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## Incumbents' asymmetric responses to environmentally friendly entrants in the automotive industry

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# JENA ECONOMIC RESEARCH PAPERS



# 2017 – 004

## **Incumbents' Asymmetric Responses to Environmentally Friendly Entrants in the Automotive Industry**

by

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## **Incumbents' Asymmetric Responses to Environmentally Friendly Entrants in the Automotive Industry**

Key Words: Environmental Economics, Technological Change, Industry Dynamics, Entrepreneurship, Transport Industry, Electric Vehicle

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### **Abstract**

In the context of technological change, the influence of innovative entrants on incumbents is considered a major driving force. Using global patent data, we analyze this influence for the case of the transition from combustion engine vehicles towards alternative technology vehicles (ATVs). Entrants play a key role in developing ATV-related patents, whereas automotive incumbents are considered as being less motivated in pursuing this new technology. Our results indicate that entrants' ATV-related knowledge accumulation stimulates incumbents' ATV-related research. Domestic entrants had a positive effect on the large incumbent majority that exhibited low ATV patent stocks whereas incumbents with high ATV patent stocks reacted with decreasing patenting; which is assumed to be a sign of R&D outsourcing or strategic acquisitions. Entrants in foreign countries yielded increasing incumbent responses along increasing incumbents' ATV patent stocks; which is in line with previously found competitive reactions to entry. Further, younger entrants, pre-entry patent-inexperienced entrants, and entrant leaders with greater technological relevance were more influential than their counterparts (old, experienced, and less technological relevant). This suggests that not only diversifying but also new establishments have an effect on incumbents. As technological leading and inexperienced entrants showed a stronger effect on incumbents but were outnumbered by their counterparts, it underpins that entrants with important characteristics and not the pure number of entrants drive these effects on incumbents.

## **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 the introduction of 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)<sup>[a]</sup>. 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 but often remain in niche markets (Markides and Geroski, 2005; Schaltegger and Wagner, 2011). Radical technologies, in contrast, 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 firm 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<sup>[b]</sup> impedes technological change and yields industries that innovate more in dirty technologies than it is desirable for the social optimum; which thus requires 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<sup>[c]</sup>. 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

almost never 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 which, if successful, will 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 main reasons: First, this industry is currently facing the challenge of the emergence of alternative technology vehicles (ATVs)<sup>1</sup> 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 the potential to become disruptive to 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.<sup>2</sup> 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<sub>2</sub> contributor by taking up over 20% of global CO<sub>2</sub> emissions; which is even set to increase if ATV sales will not surge up strongly in subsequent periods (IEA, 2015). Given governments' ambitions to reduce global emissions, the present study focusing on firm dynamics that potentially propel the transition towards ATVs 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);

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<sup>1</sup> Automobile firms currently focus on three different ATV vehicle types: battery, fuel cell, and hybrid electric vehicles.

<sup>2</sup> 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).

this also covers 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 for advancing 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 particularly 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 influenced 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; Changoluisa and Fritsch, 2014). Such studies utilized quantitative entry measures (such as 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 for their present products, 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 or the size but rather qualitative characteristics of entrants as important. The present study firstly addresses these limitations and contributes to the literature by focusing on the following aspects: 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 by separating them into different country groups in accordance to the countries' relevance from the perspective of the incumbent at hand. In the present paper, we further advanced her methodology. We implement global and individualized policy, market, and technology-specific controls; such as government R&D subsidies, new vehicle registrations, advances in charging stations, and ATV patent growth rates. Most importantly, we take entry measures that indicate the qualitative force of entrants and simultaneously their market activity in considering their technology-specific knowledge accumulation over time; instead of simple entry numbers. 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 expected to be helpful in providing more detailed policy advice on how to target support towards the most 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 patent data, the model, and the variables are described in Section 4. The results are presented and discussed in Section 5 while Section 6 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 friendly 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 being motivated, incumbents initially react merely with environmentally friendly product line extensions but leverage the new technology from niche to mass-market in later stages of the transition (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. Incumbents can also make use of their strong innovative power, as their extensive resources facilitate large and in-depth R&D projects (Hockerts and Wüstenhagen, 2010).

We would like to note that those firm dynamics described above are not a new theory particular for sustainable innovations but find their roots in more classical economics of innovation literature. The key role of innovative entrepreneurs in accelerating technological change was firstly highlighted by Schumpeter (1911/34). 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). In particular Geroski (1995) already noted that some case studies found that entrants propeled incumbents to introduce innovations which incumbents had been holding back. Such different roles of both actors during technological change were also described comprehensively by Markides and Geroski (2005). They as well emphasized that new markets for radical innovations are driven by new entrants in early transitional stages whereas it is the power of incumbents, not the early pioneer, which transforms the innovation towards mass-market adoption. If we consider environmentally friendly innovations to be in an emerging stage and to be of relatively radical manner, it is not surprising that many 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).<sup>3</sup> However, characterizing the key role of entrants in sustainable transitions not purely by the introduction of such innovations but by their stimuli on incumbents' sustainable actions was discussed only now within Hockerts and Wüstenhagen (2010). An early empirical attempt to validate their proposition that already the entry of such green firms has an effect on incumbents' environmentally friendly research activity was later addressed by Diekhof (2015) with an affirmative result.

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<sup>3</sup> Hall et al. (2010), Levinsohn and Brundin (2011), and Klewitz and Hansen (2014) provide a comprehensive overview of recent work on the nexus of sustainability and entrepreneurship.



As it is an emerging field of research, few studies have yet begun to disentangle this effect using econometric approaches. As a result, besides findings on the basic effect of domestic industry-level entry on incumbents and the recently revealed asymmetric incumbent responses there is presently little known about the exact force of entry. The most important empirical studies that investigate the ATV transition and more generally the influence of entrants on incumbents are briefly discussed below.

Wesseling et al. (2014) conducted a related case study. Based on patent-count analyses, they investigated the continuation of ATV research within 15 original equipment manufacturers (OEMs) that are currently leading the automotive market in terms of sales indicators. 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 individual total patents increased from 2006 to 2010, the proportion of their patents from total patenting in this technology decreased. The researchers stress that this finding suggests that incumbents struggle to keep pace with technological progress in that field. Although their data were not comprehensive enough to show that the existence of entrants enhances ATV research in general, the authors did find 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.

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 situation 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 contrast, 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.

