TOYOTA ENG & MFG NORTH AMERICA
FIAT GROUP AUTOMOBILES SPA	MAN B & W DIESEL AG	TOYOTA IND CORP
FIAT RICERCHE	MAN B & W DIESEL AS	TOYOTA IND SWEDEN AB
FIAT SPA	MAN DIESEL & TURBO AF MAN DIESEL	TOYOTA MOTOR CO LTD
FIAT TRATTORI SPA	MAN DIESEL & TURBO SE	TOYOTA MOTOR CORP
FIAT VEICOLI IND	MAN DIESEL SE	VOLKSWAGEN AG
FORD FRANCE	MAN NUTZFAHRZEUGE AG	VOLKSWAGENWERK AG
FORD GLOBAL TECH	MAN NUTZFAHRZEUGE GMBH	VOLVO AB
FORD GLOBAL TECH INC	MAN NUTZFAHRZEUGE OESTERREICH	VOLVO CAR BV
FORD GLOBAL TECH LLC	MAN TECHNOLOGIE GMBH	VOLVO CAR CORP
FORD GLOBAL TECHNOLOGY LLC	MAN TRUCK & BUS AG	VOLVO CONSTR EQUIP AB
FORD MOTOR CO	MAZDA MOTOR	VOLVO CONSTR EQUIP COMPONENTS
FORD NEW HOLLAND INC	NISSAN MOTOR	VOLVO CONSTR EQUIP HOLDING SE
FORD NEW HOLLAND NV	NISSAN MOTOR MFG UK LTD	VOLVO FLYGMOTOR AB
FORD WERKE AG	OPEL ADAM AG	VOLVO LASTVAGNAR AB
FORD WERKE GMBH	OPEL EISENACH GMBH	VOLVO PENTA AB
GEN MOTORS CORP	PEUGEOT & RENAULT	VOLVO TECHNOLOGY CORP
GEN MOTORS CORPORTION	PEUGEOT CITROEN AUTOMOBILES SA	

Source: Authors' elaboration based on global patent query from PATSTAT database.

Table 9: Descriptive Statistics

Variable	Original Variables: Max	Min	Mean	SD	Standardized Variables: Max	Min	Mean	SD	N
Incumbents' Number of ATV Patents	1108	0	12.35	63.18					1655
EKS (home)	1370	0	228.92	300.96	3.79	-0.76	0	1	1655
EKS (all foreign)	5057.8	63.2	1668.96	1272.63	2.66	-1.26	0	1	1655
EKS (relevant foreign)	4484.2	0	934.67	1012.26	3.51	-0.92	0	1	1655
EKS (3 most relevant foreign)	3063.4	0	457.79	505.06	5.16	-0.91	0	1	1655
EKS (remaining relevant foreign)	3866.4	0	476.88	692.84	4.89	-0.69	0	1	1655
EKS (irrelevant foreign)	4460	1.60	734.29	833.14	4.47	-0.88	0	1	1655
EKS, leader	1458.24	0.00	384.98	390.23	2.75	-0.99	0	1	1655
EKS, follower	967.70	0.02	216.73	191.55	3.92	-1.13	0	1	1655
EKS, old	1521.84	0	335.42	372.44	3.19	-0.90	0	1	1655
EKS, young	905.13	0.03	264.07	208.03	3.08	-1.27	0	1	1655
EKS, pre-entry patents	1593.70	0	366.62	398.07	3.08	-0.92	0	1	1655
EKS, no pre-entry patents	831.36	0.03	232.87	181.58	3.30	-1.28	0	1	1655
Hybrid NB Model									
ATV Knowledge Stock (DM)	1089.63	-275.80	0.00	57.46	18.96	-4.80	0	1	1655
ATV Knowledge Stock (M)	317.62	0	14.97	45.74	6.62	-0.33	0	1	1655
Patent Propensity (DM)	0.10	-0.2	0	0.01	6.93	-8.64	0	1	1655
Patent Propensity (M)	0.23	2.69e-06	0.02	0.04	4.92	-0.42	0	1	1655
Age (DM)	14.50	-14.50	0.13	6.43	2.23	-2.27	0	1	1655
Age (M)	24.50	1	13.65	8.01	1.36	-1.58	0	1	1655
R&D Subsidies (DM)	1.83e+08	-2.39e+08	-5.89e+06	3.39e+07	5.57	-6.88	0	1	1655
R&D Subsidies (M)	4.12e+08	51468.48	5.54e+07	6.47e+07	5.52	-0.86	0	1	1655
Vehicle Registration (DM)	85.34	-86.17	0.48	13.80	6.15	-6.28	0	1	1655
Vehicle Registration (M)	155.67	6.03	94.31	18.37	3.34	-4.81	0	1	1655
Charging Station Advances (DM)	724.70	-429.23	-12.15	96.63	7.63	-4.32	0	1	1655
Charging Station Advances (M)	829.75	6.58	118.61	133.32	5.33	-0.84	0	1	1655
ATV Patent Growth (DM)	3.84	-1.48	-0.00	0.31	12.34	-4.74	0	1	1655
ATV Patent Growth (M)	0.51	0.03	0.19	0.08	4.09	-1.96	0	1	1655
Fixed Effect NB Model									
ATV Knowledge Stock	1365.43	0	14.02	72.42	18.66	-0.19	0	1	1543
Patent Propensity	0.32	0	0.02	0.05	6.32	-0.41	0	1	1543
Age	39.00	0	14.22	10.44	2.38	-1.36	0	1	1543
R&D Subsidies	4.74e+08	0	4.90e+07	6.36e+07	6.69	-0.77	0	1	1543
Vehicle Registration	190.74	0	95.02	22.91	4.18	-4.15	0	1	1543
Charging Station Advances	1173.57	1	103.19	150.38	7.12	-0.68	0	1	1543
ATV Patent Growth	4.31	-1.00	0.19	0.32	12.84	-3.71	0	1	1543

Note: DM: deviation from firm mean; M: firm mean; the descriptive statistics are all based on the lagged variables such as implemented in the estimations. Although only the standardized variables were implemented in the estimations, also the descriptive statistics of the original variables are provided for the sake of information.

Table 10: Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	EKS (home)	1																								
2	EKS (all foreign)	0.43	1																							
3	EKS (relevant foreign)	0.34		1																						
4	EKS (3 most relevant foreign)	0.34			1																					
5	EKS (remaining relevant foreign)	0.24			0.41	1																				
6	EKS (irrelevant foreign)	0.25		-0.06	0.03	-0.11	1																			
7	EKS, leader							1																		
8	EKS, follower								1																	
9	EKS, old									1																
10	EKS, young										1															
11	EKS, pre-entry patents											1														
12	EKS, no pre-entry patents												1													
13	ATV Knowledge Stock (DM)	0.27	0.19	0.21	0.22	0.15	0.03	0.26	0.25	0.27	0.25	0.27	0.24	1												
14	ATV Knowledge Stock (M)	0.11	-0.04	0.05	0.08	0.01	-0.12	0.08	0.09	0.07	0.09	0.07	0.09	-0.00	1											
15	Patent Propensity (DM)	-0.04	-0.00	0.00	0.00	0.00	-0.01	-0.01	0.01	-0.00	0.01	-0.00	0.01	0.28	-0.06	1										
16	Patent Propensity (M)	0.11	-0.12	0.06	0.11	0.01	-0.26	0.07	0.14	0.07	0.14	0.07	0.14	-0.00	0.67	-0.01	1									
17	Age (DM)	0.48	0.69	0.74	0.65	0.61	0.15	0.78	0.70	0.76	0.76	0.76	0.76	0.26	0.01	-0.03	-0.00	1								
18	Age (M)	-0.11	-0.32	0.12	0.10	0.10	-0.64	0.06	0.18	0.06	0.19	0.06	0.19	-0.00	0.14	0.02	0.40	0.01	1							
19	R&D Subsidies (DM)	0.15	0.27	0.38	0.33	0.32	-0.04	0.36	0.42	0.39	0.39	0.39	0.39	0.12	-0.00	-0.03	0.00	0.40	0.07	1						
20	R&D Subsidies (M)	0.50	0.08	-0.02	0.05	-0.07	0.16	0.11	0.06	0.08	0.10	0.08	0.10	0.00	0.02	0.01	0.11	-0.00	-0.08	-0.23	1					
21	Vehicle Registration (DM)	-0.15	-0.12	-0.15	-0.10	-0.14	0.00	-0.18	-0.18	-0.19	-0.16	-0.19	-0.16	-0.12	-0.00	0.06	-0.01	-0.07	-0.04	-0.03	0.03	1				
22	Vehicle Registration (M)	0.36	-0.18	-0.04	0.06	-0.11	-0.22	0.06	0.06	0.05	0.09	0.05	0.09	-0.00	0.27	-0.00	0.35	-0.02	0.24	-0.06	0.46	0.02	1			
23	Charging Station Advances (DM)	0.41	0.38	0.42	0.44	0.30	0.06	0.50	0.49	0.50	0.49	0.50	0.50	0.49	-0.07	0.12	-0.05	0.59	0.00	0.37	-0.03	-0.22	-0.05	1		
24	Charging Station Advances (M)	0.41	0.07	0.01	0.15	-0.09	0.09	0.16	0.08	0.15	0.10	0.15	0.09	-0.00	0.38	-0.03	0.30	-0.00	-0.05	-0.06	0.23	0.02	0.46	-0.11	1	
25	ATV Patent Growth (DM)	-0.02	-0.01	-0.01	-0.03	0.00	0.00	-0.03	-0.01	-0.02	-0.02	-0.03	-0.02	-0.02	-0.00	-0.06	-0.00	0.01	0.00	-0.05	-0.01	-0.04	0.00	0.02	-0.00	1
26	ATV Patent Growth (M)	-0.32	0.19	0.10	0.07	0.10	0.16	0.00	0.02	0.02	-0.00	0.02	-0.01	0.00	-0.05	-0.02	-0.16	0.04	-0.19	0.06	-0.39	-0.00	-0.63	0.02	-0.21	-0.00

Note: DM: deviation from firm mean; M: firm mean; the correlation matrix is based on the lagged and standardized variables such as implemented in the estimations. We only show correlations for those variables that were implemented jointly in our estimations; other correlations were left blank, which mainly applies to the different specifications of entrant variables. The only control variable that is disturbingly high correlated to entrant variables is age (deviation from firm mean); see line 17 in the table above. Note that the actual problem that causes estimation biases is not correlation but collinearity. To test the collinearity, we estimated Variance Inflation Factors (VIFs) and Condition Indexes for all model specifications. The results thereof indicate that all single VIFs, Mean VIFs and global Condition Indexes are far below the critical value ten (apart from Model 4 which is based on interaction terms and thus expected to suffer from collinearity). As an example, three results of the collinearity diagnostics for the Models 5, 8, and 9 are provided in Table 11; we chose to present these examples as the correlation between age (DM) and the respective entrant variables were among the highest correlations and thus most critical (see above in Table 10 line 17 in combination with column 7, 10, and 11).

Table 11: Collinearity Diagnostics

Variable	VIF	SQRT VIF	Tolerance	R-Squared	Eigenvalue	Cond. Index
Model (5)						
EKS, leader	3.10	1.76	0.3221	0.6779	2.7970	1.0000
ATV Knowledge Stock (DM)	1.42	1.19	0.7039	0.2961	2.7111	1.0157
ATV Knowledge Stock (M)	2.09	1.44	0.4794	0.5206	1.5443	1.3458
Patent Propensity (DM)	1.13	1.06	0.8886	0.1114	1.2532	1.4939
Patent Propensity (M)	2.32	1.52	0.4302	0.5698	1.1370	1.5684
Age (DM)	3.27	1.81	0.3063	0.6937	1.0631	1.6220
Age (M)	1.45	1.20	0.6909	0.3091	0.9510	1.7149
R&D Subsidies (DM)	1.36	1.17	0.7363	0.2637	0.7483	1.9333
R&D Subsidies (M)	1.56	1.25	0.6422	0.3578	0.6597	2.0590
Vehicle Registration (DM)	1.12	1.06	0.8928	0.1072	0.5847	2.1871
Vehicle Registration (M)	2.47	1.57	0.4041	0.5959	0.4735	2.4305
Charging Station Advances (DM)	2.09	1.44	0.4790	0.5210	0.3678	2.7575
Charging Station Advances (M)	1.59	1.26	0.6305	0.3695	0.2888	3.1119
ATV Patent Growth (DM)	1.01	1.01	0.9876	0.0124	0.2483	3.3562
ATV Patent Growth (M)	1.77	1.33	0.5655	0.4345	0.1720	4.0320
Mean VIF	1.85				Condition Number	4.0320
Model (8)						
EKS, young	3.01	1.74	0.3317	0.6683	2.7858	1.0000
ATV Knowledge Stock (DM)	1.42	1.19	0.7051	0.2949	2.7332	1.0096
ATV Knowledge Stock (M)	2.08	1.44	0.4797	0.5203	1.5438	1.3433
Patent Propensity (DM)	1.13	1.06	0.8877	0.1123	1.2288	1.5057
Patent Propensity (M)	2.33	1.52	0.4301	0.5699	1.1292	1.5707
Age (DM)	3.09	1.76	0.3236	0.6764	1.0669	1.6159
Age (M)	1.53	1.24	0.6518	0.3482	0.9512	1.7114
R&D Subsidies (DM)	1.37	1.17	0.7279	0.2721	0.7687	1.9037
R&D Subsidies (M)	1.57	1.25	0.6352	0.3648	0.6586	2.0567
Vehicle Registration (DM)	1.11	1.05	0.9041	0.0959	0.5807	2.1904
Vehicle Registration (M)	2.47	1.57	0.4050	0.5950	0.4734	2.4258
Charging Station Advances (DM)	2.09	1.45	0.4787	0.5213	0.3631	2.7699
Charging Station Advances (M)	1.52	1.23	0.6558	0.3442	0.2887	3.1063
ATV Patent Growth (DM)	1.01	1.01	0.9882	0.0118	0.2479	3.3520
ATV Patent Growth (M)	1.78	1.33	0.5625	0.4375	0.1800	3.9337
Mean VIF	1.83				Condition Number	3.9337
Model (9)						
EKS, pre-entry knowledge	2.91	1.70	0.3441	0.6559	2.8072	1.0000
ATV Knowledge Stock (DM)	1.42	1.19	0.7031	0.2969	2.7005	1.0196
ATV Knowledge Stock (M)	2.08	1.44	0.4798	0.5202	1.5435	1.3486
Patent Propensity (DM)	1.13	1.06	0.8885	0.1115	1.2487	1.4993
Patent Propensity (M)	2.32	1.52	0.4305	0.5695	1.1366	1.5715
Age (DM)	3.02	1.74	0.3310	0.6690	1.0626	1.6253
Age (M)	1.44	1.20	0.6928	0.3072	0.9511	1.7180
R&D Subsidies (DM)	1.38	1.17	0.7248	0.2752	0.7393	1.9485
R&D Subsidies (M)	1.54	1.24	0.6475	0.3525	0.6606	2.0614
Vehicle Registration (DM)	1.13	1.06	0.8873	0.1127	0.5826	2.1951
Vehicle Registration (M)	2.48	1.57	0.4038	0.5962	0.4732	2.4355
Charging Station Advances (DM)	2.09	1.44	0.4790	0.5210	0.3708	2.7515
Charging Station Advances (M)	1.58	1.26	0.6319	0.3681	0.2890	3.1165
ATV Patent Growth (DM)	1.01	1.01	0.9881	0.0119	0.2479	3.3649
ATV Patent Growth (M)	1.77	1.33	0.5650	0.4350	0.1862	3.8828
Mean VIF	1.82				Condition Number	3.8828

Note: DM: deviation from firm mean; M: firm mean; the collinearity diagnostics are based on the lagged and standardized variables; such as implemented in the estimations.