Changoluisa and Fritsch (2014) investigate the response of German manufacturing incumbents to regional entrants within the same industry. Their findings suggest a positive entry effect on incumbents' productivity while

incumbents with state of the art machinery responded strongest. Though, this effect was limited to entry within the incumbents' regions whereas aggregated entry in all German regions did not exhibit a significant effect. Also Andersson et al. (2012) found a positive effect of Swedish 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, and thus termed it the delayed entry effect. Manufacturing incumbents were found to be 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 the present 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) found asymmetric responses across Mexican manufacturing firms, whilst observing these firms' innovative internal changes in areas such as job rotation or quality control in response to new import competition by Chinese entrants. Their results indicate that entry induced productive incumbents to innovate more and less productive incumbents to innovate less. They argue that this competitive pressure reinforces the differences between strongly and weakly performing firms, eventually causing heterogeneous responses to entry. Aghion et al. (2004) conducted a study on trade liberalization within the United Kingdom. The authors come to the conclusion that entry has a positive effect on incumbents' total factor productivity growth. Aghion and Bessonova (2006) investigated the effect of entry on Russian incumbents' total factor productivity growth. Their results show that foreign firms' entry into Russia had an asymmetric effect among incumbents: those operating more close to their industry frontier responded stronger as compared to those 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 not only on domestic incumbents' productivity but also on their patenting. This effect, however, was only found for incumbents that operate in technologically advanced industries.

### **3 Hypotheses**

In line with Hockerts and Wüstenhagen (2010), also we consider the stimuli of innovative entrants on incumbents' sustainable activities as crucial for industries' transitions towards a lower environmental impact. Our hypotheses build on findings of previous literature 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 qualitative forces, incumbents' technology-specific responses in dependence on their technology-specific knowledge, as well as the role of entrants' characteristics when imposing an effect on incumbents. Three main sets of hypotheses are derived.

To our knowledge, the different channels through which entrants may influence incumbents have yet not been discussed intensively in the literature. This is likely to be due to the different angle of previous studies in which foreign firm entry into domestic markets or new domestic establishments were considered. This procedure includes entrants that are not necessarily innovative and may sell only existing technologies in markets new-to-the-firm but not new technologies which are difficult to adopt. This seems to be an appropriate framework to purely study the competition effect of entry on incumbents' general productivity changes. The present study, in contrast, considers purely innovative entrants that undertake research within new, immature, and radical technologies for which the adoption process is considered to be difficult (Markides and Geroski, 2005). We also do not look at general incumbent responses but at their innovative responses within a radical technology that challenge their dominant design. In this different framework, it seems more appropriate to not only consider the competitive force of entry but various channels through which entrants may influence incumbents; such as directly, via complementary knowledge as well as indirectly, via market initialization. Although we cannot test for these different channels, we believe that they are crucial, likely to occur, helpful to interpret results, and should be discussed more intensively also in future studies. The different channels will be highlighted briefly below under the consideration of the specific technology in question.

We expect the considered entrants to stimulate incumbents' ATV-related patenting via three channels: directly, via competitive pressure and complementary knowledge, as well as indirectly, via market initialization. As to competitive entrants that intend to sell ATVs: we consider patent entry and thus innovative entry in the Schumpeterian sense which would be in support of entrants' challenging potential. In the case of the automotive industry, however, the effect of competitive entry is likely to be limited because this industry is strongly consolidated and led by powerful incumbents. 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 also influence OEMs indirectly by their niche market activity. Entrants that sell ATVs acquire more and more early ATV adopters and thereby steadily enlarge the market scope for ATVs. They spark not only the development of a sufficient charging infrastructure but also standard settings; e.g., for charging plugs and battery exchange systems. Eventually, competitive entrants penetrate the automotive market and thereby gradually increase the ATVs' profitability and thus indirectly improve the conditions for incumbents' ATV commitment. As entrants that supply complementary knowledge: the present study follows Wesseling et al.'s (2014) conclusion that not only de novo entrants but also diversifying entrants are important drivers of advancements in ATV technologies. In fact, there is a high likelihood that many suppliers from lateral industries, such as battery or electric motor manufacturers, will enter the ATV niche market. These diversifying firms can draw on long-term experience and leverage crucial capabilities, which might enable them to achieve rapid technological advances and benefit from new profit opportunities. 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' patenting.<sup>4</sup>

#### *First Hypotheses Set*

A first set of hypotheses addresses the questions of 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 also on incumbents' technology-specific patenting when entrants with substitutive technologies were considered (Diekhof, 2015). Instead of approximating entrants' quantitative forces (by their numbers, or employment sizes) we utilize an indicator that rather reflects technology-specific qualitative entry forces; namely, entrants' ATV-related knowledge accumulation. We believe that such a measure is more meaningful than approximating quantitative entry forces as the entrants' effect on incumbents is unlikely to increase purely with entrant numbers but rather with their qualitative performance. Taking the three channels through which we expect entrants influence incumbents, we assume that the greater the entrants' ATV-related knowledge the stronger will be their competitive power and their capacity for market penetration in case of competitive entry and the more supportive will

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<sup>4</sup> An example for such diversifying incumbent entrants in the ATV research regime are for instance firms such as Siemens A.G. that start research on electric drive systems.

be their potential spillovers towards incumbents in case of complementary entrants. The present study therefore generally hypothesizes that entrants' ATV-related patent accumulation has a positive effect on incumbents' ATV-related patent activity.

In contrast to Changoluisa and Fritsch (2014), who do not find an effect of aggregated domestic entry but only for regional entry (which could suggest that the considered entrants are mainly regional business orientated), we neither expect the effect of entrants that begin to innovate on ATVs to be limited to regions nor 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 as important and investigated in further detail. Aghion et al. (2012) suggests that the extent to which OEMs considers 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 entry to be influential only if they origin from relevant countries in which the incumbent is patenting but to bear no influence if they originate from irrelevant countries in which the incumbent is not patenting. We hypothesize in particular that not only domestic (Hypothesis H1.1) but also foreign entrants from relevant countries (Hypothesis H1.2) positively influence 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 on entry. Aghion and Bessonova (2006), Czarnitzki et al. (2011), Iacovone et al. (2011), and Changoluisa and Fritsch (2014) find stronger incumbent responses on entry for leading incumbents in terms of sales, productivity, and their 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 hypothesize decreasing incumbent patent responses on entry, along 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 seriously challenged by new 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 on the R&D of highly advanced incumbents and further underlines a decreasing patent response of incumbents with increasing ATV-related knowledge stock. To the contrary, OEMs that filed very few ATV-related patents are likely to be challenged by competitive entrants and likely to seek research support from complementary entrants in terms of knowledge spillovers. 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, as 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 and 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), also in the present study we are interested in this effect as we implement many different variables that may lead to different findings. In the present study, we use different indicators for the main variables of interest; that is,

an indicator to approximate not quantitative but qualitative entry forces and an indicator for incumbents' technology-specific knowledge stock instead of ATV-related productivity. We further extend her approach by implementing controls that also account for political, technology-specific, and demand side aspects and further separate foreign entry into relevant and irrelevant country groups. Asymmetric response behavior across incumbents is a relatively new finding in the literature and has not yet been explored from many different perspectives. The new technology-specific perspective of Diekhof (2015) and the present study open up an opportunity to extend current literature and investigate incumbents' asymmetric responses on entry in more detail and beyond country- and industry-level-entry phenomena. We believe that those asymmetric incumbent responses are important to understand the full picture of entrants' role in stimulating technological change via their influence on incumbents.