Table 12: Incumbents' Responses to Entrants from Different Countries

Dependent Variable: Incumbents' Number of ATV Patents

	Hybrid NB Model (1)	Hybrid NB Model (2)	Hybrid NB Model (3)
EKS (home) $_{t-1}$	0.146**	0.171**	0.171**
	(2.06)	(2.39)	(2.39)
EKS (all foreign) $_{t-1}$	0.351**		
	(2.38)		
EKS (relevant foreign) $_{t-1}$		0.453***	
		(3.55)	
EKS (3 most relevant foreign) $_{t-1}$			0.220***
			(2.73)
EKS (remaining relevant foreign) $_{t-1}$			0.313***
			(3.46)
EKS (irrelevant foreign) $_{t-1}$		0.0738	0.0748
		(0.68)	(0.69)
ATV Knowledge Stock (DM) $_{t-1}$	0.0172	0.0273*	0.0273*
	(1.09)	(1.67)	(1.67)
Patent Propensity (DM) $_{t-1}$	0.085***	0.078***	0.078***
	(3.20)	(2.95)	(2.94)
Age (DM) $_{t-1}$	-0.0189	-0.228	-0.227
	(-0.13)	(-1.43)	(-1.42)
R&D Subsidies (DM) $_{t-1}$	0.0005	0.0069	0.0077
	(0.01)	(0.16)	(0.18)
Vehicle Registration (DM) $_{t-1}$	0.0382	0.0330	0.0333
	(0.92)	(0.79)	(0.80)
Charging Station Advances (DM) $_{t-1}$	0.125***	0.124***	0.125***
	(3.17)	(3.08)	(3.06)
ATV Patent Growth (DM) $_{t-1}$	-0.0481	-0.0453	-0.0455
	(-1.13)	(-1.04)	(-1.05)
ATV Knowledge Stock (M)	0.121*	0.132*	0.132*
	(1.68)	(1.85)	(1.85)
Patent Propensity (M)	0.0937	0.118	0.118
	(1.14)	(1.41)	(1.42)
Age (M)	0.512***	0.439***	0.439***
	(4.94)	(4.18)	(4.18)
R&D Subsidies (M)	-0.0549	-0.0381	-0.0385
	(-0.67)	(-0.46)	(-0.47)
Vehicle Registration (M)	-0.300**	-0.258**	-0.257**
	(-2.29)	(-1.99)	(-1.99)
Charging Station Advances (M)	0.431***	0.355***	0.355***
	(3.95)	(3.39)	(3.39)
ATV Patent Growth (M)	0.0163	0.0397	0.0397
	(0.18)	(0.44)	(0.44)
Constant	-0.838***	-0.958***	-0.959***
	(-4.62)	(-5.20)	(-5.20)
Firm FE	yes	yes	yes
Year FE	yes	yes	yes
R2 Mc Fadden (adjusted)	0.050	0.052	0.051
N	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 13: Incidence Rate Ratios for Incumbents' Responses to Entrants from Different Countries

Dependent Variable: Incumbents' Number of ATV Patents

	IRR for Model (1)	IRR for Model (2)	IRR for Model (3)
EKS (home) $_{t-1}$	1.157**	1.186**	1.186**
	(2.06)	(2.39)	(2.39)
EKS (all foreign) $_{t-1}$	1.421**		
	(2.38)		
EKS (relevant foreign) $_{t-1}$		1.572***	
		(3.55)	
EKS (3 most relevant foreign) $_{t-1}$			1.246***
			(2.73)
EKS (remaining relevant foreign) $_{t-1}$			1.367***
			(3.46)
EKS (irrelevant foreign) $_{t-1}$		1.077	1.078
		(0.68)	(0.69)
ATV Knowledge Stock (DM) $_{t-1}$	1.017	1.028*	1.028*
	(1.09)	(1.67)	(1.67)
Patent Propensity (DM) $_{t-1}$	1.089***	1.081***	1.081***
	(3.20)	(2.95)	(2.94)
Age (DM) $_{t-1}$	0.981	0.796	0.797
	(-0.13)	(-1.43)	(-1.42)
R&D Subsidies (DM) $_{t-1}$	1.001	1.007	1.008
	(0.01)	(0.16)	(0.18)
Vehicle Registration (DM) $_{t-1}$	1.039	1.034	1.034
	(0.92)	(0.79)	(0.80)
Charging Station Advances (DM) $_{t-1}$	1.133***	1.132***	1.133***
	(3.17)	(3.08)	(3.06)
ATV Patent Growth (DM) $_{t-1}$	0.953	0.956	0.955
	(-1.13)	(-1.04)	(-1.05)
ATV Knowledge Stock (M)	1.129*	1.141*	1.141*
	(1.68)	(1.85)	(1.85)
Patent Propensity (M)	1.098	1.125	1.126
	(1.14)	(1.41)	(1.42)
Age (M)	1.668***	1.551***	1.552***
	(4.94)	(4.18)	(4.18)
R&D Subsidies (M)	0.947	0.963	0.962
	(-0.67)	(-0.46)	(-0.47)
Vehicle Registration (M)	0.741**	0.773**	0.773**
	(-2.29)	(-1.99)	(-1.99)
Charging Station Advances (M)	1.539***	1.427***	1.427***
	(3.95)	(3.39)	(3.39)
ATV Patent Growth (M)	1.016	1.041	1.040
	(0.18)	(0.44)	(0.44)
Constant	0.432***	0.384***	0.383***
	(-4.62)	(-5.20)	(-5.20)
Firm FE	yes	yes	yes
Year FE	yes	yes	yes
R2 Mc Fadden (adjusted)	0.050	0.052	0.051
N	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 14: Incumbents' Responses to Entrants Depending on their ATV Knowledge Stocks

Dependent Variable: Incumbents' Number of ATV Patents

	Hybrid NB Model (4.1)	FENB Model (4.2)
Entrants' ATV Knowledge Stock (home) $_{t-1}$	0.154**	0.132*
	(2.28)	(1.83)
Entrants' ATV Knowledge Stock (home) x IKS $_{t-1}$	-0.100***	-0.134***
	(-5.91)	(-8.22)
Entrants' ATV Knowledge Stock (relevant foreign) $_{t-1}$	0.470***	0.398***
	(3.29)	(3.23)
Entrants' ATV Knowledge Stock (relevant foreign) x IKS $_{t-1}$	0.0327	0.0509
	(1.03)	(1.49)
ATV Knowledge Stock (IKS) (DM) $_{t-1}$	0.303***	0.449***
	(10.87)	(10.62)
Entrants' ATV Knowledge Stock (irrelevant foreign) $_{t-1}$)	0.120	0.190
	(1.05)	(1.46)
Patent Propensity (DM) $_{t-1}$	0.0497**	0.251***
	(2.49)	(6.34)
Age (DM) $_{t-1}$	-0.293*	0.217***
	(-1.87)	(2.59)
R&D Subsidies (DM) $_{t-1}$	0.0798**	-0.0346
	(2.05)	(-0.60)
Vehicle Registration (DM) $_{t-1}$	0.0539	-0.0744
	(1.30)	(-1.31)
Charging Station Advances (DM) $_{t-1}$	0.114***	0.230***
	(3.52)	(4.59)
ATV Patent Growth (DM) $_{t-1}$	0.00380	-0.0260
	(0.09)	(-0.61)
ATV Knowledge Stock (M)	0.400***	
	(4.75)	
Patent Propensity (M)	0.261***	
	(2.74)	
Age (M)	0.376***	
	(3.68)	
R&D Subsidies (M)	-0.0304	
	(-0.38)	
Vehicle Registration (M)	-0.292**	
	(-2.31)	
Charging Station Advances (M)	0.294***	
	(3.00)	
ATV Patent Growth (M)	-0.0392	
	(-0.44)	
Constant	-0.720***	-1.147***
	(-3.22)	(-3.85)
Firm FE	yes	yes
Year FE	yes	yes
R2 Mc Fadden (adjusted)	0.069	0.205
N	1655	1543

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 15: Incidence Rate Ratios for Incumbents' Responses to Entrants Depending on their ATV Knowledge Stock

Dependent Variable: Incumbents' Number of ATV Patents

	IRR for Model (4.1)	IRR for Model (4.2)
Entrants' ATV Knowledge Stock (home) $_{t-1}$	1.166**	1.141*
	(2.28)	(1.83)
Entrants' ATV Knowledge Stock (home) x IKS $_{t-1}$	0.904***	0.874***
	(-5.91)	(-8.22)
Entrants' ATV Knowledge Stock (relevant foreign) $_{t-1}$	1.600***	1.488***
	(3.29)	(3.23)
Entrants' ATV Knowledge Stock (relevant foreign) x IKS $_{t-1}$	1.033	1.052
	(1.03)	(1.49)
ATV Knowledge Stock (IKS) (DM) $_{t-1}$	1.354***	1.566***
	(10.87)	(10.62)
Entrants' ATV Knowledge Stock (irrelevant foreign) $_{t-1}$)	1.128	1.209
	(1.05)	(1.46)
Patent Propensity (DM) $_{t-1}$	1.051**	1.286***
	(2.49)	(6.34)
Age (DM) $_{t-1}$	0.746*	1.242***
	(-1.87)	(2.59)
R&D Subsidies (DM) $_{t-1}$	1.083**	0.966
	(2.05)	(-0.60)
Vehicle Registration (DM) $_{t-1}$	1.055	0.928
	(1.30)	(-1.31)
Charging Station Advances (DM) $_{t-1}$	1.121***	1.258***
	(3.52)	(4.59)
ATV Patent Growth (DM) $_{t-1}$	1.004	0.974
	(0.09)	(-0.61)
ATV Knowledge Stock (M)	1.492***	
	(4.75)	
Patent Propensity (M)	1.298***	
	(2.74)	
Age (M)	1.456***	
	(3.68)	
R&D Subsidies (M)	0.970	
	(-0.38)	
Vehicle Registration (M)	0.747**	
	(-2.31)	
Charging Station Advances (M)	1.342***	
	(3.00)	
ATV Patent Growth (M)	0.962	
	(-0.44)	
Constant	0.487***	0.318***
	(-3.22)	(-3.85)
Firm FE	yes	yes
Year FE	yes	yes
R2 Mc Fadden (adjusted)	0.069	0.205
N	1655	1543

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 16: Effect of Entrants for Different Levels of Incumbents' ATV Knowledge Stocks

Effects of Entrants' ATV Knowledge Stock (Based on Previous Estimates)

Entrants from Incumbent's Home Country				Entrants from Relevant Foreign Countries			
IKS Level	Hybrid NB (4.1)	FENB (4.2)	IKS Level	IKS Level	Hybrid NB (4.1)	FENB (4.2)	IKS Level
-5	0.656***	0.158**	-0.2	-5	0.306	0.387***	-0.2
	(5.87)	(2.18)			(1.38)	(3.10)	
-4.2	0.576***	0.0643	0.5	-4.2	0.332	0.423***	0.5
	(5.69)	(0.91)			(1.64)	(3.52)	
-3.4	0.496***	-0.0298	1.2	-3.4	0.359*	0.459***	1.2
	(5.41)	(-0.42)			(1.93)	(3.82)	
-2.6	0.415***	-0.124*	1.9	-2.6	0.385**	0.494***	1.9
	(5.00)	(-1.72)			(2.25)	(3.97)	
-1.8	0.335***	-0.218***	2.6	-1.8	0.411***	0.530***	2.6
	(4.41)	(-2.89)			(2.59)	(3.97)	
-1	0.254***	-0.312***	3.3	-1	0.437***	0.565***	3.3
	(3.60)	(-3.89)			(2.93)	(3.88)	
-0.2	0.174**	-0.406***	4	-0.2	0.463***	0.601***	4
	(2.56)	(-4.70)			(3.22)	(3.75)	
0.6	0.0937	-0.500***	4.7	0.6	0.489***	0.637***	4.7
	(1.38)	(-5.35)			(3.43)	(3.59)	
1.4	0.0133	-0.594***	5.4	1.4	0.516***	0.672***	5.4
	(0.19)	(-5.86)			(3.53)	(3.44)	
2.2	-0.0670	-0.688***	6.1	2.2	0.542***	0.708***	6.1
	(-0.89)	(-6.26)			(3.53)	(3.29)	
3	-0.147*	-0.782***	6.8	3	0.568***	0.743***	6.8
	(-1.79)	(-6.57)			(3.45)	(3.16)	
3.8	-0.228**	-0.877***	7.5	3.8	0.594***	0.779***	7.5
	(-2.51)	(-6.82)			(3.33)	(3.04)	
4.6	-0.308***	-0.971***	8.2	4.6	0.620***	0.814***	8.2
	(-3.07)	(-7.02)			(3.18)	(2.94)	
5.4	-0.389***	-1.065***	8.9	5.4	0.646***	0.850***	8.9
	(-3.51)	(-7.19)			(3.04)	(2.84)	
6.2	-0.469***	-1.159***	9.6	6.2	0.672***	0.886***	9.6
	(-3.85)	(-7.32)			(2.89)	(2.76)	
7	-0.549***	-1.253***	10.3	7	0.699***	0.921***	10.3
	(-4.12)	(-7.43)			(2.76)	(2.68)	
7.8	-0.630***	-1.347***	11	7.8	0.725***	0.957***	11
	(-4.33)	(-7.52)			(2.65)	(2.61)	
8.6	-0.710***	-1.441***	11.7	8.6	0.751**	0.992**	11.7
	(-4.51)	(-7.60)			(2.54)	(2.55)	
9.4	-0.790***	-1.535***	12.4	9.4	0.777**	1.028**	12.4
	(-4.65)	(-7.66)			(2.44)	(2.50)	
10.2	-0.871***	-1.629***	13.1	10.2	0.803**	1.064**	13.1
	(-4.77)	(-7.72)			(2.36)	(2.45)	
11	-0.951***	-1.723***	13.8	11	0.829**	1.099**	13.8
	(-4.87)	(-7.76)			(2.28)	(2.40)	
11.8	-1.032***	-1.817***	14.5	11.8	0.856**	1.135**	14.5
	(-4.96)	(-7.81)			(2.21)	(2.36)	
12.6	-1.112***	-1.912***	15.2	12.6	0.882**	1.170**	15.2
	(-5.03)	(-7.84)			(2.14)	(2.32)	
13.4	-1.192***	-2.006***	15.9	13.4	0.908**	1.206**	15.9
	(-5.10)	(-7.87)			(2.09)	(2.29)	
14.2	-1.273***	-2.100***	16.6	14.2	0.934**	1.242**	16.6
	(-5.15)	(-7.90)			(2.04)	(2.26)	
15	-1.353***	-2.194***	17.3	15	0.960**	1.277**	17.3
	(-5.20)	(-7.93)			(1.99)	(2.23)	
15.8	-1.433***	-2.288***	18	15.8	0.986*	1.313**	18
	(-5.25)	(-7.95)			(1.94)	(2.20)	
16.6	-1.514***	-2.382***	18.7	16.6	1.012*	1.348**	18.7
	(-5.29)	(-7.97)			(1.90)	(2.17)	
17.4	-1.594***			17.4	1.039*		
	(-5.32)				(1.87)		
18.2	-1.675***			18.2	1.065*		
	(-5.35)				(1.83)		