### *Third Hypotheses Set*

From a policy perspective it seems important to identify the relevant characteristics of entrants when their influence on incumbent is considered. Although the considered entrant pool is very heterogeneous and contains different types of entrants that begin ATV research, we intend to identify some relevant characteristics of entrants with the third set of hypotheses. We test six contrasting entrant 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 regarding technological relevance, we intend to shed more light on the importance of entrants' qualitative expertise associated to the technology in question; also to elaborate farther our approach of investigating rather qualitative than pure quantitative entry forces. Incumbents are unlikely to perceive an entrant follower with minor technological relevance as important. Instead, leading entrants that give birth to major advances which are important in subsequent periods are expected to have greater challenging and supportive potential with which they can influence incumbents and are therefore likely to attract more attention. The present study therefore 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 besides ATVs is stronger than the effect of entrants without pre-entry patent experience.

In addition, we test for entrants' characteristics that are typical for diversifying entrants versus characteristics that are typical for new establishments (de novo entrants and parent-company ventures); namely, high versus low age and none versus pre-entry patent experience in other fields besides ATVs. This is expected to help distinguishing to some extent the different effect that might occur from these different entrant types. Following Helfat and Lieberman (2002), pre-entry complementary and general organizational 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 incumbent diversifying entrants competitive advantages over de novo entrants when entering new markets (King and Tucci, 2002). We adopt these findings of entrants' relevant characteristics for success and survival for our framework in arguing as follows: also diversifying entrants into the ATV market can take advantage of their pre-entry experience from lateral markets and are therefore likely to be more successful compared to new establishments that are instead expected to suffer from liability of newness. In turn, the more successful an entrant prospers or the more successful the entrant initializes the market the more likely it is that the incumbent will perceive this entrant as challenging or supportive. For these reasons, diversifying entrants that are older and have pre-entry patent experience in other fields are assumed to be more influential on incumbents than young establishments without pre-entry patent experience (Hypotheses H3.2 and H3.3).

## **4 Methodology**

### **4.1 Patent Database Construction**

Patent data were used to gather information about firms' innovation activities on technologies related to ATVs. This section explains the procedure for the patent queries and discusses the usage of patents as an indicator for the main variables of interest; namely, incumbents' motivation to innovate and advance ATV-related technologies and entrants' knowledge accumulation in ATV-related technologies.

Patents have been proven to be appropriate indicators with which to analyze inventive technical activities (Griliches et al., 1988; OECD, 1994). However, patents also bring along some drawbacks. First, innovative efforts do not necessarily result in patents—R&D does not always lead to 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 also 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 automotive R&D activity. In contrast, OEMs' media 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 releasing products on the market, patents have been instrumental in prior research for identifying firms' innovative strategies in early R&D stages even before market entry occurs (Archibugi and Pianta, 1996). This aspect is important for the purpose of the present study as many firms have undertaken ATV-related research but have not yet launched ATVs or related components. Furthermore, while firms' R&D expenditures are usually not made available to researchers, patent data are free of costs and publically available, offering a large dataset spanning a long time period (Archibugi and Pianta, 1996).

Most importantly, although patents do not reveal actual innovative output, they are strong indicators of firms' input to the 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), supporting our choice to analyze incumbents' ATV-related innovative effort by their patent activity in this field.

The analysis makes 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; namely, 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 in 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 different dates (application, publication, and granting) that can be considered for search queries. Patent queries based on application and publication dates yield patent pools that include all patents, regardless of whether those patents were later granted.<sup>5</sup> Such queries better represent firms' overall

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<sup>5</sup> This holds for patent offices in most countries: e.g., the U.S., Japan, China, and Europe (OECD, 1994; USPTO, 2000; Hu, 2010; EPO, 2011).

innovative effort, as they include all patent applications—not just successful ones—in the patent count. Further, the data on application and publication dates are available about 18 months after the first priority application, while granting dates may take five years to be published due to time-consuming review processes (OECD, 1994; Harhoff and Wagner, 2009). The present patent query was based on application and publication dates since this procedure 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 analytical purposes, as will be discussed below.

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

We 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). This definition is in line with previous patent studies on ATVs such as Wesseling et al. (2014). 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 (which is one of the 20 most successful OEMs). Furthermore, OEMs' foreign establishments that also conduct R&D often develop innovation strategies that focus on country-specific R&D projects to satisfy local needs and are very 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 study sample.<sup>7</sup>

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<sup>6</sup> Utility models, for example, are excluded from the patent count.

<sup>7</sup> An overview of considered incumbents is provided in the Appendix, Table 8.

Application dates were used in the present analysis to retrieve the number of patents filed by incumbents. Since application is the point in time when firms first file their patent at the patent office, this is the date most closely related to their hypothesized innovative responses to new entrants. Using the application date also brings another computational advantage: after the initial application is made, patent offices wait 18 months to publish the patent document.<sup>8</sup> Before the patent office publishes the patent document the existence of the patent is kept strictly confidential. For this 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 consider each of their inventions only once when calculating the patent count. However, often an entire group of patents (known as the patent family) refer to the same invention. Only the first priority application was therefore included in the final patent count.<sup>9</sup> The individual incumbents' yearly number of ATV-related patents is tracked from  $t=1980$  to  $t=2009$ , which serves as the observation period in the present 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, for example, the date of product launch. Firms in the automotive industry ordinarily start patenting long before market entry occurs. Incumbents carefully monitor patent activities within their competitive business environment, and are therefore likely to already take strategic actions in response to other actors' patent activities. As explained in the preceding paragraph, applications are kept confidential by the patent office for 18 months, making the publication date the earliest point at which incumbents could be aware of entrants' patent activities. Since the target of the present study is to analyze incumbents' responses on innovative entry, whereby entry is measured with patents, not the application but the publication dates were used as an indicator for the year of entrants' entry into the ATV research regime. Subsequently, all remaining firms of the firm pool (beyond the previously extracted incumbents) were considered as research entrants from the year at which their first ATV-related patent publication occurred. If their entry occurred between  $t=1975$  and  $t=2008$ , they were classified as relevant entrants, extracted from the firm pool and their number of ATV-related patent publications was taken to construct the entry variables. 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).<sup>10 11</sup>

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<sup>8</sup> An overview of this procedure can be found in OECD (1994) and in Harhoff and Wagner (2009).