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 17: Incumbents' Responses to Entrants with Different Characteristics

Dependent Variable: Incumbents' Number of ATV Patents

	Hybrid NB Estimates					
	Entrants' Characteristics					
	Technological Relevancy		**Age**		**Pre-Entry Patent Experience**	
	Leader (5)	Follower (6)	Old (7)	Young (8)	Yes (9)	No (10)
Entrants' ATV Knowledge Stock $_{t-1}$	0.440***	0.383***	0.418***	0.567***	0.433***	0.571***
	(4.20)	(4.57)	(4.25)	(5.89)	(4.33)	(6.02)
ATV Knowledge Stock (DM) $_{t-1}$	0.0321**	0.0305**	0.0299*	0.0364**	0.0306**	0.0357**
	(2.08)	(1.97)	(1.94)	(2.38)	(1.99)	(2.29)
Patent Propensity (DM) $_{t-1}$	0.0710***	0.0709***	0.0724***	0.0636**	0.0723***	0.0622**
	(2.81)	(2.80)	(2.87)	(2.52)	(2.86)	(2.48)
Age (DM) $_{t-1}$	-0.239	-0.270*	-0.259*	-0.401***	-0.264*	-0.435***
	(-1.57)	(-1.80)	(-1.68)	(-2.71)	(-1.73)	(-2.89)
R&D Subsidies (DM) $_{t-1}$	0.0118	-0.00730	-0.000311	-0.00682	-0.00128	-0.00633
	(0.28)	(-0.17)	(-0.01)	(-0.16)	(-0.03)	(-0.15)
Vehicle Registration (DM) $_{t-1}$	0.0302	0.0243	0.0321	0.0277	0.0325	0.0262
	(0.73)	(0.59)	(0.78)	(0.66)	(0.79)	(0.63)
Charging Station Advances (DM) $_{t-1}$	0.125***	0.119***	0.123***	0.125***	0.124***	0.120***
	(3.22)	(3.08)	(3.17)	(3.21)	(3.21)	(3.07)
ATV Patent Growth (DM) $_{t-1}$	-0.0460	-0.0488	-0.0475	-0.0460	-0.0470	-0.0470
	(-1.06)	(-1.11)	(-1.09)	(-1.03)	(-1.08)	(-1.05)
ATV Knowledge Stock (M)	0.127*	0.150**	0.131*	0.160**	0.135*	0.153**
	(1.79)	(2.10)	(1.84)	(2.26)	(1.90)	(2.19)
Patent Propensity (M)	0.147*	0.0946	0.127	0.130	0.128	0.128
	(1.75)	(1.15)	(1.53)	(1.56)	(1.54)	(1.55)
Age (M)	0.430***	0.454***	0.459***	0.388***	0.451***	0.403***
	(4.68)	(4.87)	(4.94)	(4.23)	(4.86)	(4.38)
R&D Subsidies (M)	-0.0270	-0.0350	-0.0302	-0.0561	-0.0299	-0.0627
	(-0.35)	(-0.45)	(-0.39)	(-0.73)	(-0.39)	(-0.81)
Vehicle Registration (M)	-0.258**	-0.236*	-0.244*	-0.206*	-0.243*	-0.197
	(-2.04)	(-1.87)	(-1.92)	(-1.65)	(-1.91)	(-1.57)
Charging Station Advances (M)	0.333***	0.351***	0.337***	0.280***	0.332***	0.274***
	(3.16)	(3.34)	(3.16)	(2.85)	(3.13)	(2.79)
ATV Patent Growth (M)	0.0220	0.0287	0.0237	0.0320	0.0238	0.0356
	(0.24)	(0.32)	(0.26)	(0.36)	(0.26)	(0.39)
Constant	-0.553***	-0.574***	-0.560***	-0.547***	-0.549***	-0.587***
	(-3.32)	(-3.29)	(-3.27)	(-3.24)	(-3.23)	(-3.39)
Firm FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
R2 Mc Fadden (adjusted)	0.053	0.053	0.053	0.055	0.053	0.056
N	1655	1655	1655	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 18: Incidence Rate Ratios for the Incumbents' Responses to Entrants with Different Characteristics

Dependent Variable: Incumbents' Number of ATV Patents

	IRR based on Model (5-10) **Entrants' Characteristics**					
	Technological Relevancy		**Age**		**Pre-Entry Patent Experience**	
	Leader (5)	Follower (6)	Old (7)	Young (8)	Yes (9)	No (10)
Entrants' ATV Knowledge Stock $_{t-1}$	1.552***	1.467***	1.520***	1.764***	1.542***	1.771***
	(4.20)	(4.57)	(4.25)	(5.89)	(4.33)	(6.02)
ATV Knowledge Stock (DM) $_{t-1}$	1.033**	1.031**	1.030*	1.037**	1.031**	1.036**
	(2.08)	(1.97)	(1.94)	(2.38)	(1.99)	(2.29)
Patent Propensity (DM) $_{t-1}$	1.074***	1.074***	1.075***	1.066**	1.075***	1.064**
	(2.81)	(2.80)	(2.87)	(2.52)	(2.86)	(2.48)
Age (DM) $_{t-1}$	0.788	0.763*	0.772*	0.669***	0.768*	0.647***
	(-1.57)	(-1.80)	(-1.68)	(-2.71)	(-1.73)	(-2.89)
R&D Subsidies (DM) $_{t-1}$	1.012	0.993	1.000	0.993	0.999	0.994
	(0.28)	(-0.17)	(-0.01)	(-0.16)	(-0.03)	(-0.15)
Vehicle Registration (DM) $_{t-1}$	1.031	1.025	1.033	1.028	1.033	1.027
	(0.73)	(0.59)	(0.78)	(0.66)	(0.79)	(0.63)
Charging Station Advances (DM) $_{t-1}$	1.133***	1.127***	1.130***	1.133***	1.132***	1.127***
	(3.22)	(3.08)	(3.17)	(3.21)	(3.21)	(3.07)
ATV Patent Growth (DM) $_{t-1}$	0.955	0.952	0.954	0.955	0.954	0.954
	(-1.06)	(-1.11)	(-1.09)	(-1.03)	(-1.08)	(-1.05)
ATV Knowledge Stock (M)	1.136*	1.162**	1.140*	1.173**	1.145*	1.165**
	(1.79)	(2.10)	(1.84)	(2.26)	(1.90)	(2.19)
Patent Propensity (M)	1.159*	1.099	1.135	1.139	1.137	1.136
	(1.75)	(1.15)	(1.53)	(1.56)	(1.54)	(1.55)
Age (M)	1.538***	1.574***	1.582***	1.474***	1.569***	1.496***
	(4.68)	(4.87)	(4.94)	(4.23)	(4.86)	(4.38)
R&D Subsidies (M)	0.973	0.966	0.970	0.945	0.971	0.939
	(-0.35)	(-0.45)	(-0.39)	(-0.73)	(-0.39)	(-0.81)
Vehicle Registration (M)	0.772**	0.790*	0.783*	0.814*	0.784*	0.821
	(-2.04)	(-1.87)	(-1.92)	(-1.65)	(-1.91)	(-1.57)
Charging Station Advances (M)	1.395***	1.420***	1.401***	1.323***	1.394***	1.315***
	(3.16)	(3.34)	(3.16)	(2.85)	(3.13)	(2.79)
ATV Patent Growth (M)	1.022	1.029	1.024	1.033	1.024	1.036
	(0.24)	(0.32)	(0.26)	(0.36)	(0.26)	(0.39)
Constant	0.575***	0.564***	0.571***	0.579***	0.578***	0.556***
	(-3.32)	(-3.29)	(-3.27)	(-3.24)	(-3.23)	(-3.39)
Firm FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
R2 Mc Fadden (adjusted)	0.053	0.053	0.053	0.055	0.053	0.056
N	1655	1655	1655	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; t-statistics in parentheses; DM: deviation from firm mean; M: firm mean.