<sup>9</sup> To further prevent double counts of inventions, the data was reviewed to ensure that each DOCDB patent family is counted only once per firm.

<sup>10</sup> For further explications on this classification of entrants, please see Helfat and Liebermann (2002).

The 2013 fall edition of the PATSTAT database contains accurate patent data from 1970 to 2011.<sup>12</sup> 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.<sup>13</sup> The observation period of the analysis, however, was restricted from  $t=1980$  to  $t=2009$ , as the construction of several variables required accurate patent data from earlier and later periods, respectively. The earliest year considered was 1980 because in each period  $t$ , accurate patent data from the preceding five years were needed to construct the variables of entrants' and incumbents' accumulated patent stocks in  $t$ . The latest year considered was 2009 because in each period  $t$ , accurate patent data until the following two years were needed to evaluate the technological relevance of entrants' knowledge stock in  $t$ . The variable constructions are further explained in Section 4.2.

Country codes provided by the PATSTAT database were used to infer incumbents' and entrants' national affiliations.<sup>14</sup> With this procedure, the analysis accounts for all countries affiliated with the considered relevant incumbents and entrants; while the former originate from 15 and the latter from 92 different countries, respectively.

## **4.2 Empirical Specification**

To estimate incumbents' innovative responses, the present study relied on firm-level longitudinal patent count data. Due to the highly skewed and over dispersed data distribution, a negative binomial model (NB) for panel data was utilized, which controls for within-group correlations among multiple firm observations over time.<sup>15</sup> Incumbents are likely to show stable individual characteristics that they have established over time, such as firm-specific cultures, habits, or attitudes, which could bias the predictor variables. Fixed effects models remove these time-

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<sup>11</sup> Note that all remaining firms who were neither assigned to the incumbent nor to the entrant group were excluded from the sample.

<sup>12</sup> Due to the updating process of the PATSTAT database and the common 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.

<sup>13</sup> A lead-time of five years without any ATV-related patents was deemed sufficient, as this industry is characterized by frequent patenting.

<sup>14</sup> Firms for which no country affiliation was available in the PATSTAT database were excluded from the sample.

<sup>15</sup> Note that we preferred the NB model over a poisson regression as the mean of the dependent variable (12.35) is very different from its variance (3991.63). An overview of the descriptive statistics is provided in the Appendix, Table 9.

invariant characteristics of variables to ensure the unbiased consideration of the predictors' net effects. Since the present analysis is investigating the causes of change over time in incumbents' ATV-related patenting, time-invariant characteristics must be controlled, as they are constant over time and therefore cannot determine the corresponding changes in patenting. However, there has been discussion recently regarding the application of the conditional fixed effects negative binomial model (FENB), which was introduced by Hausman et al. (1984). The model is expected to not fully control for individual fixed effects in longitudinal count data as the fixed effects are implemented in the model via the dispersion parameter rather than via the conditional mean function; the model may therefore exhibit an incidental parameter problem (Allison and Waterman, 2002; Guimarães, 2008). However, Greene (2007) indicated that this model may not have an incidental parameter problem, but instead may suffer from an omitted variable bias. He further stated that the FENB model provides a sufficient statistic for the fixed effects while the size of the potential bias still remains to be investigated in future research. Since the conditional FENB model is nevertheless potentially problematic, the analysis rests on a hybrid NB model in accordance with the method introduced by Allison (2005, pp. 101-105). This hybrid NB model builds on a random effects model in which the firm-specific time-varying covariates are split into two parts: the firm-specific mean and the deviations from this mean. The latter variable represents the corrected fixed effects estimates, while the former variable controls for all stable effects (i.e., the potentially unobserved time-invariant firm-specific characteristics).

The remainder of this section firstly explains the construction of the dependent variable, continues with the explanatory variables of interest in combination with the respective model settings, and finally illustrates the construction of controls. The descriptive statistics and the correlation matrix of all variables as well as selected collinearity diagnostics are provided in the Appendix (Table 9 to 11).

The *dependent variable* ( $IPA_{i,t,h}$ ) describes the incumbent  $i$ 's number of ATV-related patent applications filed in year  $t$ . The incumbents' yearly ATV-related patenting was tracked from  $t=1980$  to  $t=2009$ .<sup>16</sup> It needs to be noted that incumbents' reactions to entry is difficult to capture precisely in time; many researchers have shown that the effect of entry differs over time (e.g., Fritsch and Mueller, 2004; Andersson et al., 2012). For the case of the present study, incumbents may differ in the time needed to respond to entrants with a change in their R&D activities: some may invest in R&D one year after they observe

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<sup>16</sup> Note that we use simple patent counts instead of citation weighted patents as for example suggested in (Trajtenberg, 1990) since we are interested in an incumbent's overall willingness to put effort into achieving ATV-related technological advances, independent from the output value of their innovative effort.

entrants' patent activities while others may invest after three years. Further, it is not R&D investments, but patent applications that serve as an indicator for incumbents' responses. The time interval from starting to invest in new R&D projects to patent may differ, not only by firm (due to different innovative capabilities) but also among individual R&D projects (according to their 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 overall effect; instead, wide-ranging time horizons seem meaningful for observing incumbents' reactions to entry in the dependent variable.

The main *explanatory variables* of interest account for this imperfection. The variable indicating an entrant's knowledge stock ( $EKS_{j,t,z_j}$ ) was constructed by applying Griliches' (1979) perpetual inventory method that is used in many innovation studies:

$$EKS_{j,t,z_j} = EPP_{j,t,z_j} + (1 - \delta)EKS_{j,t-1,z_j} \quad (1)$$

where: entrant  $j = 1, \dots, J$ ;  $t$  refers to the time in question,  $j$ 's home country  $z_j = 1, \dots, Z_j$ .

The variable  $EKS_{j,t,z_j}$  is calculated by accumulating the yearly number of entrant  $j$ 's ATV-related patent publications ( $EPP_{j,t,z_j}$ ). The accumulation regards the period from entrant  $j$ 's first ATV-related patent publication until the time at hand ( $t$ ). The entry variables therefore contain, in each period  $t$ , also information about entrants' patenting in previous periods, to which the incumbents can react individually.<sup>17</sup> The depreciation rate of entrants' previous patent stock ( $\delta$ ) is set to the commonly used 20% in innovation studies. Depending on the hypotheses in question, the entrants' knowledge stocks were aggregated to different groups referring to certain country origins (first and second hypotheses set) or certain characteristics (third hypotheses set); as described in the following paragraphs.

Each set of our hypotheses relates to a certain model setting; Table 1 displays an overview. We test the first set of hypotheses with three separate models containing differently aggregated entrants to certain country groups. The second set of hypotheses is addressed by implementing interaction terms of the incumbents' knowledge stock with domestic and foreign entrants from relevant countries. Lastly, for the third set of hypotheses we separately test six models containing differently aggregated entrants to certain characteristic groups. For all estimations we apply the hybrid NB model and additionally estimate Model 4 with the conditional FENB model to validate robustness.