Table 19: Model 2 Including Different Autoregressive Dependent Variables

Dependent Variable: Incumbents' Number of ATV Patents

	Hybrid NB Model Estimates							
Parameter	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
EKS (home) $_{t-1}$	0.158**	0.177**	0.179**	0.191***	0.202***	0.204***	0.203***	0.192***
EKS (relevant foreign) $_{t-1}$	0.461***	0.427***	0.418***	0.398***	0.393***	0.395***	0.403***	0.407***
EKS (irrelevant foreign) $_{t-1}$	0.0749	0.0869	0.0902	0.0933	0.0953	0.0944	0.0952	0.0934
Patent Propensity (DM) $_{t-1}$	0.0574**	0.0774***	0.0830***	0.0895***	0.0906***	0.0896***	0.0889***	0.0877***
Age (DM) $_{t-1}$	-0.228	-0.197	-0.188	-0.170	-0.165	-0.168	-0.174	-0.178
R&D Subsidies (DM) $_{t-1}$	0.00906	-0.00299	-0.00509	-0.0105	-0.0123	-0.0117	-0.00984	-0.00901
Vehicle Registration (DM) $_{t-1}$	0.0306	0.0348	0.0359	0.0398	0.0414	0.0417	0.0401	0.0388
Charging Station Adv. (DM) $_{t-1}$	0.118***	0.149***	0.157***	0.176***	0.183***	0.182***	0.174***	0.169***
ATV Patent Growth (DM) $_{t-1}$	-0.0459	-0.0433	-0.0424	-0.0415	-0.0414	-0.0414	-0.0413	-0.0417
DV (t-1)	0.000929***							
DV (t-2)		0.000325						
DV (t-3)			0.000195					
DV (t-4)				-0.000327				
DV (t-5)					-0.000689			
DV (t-6)						-0.000833		
DV (t-7)							-0.000789	
DV (t-8)								-0.000438
Patent Propensity (M)	0.203***	0.172***	0.165***	0.166***	0.172***	0.173***	0.170***	0.166***
Age (M)	0.391***	0.402***	0.404***	0.403***	0.402***	0.402***	0.404***	0.404***
R&D Subsidies (M)	-0.0549	-0.0804	-0.0867	-0.101	-0.108	-0.107	-0.103	-0.0973
Vehicle Registration (M)	-0.248*	-0.239*	-0.235*	-0.230*	-0.230*	-0.230*	-0.230*	-0.231*
Charging Station Adv. (M)	0.389***	0.439***	0.452***	0.469***	0.470***	0.466***	0.459***	0.459***
ATV Patent Growth (M)	0.0462	0.0585	0.0623	0.0690	0.0703	0.0707	0.0693	0.0679
Constant	-0.941***	-0.888***	-0.872***	-0.849***	-0.840***	-0.840***	-0.843***	-0.854***
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
R2 Mc Fadden (adjusted)	0.052	0.051	0.051	0.051	0.051	0.051	0.051	0.051
N	1655	1655	1655	1655	1655	1655	1655	1655

Note: *p<0.10, ** p<0.05, *** p<0.01; DM: deviation from firm mean; M: firm mean.

References

ACEMOGLU, D., AGHION, P., BURSZTYN, L., HEMOUS, D. (2012), "The Environment and Directed Technical Change", American Economic Review, 102 (1), 131–166.

AGHION, P., BESSONOVA, B. (2006), "On Entry and Growth: Theory and Evidence", Revue de l'OFCE, 97 (5), 259–278.

AGHION, P., BLUNDELL, R., GRIFFITH, R., HOWITT, P., PRANTL, S. (2009), "The Effects of Entry on Incumbent Innovation and Productivity", The Review of Economics and Statistics, 91 (1), 20–32.

AGHION, P., BLUNDELL, R., GRIFFITH, R., HOWITT, P., PRANTL, S. (2004), "Entry and Productivity Growth: Evidence from Microlevel Panel Data", Journal of the European Economic Association, 2 (2-3), 265–276.

AGHION, P., Dechezlepretre, A., Hemous, D., Martin, R., Van Reenen, J. (2012), "Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry", working paper.

AGHION, P., HEPBURN, C., TEYTELBOYM, A., ZENGHELIS, D. (2014), "Path Dependence, Innovation and the Economics of Climate Change", policy paper.

ALLISON, P.D. (2005), "Fixed Effects Regression Methods for Longitudinal Data Using SAS", Cary, NC: The SAS Institute.

ALLISON, P.D., WATERMAN, R. (2002), "Fixed–Effects Negative Binomial Regression Models", Sociological Methodology, 32 (1), 247–265.

ANDERSSON, M., BRAUNERHJELM, P., THULIN, P. (2012), "Creative Destruction and Productivity: Entrepreneurship by Type, Sector and Sequence", Journal of Entrepreneurship and Public Policy, 1 (2), 125–146.

ARCHIBUGI, D., PIANTA, M. (1996), "Measuring Technological Change through Patents and Innovation Survey", Technovation, 16 (9), 451–519.

BARKENBUS, J. (2009), "Our Electric Automotive Future: CO2 Savings through a Disruptive Technology", Policy and Society, 27 (4), 399–410.

BERGEK, A., BERGGREN, C., MAGNUSSON, T., HOBDAY, M. (2013), "Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation?", Research Policy, 42 (6–7), 1210–1224.

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

COHEN, W.M., NELSON, R.R., WALSH, J.P. (2000), "Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)", working paper 7552, National Bureau of Economic Research.

COWAN, R., HULTÉN, S. (1996), "Escaping Lock-In: The Case of the Electric Vehicle", Technological Forecasting and Social Change, 53 (1), 61–79.

CPC, Cooperative Patent Classifications (2014), "Climate Change Mitigation Technologies Related to Transportation", http://www.cooperativepatentclassification.org/cpc/scheme/Y/scheme-Y02T.pdf, retrieved: 04:2014.

CRISCUOLO, P., VERSPAGEN, B. (2008), "Does it matter where patent citations come from? Inventor vs. examiner citations in European patents", Research Policy, 37 (10), 1892–1908.

CZARNITZKI, D., ETRO, F., KRAFT, K. (2008), "The Effect of Entry on R&D Investment of Leaders: Theory and Empirical Evidence", ZEW - Centre for European Economic Research, discussion paper no. 08–078.

CZARNITZKI, D., ETRO, F., KRAFT, K. (2011), "Endogenous Market Structures and Innovation by Leaders: an Empirical Test", Department of Economics, University of Venice 'Ca' Foscari', working paper no. 2011_04.

DESMARAIS, B.A., HARDEN, J.J. (2013), "Testing for Zero Inflation in Count Models: Bias Correction for the Vuong Test", The Stata Journal, 13 (4), 810–835.

DIEKHOF, J. (2015), “Do Entrants Increase Incumbents’ Innovation Activity? Escaping the Lock-In, Stimulating Technological Change and the Transition towards Environmentally Friendly Vehicles”, Journal of Innovation Economics and Management, 4 (16), 101–137.

EPO, European Patent Office (2011), “Publication Date”, https://register.epo.org/espacenet/help?lng=en&locale=de&topic=publicationdate, retrieved: 11:2011.

FARLEY, H.M., SMITH, Z.A. (2014), “Sustainability: If It's Everything, Is It Nothing?”, New York: Routledge.

FREESE, J., LONG, J.S. (2006), “Regression Models for Categorical Dependent Variables Using Stata”, College Station, Texas: Stata Press.

FRITSCH, M., CHANGOLUISA, J. (2014), “New Business Formation and the Productivity of Manufacturing Incumbents: Effects and Mechanisms”, Jena Economic Research Papers, No. 2014-025.

FRITSCH, M., CHANGOLUISA, J. (2017), “New business formation and the productivity of manufacturing incumbents: Effects and mechanisms”, Journal of Business Venturing, 32 (3).

FRITSCH, M., MUELLER, P., (2004), “Effects of new business formation on regional development over time”, Regional Studies, 38 (8), 961–975.

GEROSKI, P.A. (1990), “Innovation, Technological Opportunity, and Market Structure”, Oxford Economic Papers, 42 (3), 586–602.

GEROSKI, P.A. (1995), “What Do We Know about Entry?”, International Journal of Industrial Organization, 13 (4), 421–440.

GILBERT, R.J., NEWBERY, D.M.G. (1982), “Preemptive Patenting and the Persistence of Monopoly”, The American Economic Review, 72 (3), 514–526.

GORT, M., KLEPPER, S. (1982), “Time Paths in the Diffusion of Product Innovations”, The Economic Journal, 92 (367), 630–653.

GREENE, W.H. (2007), “Fixed and Random Effects Models for Count Data”, New York University, Stern School of Business, NYU working paper no. 2451/26046.

GRILICHES, Z., (1979), “Issues in Assessing the Contribution of Research and Development to Productivity Growth”, The Bell Journal of Economics, 10 (1), 92–116.

GRILICHES, Z., PAKES, A., HALL, B.H. (1988), “The Value of Patents as Indicators of Inventive Activity”, NBER working paper no. w2083.

GUIMARÃES, P. (2008), “The Fixed Effects Negative Binomial Model Revisited”, *Economics Letters*, 99 (1), 63–66.

HALL, J.K., DANEKE, G.A., LENOX, M.J. (2010), “Sustainable Development and Entrepreneurship: Past Contributions and Future Directions”, Journal of Business Venturing, 25 (5), 439–448.

HARHOFF, D., WAGNER, S. (2009), “The Duration of Patent Examination at the European Patent Office”, Management Science, 55 (12), 1969–1984.

HASTIE, T., TIBSHIRANI, R. (1986), “Generalized Additive Model”, Statistical Science, 1 (3), 297–318.

HAUSMAN, J., HALL, B.H., GRILICHES, Z. (1984), “Econometric Models for Count Data with an Application to the Patents-R&D Relationship”, *Econometrica*, 52 (4), 909–938.

HELFAT, C.H., LIEBERMAN, M.B. (2002), “The Birth of Capabilities: Market Entry and the Importance of Pre-History”, Industrial and Corporate Change, 11 (4), 725–760.

HENDERSON, R.M., CLARK, K.B. (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.

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 .
HU, G.A. (2010), "Propensity to patent, competition and China's foreign patenting surge", Research Policy, 39 (7), 985–993.
IACOVONE, L., KELLER, W., RAUCH, F. (2011), "Innovation Responses to Import Competition", working paper.
IEA, International Energy Agency (2015), "Energy and Climate Change", World Energy Outlook Special Report.
KING, A.A., TUCCI, C.L. (2002), "Incumbent Entry into New Market Niches: The Role of Experience and Managerial Choice in the Creation of Dynamic Capabilities", Management Science, 48 (2), 171–186.
KLEWITZ, J., HANSEN, E.G. (2014), "Sustainability-Oriented Innovation of SMEs: a Systematic Review", Journal of Cleaner Production, 65, 57–75.
LEVINSOHN, D., BRUNDIN, E. (2011), "Beyond "Shades of Green": Opportunities for a Renewed Conceptualisation of Entrepreneurial Sustainability in SMEs: a Literature Review", conference paper, The 56th Annual ICSB World Conference.
MARKIDES, C. (2006), "Disruptive Innovation: In Need of Better Theory", The Journal of Product Innovation Management, 23 (1), 19–25.
MARKIDES, C.C., GEROSKI, P.A. (2005), "Fast Second: How Smart Companies Bypass Radical Innovation to Enter and Dominate New Markets", San Francisco, CA: Jossey-Bass.
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.
MICHEL, J., BETTELS, B. (2001), "Patent citation Analysis. A Closer Look at the Basic Input Data from Patent Search Reports", Scientometrics, 51 (1), 795–816.
MOORE, S., MANRING, S.L. (2009), "Strategy Development in Small and Medium Sized Enterprises for Sustainability and Increased Value Creation", Journal of Cleaner Production, 17 (2), 276–282.
MUSK, E. (2014), "All Our Patent Are Belong To You", http://www.teslamotors.com/blog/all-our-patent-are-belong-you, retrieved: 02:2015.
NELSON, R.R., WINTER, S.G. (1982), "An Evolutionary Theory of Economic Change", USA: President and Fellows of Harvard College.
OECD Statistical Service, Organisation for Economic Co-operation and Development (2014a), "Public R&D expenditures in Energy efficiency: transportation (Flow 13)", http://stats.oecd.org/BrandedView.aspx?oecd_bv_id=enetech-data-en&doi=data-00488-en, retrieved: 10:2014.
OECD Statistical Service, Organisation for Economic Co-operation and Development (2014b), "Passenger car registration data", http://stats.oecd.org/Index.aspx?querytype=view&queryname=91#, retrieved: 06:2014.
OECD, Organisation for Economic Co-operation and Development (1994), "The Measurement of Scientific and Technological Activities: Using Patent Data as Science and Technology Indicators", Patent Manual, OECD/ GD(94)114.
OECD, Organisation for Economic Co-operation and Development (2011), "Patent Search Strategies for the Identification of Selected Environment-Related Technologies", OECD publication.
OICA, Organisation Internationale des Constructeurs d'Automobiles (2013), "World Motor Vehicle Production: World Ranking of Manufacturers", OICA Correspondents Survey.
ROTHWELL, R., ZEGVELD, W. (1985), "Reindustrialization and Technology", New York: M.E. Sharpe Inc.

SCHALTEGGER, S., WAGNER, M. (2011), “Sustainable Entrepreneurship and Sustainability Innovation: Categories and Interactions”, Business Strategy and the Environment, 20 (4), 222–237.
SCHUMPETER, J.A. (1911/34), “Die Theorie Wirtschaftlicher Entwicklung” (1911), Berlin: Duncker & Humblot; English edn.: “The Theory of Economic Development” (1934), Cambridge, MA: Cambridge University Press.
TEECE, D.J., PISANO, G., SHUEN, A. (1997), “Dynamic Capabilities and Strategic Management”, Strategic Management Journal, 18 (7), 509–533.
TRAJTENBERG, M. (1990), “A penny for your quotes: patent citations and the value of innovations”, RAND Journal of Economics, 21 (1), 172–187.
TUSHMAN, M.L., ANDERSON, P. (1986), “Technological Discontinuities and Organizational Environments”, Administrative Science Quarterly, 31 (3), 439–465.
USPTO, United States Patent and Trademark Office (2000), “USPTO Will Begin Publishing Patent Application”, http://www.uspto.gov/news/pr/2000/00-72.jsp, retrieved: 06:2013.
UTTERBACK, J.M. (1994), “Master the Dynamics of Innovation: How Companies Can Size up the Opportunities in the Face of the Technological Change”, Boston, MA: Harvard Business School Press.
VAN DEN HOED, R. (2005), “Commitment to Fuel Cell Technology? How to Interpret Carmakers’ Efforts in this Radical 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.
VUONG, Q.H. (1989), “Likelihood Ratio Tests for Model Selection and Non-Nested Hypotheses”, Econometrica, 57 (2), 307–333.
WALLENTOWITZ, H., FREIALDENHOVEN, A., OLSCHEWSKI, I. (2010), “Strategien zur Elektrifizierung des Antriebstranges”, Wiesbaden: Vieweg & Teubner.
WCED, World Commission on Environment and Development (1987), “Our Common Future”, UN Document A/42/427, Chapter 2: Towards Sustainable Development.
WESSELING, J.H., FABER, J., HEKKERT, M.P. (2014), “How Competitive Forces Sustain Electric Vehicle Development”, Technological Forecasting and Social Change, 81, 154–164.
WIPO, World Intellectual Property Organization (2011), “IPC Green Inventory”, http://www.wipo.int/classifications/ipc/en/est/, retrieved: 12:2012.
ZUBER-SKERRITT, O. (2012), “Action Research for Sustainable Development in a Turbulent World”, Bingley: Emerald Group Publishing Ltd.