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<sup>17</sup> Note that entrants' patents are considered from  $t=1975$  onwards (see also Section 4.1). A lead period of five years was considered sufficient to build their accumulated knowledge stock in the first period  $t=1980$  as related studies found positive entry effects after four (Andersson et al., 2012) and after five years onwards (Fritsch and Mueller, 2004).

**Table 1: Relation of Hypotheses and Model Settings**

Hypotheses	Model & Content
1 <sup>st</sup> Set H1.1 – H1.3	<b>First Model Setting</b> Hybrid NB Model (1) – (3): Entrants' country origins
2 <sup>nd</sup> Set H2.1 & H2.2	<b>Second Model Setting</b> Hybrid NB Model (4.1) & FENB Model (4.2): Incumbents' asymmetric responses
3 <sup>rd</sup> Set H3.1 – H3.3	<b>Third Model Setting</b> 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, further assigned to different country groups and tested stepwise separately in three models. In Model 1, two country groups of entrants were included: domestic entrants that originated from the incumbent's home country ( $z_j=h_i$ ) as well as foreign entrants that originated from all foreign countries considered ( $z_j \in afc_i$ ). In Model 2, the previous variable containing all the foreign entrants is further split up into two new country groups: firstly, entrants from relevant foreign countries ( $z_j \in rfc_i$ ) and, secondly, entrants from irrelevant foreign countries ( $z_j \in ifc_i$ ). Each incumbent's global patent portfolio was taken to infer in which countries the incumbent is operating in. Those entrants that originated from foreign countries in which the incumbent patented were aggregated in the variable associated to relevant foreign countries ( $z_j \in rfc_i$ ) and all other entrants that originated from countries in which the incumbent did not patent were aggregated in another variable associated to irrelevant foreign countries ( $z_j \in ifc_i$ ). For example, Model 2 can be expressed by Equation 2:

$$\begin{aligned}
 IPA_{i,t} = \exp \left[ \beta_0 + \beta_1 \sum_{j=1}^J EKS_{j,t-1,z_j=h_i} + \beta_2 \sum_{j=1}^J \sum_{z_j \in rfc_i} EKS_{j,t-1,z_j} + \beta_3 \sum_{j=1}^J \sum_{z_j \in ifc_i} EKS_{j,t-1,z_j} \right. \\
 \left. + \beta_4 IKS_{i,t-1} + \beta_5 PP_{i,t-1} + \beta_6 A_{i,t-1} + \beta_7 SubRD_{i,t-1} + \beta_8 VR_{i,t-1} + \beta_9 ACS_{i,t-1} \right. \\
 \left. + \beta_{10} PGR_{i,t-1} + YFE + FFE + \epsilon_{i,t} \right] \quad (2)
 \end{aligned}$$

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

Turning to Model 3, the previously constructed variable which contains entrants from relevant foreign countries ( $z_j \in rfc_i$ ) was also split up into two new country groups: firstly, entrants that originate from the three most relevant foreign

countries ( $z_j \in \text{mrfc}_i$ ) (in which the incumbent was filing most of its international patents) and, secondly, entrants from all other remaining relevant foreign countries ( $z_j \in \text{rrfc}_i$ ) (in which the incumbent in question patented).

The *second model setting* regards the second set of hypotheses (H2.1 and H2.2): whether the incumbents' responses on entry differ with their level of ATV-related knowledge stocks. For this purpose, the entry variables ( $\text{EKS}_{j,t}$ ) were interacted with a variable that proxies the incumbents' ATV-related knowledge stocks ( $\text{IKS}_{i,t}$ ). These interaction terms were tested in Model 4.<sup>18</sup> The  $\text{IKS}_{i,t}$  variable also builds on Griliches' (1979) perpetual inventory method (see Equation 3). It was thus constructed similarly to the entrants' knowledge stocks but instead of patent publications, it rests on the accumulation of patent applications ( $\text{IPA}_{i,t}$ ) as explained in Section 4.1. Aghion et al. (2012) also constructed this variable in a similar way and tested its influence on a similar dependent variable (on automotive firms' yearly numbers of ATV-related triadic patent grants). Their result suggests that the ATV-related patent stock is an important and significant determinant; and we therefore also include this variable as control in all other models.

$$\text{IKS}_{i,t} = \text{IPA}_{i,t} + (1 - \delta)\text{IKS}_{i,t-1} \quad (3)$$

where: incumbent  $i = 1, \dots, I$ ;  $t$  refers to the time in question.

The *third model setting* regards the third set of hypothesis (H3.1 – H3.3) in which we are interested in the effects of entrants that exhibit certain characteristics (technological relevance, age, pre-entry knowledge). For each characteristic, we consider all domestic and relevant foreign entrants<sup>19</sup> and split them in two contrasting groups in accordance to a certain threshold corresponding to the characteristic at hand:

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 entrants' patents is measured by forward citations. Taking citations as an indicator of the patent's technological importance or value is an acknowledged procedure and rests on the argument that if a patent was cited it was probably valuable for the citing patent; as it opened up a new and useful

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<sup>18</sup> Note that we test for incumbents' asymmetric reaction along their different IKS levels. We test Model 4 with the hybrid NB model (Model 4.1) and with the FENB model (Model 4.2) in order to verify robustness as the IKS variable is constructed differently in both models. The difference of both IKS variables (with and without FE transformation) is further explained and depicted graphically in the Appendix, Figure 3. Nevertheless, both models yield same results (Appendix, Tables 14 to 16).

<sup>19</sup> In order to prevent noise in our estimations, in those variables that refer to entrants with different characteristics, we excluded entrants that originated in irrelevant foreign countries as they were found to have no effect on incumbents in all preceding models (see Model 1-4).



technological path or was perceived important in a lawful manner (Trajtenberg, 1990).<sup>20</sup> We thus presume that a cited patent is more relevant compared to a non-cited patent while the holder of such a relevant patent is likely to receive more attention from incumbents. We initially planned to calculate the technological relevance of entrants' patents by taking their accumulated relative forward citation. However, in investigating in a first step the absolute numbers of citations, we noticed that very few entrants at all received citations on their patents and therewith split up very naturally into two groups: leading entrants that did receive at least one citation and following entrants that did not receive any citations on their ATV-related patents.<sup>[d]</sup> As one would expect, leading entrants are fewer in numbers but file for more patents than their following counterparts: leaders represent 13% and followers 87% of all entrant observations considered whereas leaders account for 64% and followers for 36% of the total patent stock considered in these two variables. 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.<sup>21</sup> These two groups of following and leading entrants were tested separately in two models (Model 5 and 6) due to high correlation among their patent stock variables.