Endnotes

[a] Note that disruptive innovation is a vague term coined by Christensen (1997) and further refined by others. Markides (2006) classifies two types of disruptive innovations: business-model and radical product innovation. In his view, radical product innovations (which we concern in our study) have a disruptive influence on demand and supply as they cause consumers to change behaviour and challenge existing incumbents by undermining the competences on which they have built their success. They are further the result of supply-push processes, use a new set of scientific principles than the dominant design, and give birth to radically new markets (Markides and Geroski, 2005; Markides, 2006). Following Markides and Geroski, we prefer the term radical innovation (in their meaning) as many of our arguments are based on their work. If we use the term disruptive innovation, we reflect only on other authors' phrasings. To us it is important that the technologies in question (ATVs) can be perceived as substitutes to combustion engine vehicle technology and thus constitute challenging technologies and potential threats to the incumbents' design. Further important are acknowledged attributes associated to ATVs: immaturity, high-priced, small profit margins, small niche market, and the necessity to change customer behaviour. These attributes demonstrate very well that there are barriers to adopt ATVs for both end users and incumbents. ATVs fit therewith the discussion on the peculiarities of disruptive and radical innovations as discussed in Christensen (1997) and Markides and Geroski (2005).

[b] As we regard this work to a technology (ATV) which is considered to be more environmentally sound than the dominant design (combustion engine vehicle), we occasionally refer to environmentally friendly innovations. In accordance to Klewitz and Hansen (2014), environmentally friendly innovations include new or improved processes, organizational forms, and products or technologies that reduce or avoid negative environmental impacts. Although they term it eco innovation, the terminology of environmentally friendly innovation is more pertinent to us.

[c] In this context it is helpful to know that an early definition for sustainable development stems from the Brundtland report (WCED, 1987): "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The triple bottom line concept became prominent later with the United Nations' World Summit in 2005. In this view, sustainable development balances the three pillars of environmental, social, and economic objectives (Zuber-Skerritt, 2012). Farley and Smith (2014) build an extension to this; a nested model in line with their neo-sustainability view: the social and economic dimensions are restricted by and can only grow within the physical limits of the all-embracing environmental dimension. This present paper is not concerned directly with sustainability and we abstain from a deeper discussion on it. We focus on industry dynamics during the transition towards a certain technology (ATV) which is considered to be more environmentally sound than the dominant design (combustion engine vehicles). We thus contribute only broadly to the sustainability debate itself; indirectly touching the economic and environmental dimension. If we refer to sustainability, we either reflect on other authors' phrasings or speak of more universal constellations that we believe to hold for those three dimensions independently from our case.

[d] As the dependent variable contained 57% zeros, the presence of zero-inflation was tested for. The Vuong (1989) test was not utilized as it does not allow for panel data tests and is biased towards suggesting zero-inflated models. These limitations are discussed by Desmarais and Harden (2013), who have developed a new test that corrects this bias based on Akaike and Bayesian information criteria. The new test, however, is not appropriate for longitudinal data either. The present study therefore relies on a graphical test and on the Akaike and Bayesian information criteria test. The conventional hybrid NB model for panel data was compared to a pooled zero-inflated hybrid NB model with clustering on the firm level. Both tests suggested that the conventional NB distribution is to be preferred: indicated by a lower AIC value for the hybrid NB model (6036.11) than for the zero-inflated hybrid NB model (6324.46) and also indicated by the graphical fit of the data to the NB distribution (see Appendix, Figure 1).

[e] This data contains public expenditures regarded to the following technologies and subgroups: electric cars, hybrid cars, and stirling motors; analysis and optimization of energy consumption in the transport sector; efficiency improvements in light-duty vehicles, heavy-duty vehicles, and non-road vehicles; public transport systems; engine-fuel optimization; use of alternative fuels (liquid, gaseous); fuel additives; and diesel engines (OECD Statistical Service, 2014a; Aghion et al., 2012).

[f] We initially planned to calculate the technological relevance of entrants' patents by taking the number of relative forward citation. However, in investigating in a first step the absolute numbers of citations, we needed to realize that very few entrants at all received citations on their patents. We therefore chose to separate entrants into those that exhibit patent citations and others that do not.

[g] The existence of different citation guidelines across patent offices may add some noise to our classification. To name only one prominent example: at the USPTO they tend to cite three times more than at the EPO (Michel and Bettels, 2001) which leads to an overvaluation for USPTO patents in cross-country studies. Though, different citation guidelines seem more of a problem when cross-country comparisons and citation counts are considered. In our study, however, we do not compare citations across countries and also do not consider actual counts. Within each country

and based on its particular guidelines, we separate those entrants that did from others that did not receive citations. Additionally, as Criscuolo and Verspagen (2008) discuss, the scientific use of citations are perceived critically mainly for measuring knowledge flows as it is uncertain that inventors used the cited patent in the invention process. However, we are not interested in knowledge flows but whether incumbents could perceive certain entrants as more relevant than others given that their patents were cited and thus considered as relevant; independently who perceived it as relevant (the attorney, the examiner, or the applicant) and independently from whether the cited patent was actually used in the invention process of the citing patent (after-fact citation and teaching citation bias). For these reasons, we believe that substantial noise due to this peculiarity of citations can be mitigated in our study.

[h] To our understanding, the subsidies do include electric and hybrid vehicle technologies as they are part of the list to which these public expenditures apply. Hence, the variable could theoretically also be significant for firms' ATV-related patenting. Given that this variable is insignificant, it could also be concluded that incumbents stick to their R&D strategies and might welcome general public R&D support but are not spurred to change their R&D strategies significantly in accordance to such policy measures. However, as we do not have more information on the exact content of this variable and the exact amount spent to either of these R&D directions (ATV technologies versus fuel and energy efficiency technologies), we need to leave this as an open point for future research.

[i] For example, in year t=2009 in the analysis, entrants' patents were considered up to t=2008 (as using one year lag). Entrants' ultimate patents in t=2008 refer to the publication date, meaning that they applied for that patent during 2006 (18 month of confidentiality). In the best case, they just took less than one year to produce that patent, meaning that entrants' actual R&D investment has happened in t=2005. Note that only this R&D investment could be an entrant's response to incumbent patenting. Additionally, we used incumbents' patent applications as dependent variable. Hence, back in t=2005 when entrants invested in R&D, they were not aware of incumbents' patent applications in t=2005 but only aware of incumbents' patent applications from t=2003 (because of 18 month confidentiality). In sum, entrants' variables implemented to the model in t=2009, could be at best a reaction to incumbents' patent applications from t=2003. Consequently, the entrants' variables in t could at best be a reaction to the dependent variable 6 years before.