The hypotheses H3.2 and H3.3 regard potential different effects of diversifying entrants versus new establishments (de novo entrants and parent-company ventures) and test characteristics that are typical for either entrant type. For testing hypothesis H3.2, entrants were classified into two groups: 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 as we are interested to investigate the effect of a strong contrast by very young entrants and also because it was found that more than 60% of entrants exit already within the first five years after entry (Geroski, 1995). The entrants' ages were approximated by subtracting the year of an entrant's first patent publication in any field from the year  $t$  in question.<sup>22</sup> The resulting two variables are relatively balanced regarding the proportion of young and old entrants (54% and 46%, respectively) and also

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<sup>20</sup> 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). Needless to say, we excluded citations within a patent family.

<sup>21</sup> The citation window is set to three years as it is a common citation interval (Harhoff and Wagner, 2009) and as the quantity of citations per patent decreases strongly over time (Trajtenberg, 1990); so if a patent was ever cited, it is most likely to be cited very soon after publication.

<sup>22</sup> Note that an entrant's first patent publication in any field may be dated many years before its first patent publication on ATVs (their actual entry into the ATV research regime); this holds especially for diversifying entrants that previously operated in lateral industries. Although application dates may be more close to the actual start of a firms' business, we take publication dates to define entrants' ages as this is the date from which we know that incumbents could be aware of the entrants' business.

regarding their contribution to the entire ATV patent stock (44% rest on young and 56% rest on old entrants' patents). These two variables for the old entrants' and the young entrants' patents stocks were tested separately in two models (Model 7 and 8) due to high correlation among their variables.

For testing hypothesis H3.3, all relevant entrants were distinguished in entrants with pre-entry patent experience versus entrants without pre-entry patent experience. The former entrants already filed patents in other research fields (besides ATVs) before filing their first ATV-related patent whereas the latter entrants never filed any patent before their first ATV-related patent and thus before their considered entry into the ATV-research regime. Following this rule, we classified 74% of entrants into the group of experienced ones and 26% into the group of entrants without pre-entry patent-experience. As one would expect, experienced entrants contributed with more patents than inexperienced entrants to the overall ATV patent stock considered in these two variables (61% and 39%, respectively). These two resulting variables (the experienced and the inexperienced entrants' ATV patent stock) were also tested separately in two models (Model 9 and 10) due to high correlation among them.

Several *control variables* were computed. Similar to Diekhof (2015), we control for incumbents' patent propensities ( $PP_{i,t}$ ), and age ( $A_{i,t}$ ). The ATV-related R&D experience was cautiously omitted as being critically correlated to other variables. Instead of individual ATV-related patent productivity, we control for individual ATV-related knowledge stocks ( $IKS_{i,t}$ ) since it is a more acknowledged indicator and was found to be important in previous studies (Aghion et al., 2012).<sup>23</sup> We further omit the redundant variable of global oil prices since it was not found to be significant in her hybrid NB estimates and instead use new vehicle registrations ( $VR_{i,t}$ ) as a more specific indicator for the demand on the rival technology. We further extend Diekhof's (2015) model by implementing individualized policy, market, and technology-specific controls; such as global government R&D subsidies ( $SubRD_{i,t}$ ), global advances in charging stations ( $ACS_{i,t}$ ), and global ATV patent growth rates ( $PGR_{i,t}$ ). The construction and reason to add each control variable is further described in the remaining part of this section.

The present analysis aims at mitigating the noise of different firm-specific patent propensities, which are not necessarily constant and thus not caught by firm FEs but vary over time with different reactions to market trends, changes in firms' financial situations, or leadership changeovers. For example, a firm may change its patent propensity due to a new management that prefers secrecy, that tends to

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<sup>23</sup> This implies, however, that we cannot include an autoregressive term of the dependent variable as a control due to high correlation with IKS. Though, we exclude IKS and add various autoregressive terms in separate models as a robustness check (explained further in Section 6 and the outcome is shown in the Appendix, Table 19).

patent only major advancements, or that is characterized by a stronger cost-saving attitude. Since those aspects should be reflected in the firm's overall annual patenting compared to others,  $i$ 's relative number of yearly filed total patent applications were taken to control for individual patent propensities ( $PP_{i,t}$ ). The incumbents' age ( $A_{i,t}$ ) was included to control for potential distortion from firms that have operated relatively longer on the market. Older firms have likely gained more experience in R&D and the patenting procedure, and have already established large R&D facilities as well as contacts to venture capital providers, and may therefore face fewer barriers to file patents. Hence older incumbents will likely patent more than younger incumbents. Hence, this control seems especially relevant to account for firms with great age differences; such as incumbents' younger subsidies versus older incumbents' establishments. Incumbents' ages were approximated by subtracting the year of a firm's first patent application from the year  $t$  in question.

Beyond entrants and firm-specific controls, incumbents' ATV-related R&D strategies are also likely to depend on other policy, market, and technology-specific factors. Four additional variables serve as additional controls. First, governments' R&D subsidies are likely to further stimulate incumbents' ATV-related patenting. Data for public R&D expenditures in energy efficiency for transportation were taken from the OECD Statistical Service (2014a) that provides the data from the International Energy Agency.<sup>[e]</sup> Second, incumbents' expected profits from selling the dominant design (conventional vehicles propelled with an internal combustion engine) is likely to negatively influence their ATV-related patenting. We take the size of the demand, such as the number of annual new vehicle registrations, as a proxy for incumbents' profit expectations. The data was drawn from the OECD Statistical Service (2014b). Third, a sufficient charging station infrastructure is not only likely to ease ATV adoption of end users but also claimed to increase incumbents' motivation to undertake ATV-related research (Aghion et al., 2014). To proxy a country's effort to advance charging stations, we take yearly numbers of country-level patents corresponding to IPC and CPC codes for charging stations from the PASTAT data base (see Appendix, Table 7). Lastly, it seems necessary to control for technology-specific research trends; such as global patent hypes due to appearing technological opportunities or global patent decreases due to appearing technological bottle-necks. It is also likely that incumbents' ATV-related patents steadily increase over time merely since ATVs are new technologies and therewith provide many patent opportunities. We compute yearly country-level growth rates of all ATV-related patent applications to infer about ATV patent trends.

These four control variables (new vehicle registrations ( $VR_{t,d}$ ), government 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. In accordance to 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 OEMs' 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. Following Aghion et al. (2012), Equation 4 shows firm-specific country weights ( $w_{i,t,d}$ ) constructed by accumulating the yearly share of  $i$ 's patent filings within a certain country ( $d$ ) over  $i$ 's total patent filings in all countries ( $D$ ) from  $i$ 's first year of observation ( $t_{1st\text{Obs}}$ ) until the time in question ( $t$ ). The four weighted control variables were constructed by multiplying the firm-specific country weights<sup>24</sup> with the country-level variables and summing up the products over all countries (Equations 5 to 8).

$$w_{i,t,d} = \sum_{t_{1st\text{Obs}}}^t \frac{\text{number of } i\text{'s patent filings in country } d}{\text{total number of } i\text{'s patent filings in all countries } D} \quad (4)$$

$$SubRD_{i,t} = \sum_{d=1}^D w_{i,t,d} \times SubRD_{t,d} \quad VR_{i,t} = \sum_{d=1}^D w_{i,t,d} \times VR_{t,d} \quad (5, 6)$$

$$ACS_{i,t} = \sum_{d=1}^D w_{i,t,d} \times ACS_{t,d} \quad PGR_{i,t} = \sum_{d=1}^D w_{i,t,d} \times PGR_{t,d} \quad (7, 8)$$

where: incumbent  $i = 1, \dots, I$ ;  $t$  refers to the time in question, country  $d = 1, \dots, D$ .

Moreover, a set of time dummies (YFE) were included to control for macro shocks as the Wald test indicated that time fixed effects are present while some year dummies' coefficients are significantly different from zero. Beyond controlling for 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. As explained at the beginning of this section, we use a hybrid model in which firm fixed effects are constructed as follows. First, we add to the model the firm-specific mean over time for each firm-specific variable, which relates to all seven control variables (indicated in Equation 2 by FFE for the set of all mean variables). Second, the control variables are not added in their original metric but as deviation from the firm-specific mean while its coefficient constitute the FE corrected one which is of interest.

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<sup>24</sup> Note that the difference between Aghion et al.'s (2012) and our country weights is that we allow them to be time variant since it is likely that over a long time period the incumbents' perception of a country's relevance changes. For example, China gained more importance from the 90's onwards when its car market started to increase rapidly, leading to a strong difference in importance between the 80's and today.

Lastly, 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 relied 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 (which represents a model that sufficiently accounts for longitudinal data characteristics). 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 on the NB distribution (see Appendix, Figure 1).

## 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 the firm fixed effects. In the present section we present all results apart from Model 4.1 as incident rate ratios (IRRs)<sup>25</sup> and show reduced results containing only the FEs corrected estimates but provide the full results 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 stepwise separately in three models. In all three models, entrants from the incumbents' home countries ( $z_j=h_i$ ) show a positive and significant effect which supports hypothesis H1.1, see Section 3.

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<sup>25</sup> Note that the NB model is a non-linear model in which the IRRs are commonly reported instead of marginal effects in case of ordinary least square estimates. 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 increase 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  $>1$  ( $<1$ ).

Also the effects of all variables containing entrants that originate from relevant foreign countries ( $z_i \in \text{afc}_i, \text{rfc}_i, \text{mrfc}_i, \text{rrfc}_i$ ), in which incumbents are patenting in, are positive and significant (Model 1, 2, and 3). In contrast, entrants originating from irrelevant foreign countries ( $z_i \in \text{ifc}_i$ ) 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 and affirm that a classification of foreign entrants into relevant and irrelevant country groups is more accurate for estimating the effect of cross-country entry.

**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).

However, we only consider the first separation of foreign entrants into relevant and irrelevant country groups as meaningful (Model 2) and therefore rely on this classification when testing the remaining hypotheses. A more detailed separation of the relevant foreign countries ( $z_j = \text{rfc}_i$ ) into three most relevant foreign countries ( $z_j = \text{mrfc}_i$ ) and remaining relevant foreign countries ( $z_j = \text{rrfc}_i$ ) does not seem to be sensible (Model 3). Although both variables yield positive and significant effects, they show relatively similar magnitudes whereas we would have expected the effect of the three most relevant countries to be stronger. 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. The number

of OEMs' relative patents by country, in contrast, does not seem to indicate different magnitudes in OEMs' attention on entrants from different countries.

Lastly, the effect of international entrants was in all cases (Model 1, 2, and 3) higher than the effect of domestic entrants on incumbents' patenting. This outcome supports the previously asserted importance of cross-country entry for globally operating firms and underlines that it is crucial to consider as well foreign entrants when the overall effect of entry is of interest.

*Second Hypotheses Set: Results for incumbents' asymmetric responses*

The second set of hypotheses (H2.1 and H2.2) concerns asymmetric 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 IKS variable, holding other explanatory variables constant at mean values. The results thereof are presented in Table 4.

**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 Table 4 we illustrate the effects of domestic and foreign entrants for different IKS levels 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. To compare the effects for different IKS levels, a small step length of 0.8 was chosen in order to provide precise results especially for the first levels since most observations fall into small IKS levels.



Figure 3 in the Appendix provides a histogram that shows for each IKS level the corresponding number of incumbent firm observations in the underlying sample.

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 the data, these insignificant results for some IKS levels are likely to be the reason for the insignificant interaction term in Table 3; and hence we are not distracted by this finding and will continue interpreting the results of Table 3 in combination with Table 4. These findings suggest that entrants lead to asymmetric effects among incumbents and that the magnitude of this effect is dependent on incumbents' ATV knowledge stock. This outcome supports Hypothesis H2.1. The second column in Table 4 shows a decreasing effect of domestic entrants along increasing IKS levels. This decreasing effect is also indicated by the negative coefficient sign of the respective interaction term (second coefficient in Table 3). In regards to relevant international entrants, the third column shows the opposite pattern: an increasing effect along increasing IKS levels. Subsequently, Hypothesis H2.2 finds support only for the effect of domestic entrants. Nevertheless, the different findings for domestic and foreign entrants are interesting suggest promising avenues for future research for gaining new insights into connections and determinants in global innovation systems. In the following we interpret these asymmetric findings separately for each entrant group.

As to *domestic entrants*, the incumbents' reactions decreased from positive to negative responses as their IKS levels increased. Hence, the more knowledge incumbents accumulated the lower is the ATV-patent-increase effect of domestic entry on incumbents; whereas the reduction of the entry effect is so strong for incumbents with very higher ATV knowledge stocks that the effect of entry is even negative in their cases. 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 and are in accordance to Table 4 those firms that are expected to significantly increased their ATV-related patenting (seen in first seven rows towards the top of column two). The estimated negative effects for higher IKS levels (seen in last 19 rows towards the bottom of column two) merely hold for very few observations (about 1%). As a result, in case domestic entrants are considered, Hypothesis H1.1 (suggesting a positive incumbent reaction) does not hold for incumbents that exhibit relatively high ATV-related patent stocks. Considering the underlying 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 to entrants with an increase in ATV-related patenting for the following 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 the ATV niche market. 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. Further, incumbents with very few ATV-related patents also have a greater scope to increase their ATV-related patenting, as compared to their highly patenting counterparts.

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: One possible explanation when considering competitive entrants is firm acquisition. Given that these incumbents already filed many ATV-related patents, they are unlikely to perceive new entrants as challenging and are thus not provoked by entrants to increase patenting. Instead, OEMs are likely to overtake 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 ATV-related research, 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.<sup>26</sup> 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

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<sup>26</sup> 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 incumbents.

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

Both scenarios are also indicating dynamics 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 exiting early pioneers, firm turnovers, and the distribution of core tasks related to the new technology across new supply chains (Markides and Geroski, 2005). Given that only 1% of the sample reacted negatively, it could indicate the beginning of this phase during the transition towards ATVs. Wesseling et al. (2014) found that although incumbents increase their electric vehicle patents, the incumbents' share on the global patent stock of electric vehicles has been decreasing over time. The authors concluded that incumbents cannot keep pace with the progress achieved in electric vehicle technologies. The acquisition of entrants and R&D outsourcing constitute alternative explanations for the decrease of the incumbents' share on global electric vehicle patents. Moreover, similar negative incumbent reactions were found by Diekhof (2015), though, not only on domestic but also on foreign entrants. In the present study, however, the R&D outsourcing explanation is even more likely since this negative effect holds only for domestic entrants while OEMs tend to source predominantly from domestic suppliers. In addition, some researchers even identified it as a desirable strategic objective of sustainable small firms to become the acquisition target of incumbents (Moore and Manring, 2009). Those acquisitions, in turn, allow incumbents to adopt disruptive technologies and participate sooner in more radical sustainability strategies. Lastly, we do not believe that our negative effects derive from a delayed entry effect (initially negative and after some periods positive entry effects), as found in Andersson et al. (2012). Since incumbents in our analysis face entry variables that indicate the entrants' accumulated knowledge, the entry indicators provide sufficient information also of the past to which incumbents could react individually after some time.

As to *entrants from relevant foreign countries*, incumbents' responses increased along increasing IKS levels. Hence, the more ATV knowledge incumbents accumulated the higher is the ATV-patent-increase effect of foreign entry on incumbents. Given that more advanced incumbents responded more strongly, their responses seem to be of competitive nature which was found in several previous studies (e.g., Czarnitzki et al., 2011; Iacovone et al., 2011; Changoluisa and Fritsch, 2014). An initial obvious explanation is that the incumbents were motivated to increase patenting in response to a few powerful foreign entrants that

are exceptionally challenging (e.g., Tesla Motors, or BYD). Even though we consider innovative entry, to embody a serious challenge especially for incumbents that are highly active in ATV research may hold for very few entrants only; and may thus not explain the whole effect. When considering the effect found for domestic entrants in combination with the expectation that relevant foreign entrants originate from countries in which incumbent  $i$  is operating, the effect is likely to be additionally driven indirectly by foreign entry. That is, foreign entrants enhance the ATV competitiveness of their own domestic incumbents to which incumbent  $i$ , in turn, reacts with increasing patenting to keep up with the global ATV technology frontier. For example, in case the German OEM Volkswagen reacts in a competitive manner with increased patenting to improving Chinese OEMs (e.g. Chang'an Automobile, Dongfeng Motor, or SAIC) who improved their ATV-related competitiveness as receiving valuable knowledge spillovers or as being challenged by new domestic entrants (e.g., BYD, or Wanxiang). Following this line of thought, we may not measure  $i$ 's response to foreign entry itself but (partially) rather  $i$ 's competitive response to stronger becoming foreign incumbent competitors.

Another observation fits this interpretation of competitive incumbent responses. Considering that those entrants that have very low ATV knowledge stocks do not respond significantly, it is likely that they yet do not consider exporting ATVs and thus do not consider competitive entrants or indirectly improving foreign incumbents as relevant. Instead, the higher an incumbents' ATV patent stock, the more likely it is that they have yet made export strategies and the more attention they pay to challenging foreign competitors.

Diekhof (2015), in contrast, 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 incumbents may be required to cooperate with new foreign suppliers; only few countries in the world were for example already specialised in battery technologies for AD applications, mostly in Asia. It also appears difficult for suppliers without any technology-specific background to catch up in new energy storage systems. Hence, for new technologies in which key components were already mastered by foreign firms, it is likely that incumbents also source from foreign suppliers when switching to the new technology; which would be in support for a decreasing foreign entrant effect. Although she finds this result when using many different indicators, we would have expected a similar effect in the present analysis.<sup>27</sup> Nevertheless, both findings and corresponding explanations are meaningful while it appears very

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<sup>27</sup> Diekhof (2015) uses the number of entrants, all foreign entrants, incumbents' ATV productivities, and different control variables as used in the present study.

difficult to explain the contrasting results; why would the effect be different in case of indicators for qualitative entry forces from relevant foreign countries versus indicators for quantitative entry forces from all foreign countries? More research is needed to disentangle the effect of foreign entry on incumbents in global innovation systems.

*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. With this step we intend to distinguish the types of entrants which is expected to be of interest for policy makers. In Table 5 we present the results as IRRs of six model estimations containing differently aggregated entrants to certain characteristic groups.

**Table 5: Incumbents' Responses to Entrants with Different Characteristics**

Dependent Variable: Incumbents' Number of ATV-related Patents

Parameter	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***
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).

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 (parent-company ventures versus de novo entrants). 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 regarding one characteristic those two contrasting entrant counterparts are each tested in a separate model.

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 supporting or challenging incumbents, or in penetrating the ATV market. This result is in support of Hypotheses H3.1. Nevertheless, we would have expected the difference between leaders and followers to be of greater size than the estimated 8.5% (compare Model 5 with 6). The difference appears more pronounced if we consider the entrants' quantities that drive these effects. Leaders only represent 13% and followers take up 87% of all entrant observations considered. In other words, the leading 13% of entrants bring about a slightly higher effect than the remaining 87% following entrants altogether. Although leading entrants are outnumbered, they file for more patents than their counterparts: leaders account for 64% and followers for 36% of the total patent stock considered in these two variables.

Addressing the characteristics associated to different entrant types, unlike our hypotheses, entrants that share characteristics of diversifying entrants (older and pre-entry patent experienced) were estimated to yield lower effects on incumbents than entrants that share characteristics for new establishments (younger and pre-entry patent inexperienced) (compare Model 7 with 8, and Model 9 with 10). It is rather surprising that young entrants who are not expected to have gained great market experience as they undertake research not even since five years (measured by their first patent in any field) show a stronger effect than older entrants. The proportion and patent contribution of young and old entrants is relatively balanced and should thus not affect the estimates greatly (54% young entrants filed 44% of patents and 46% old entrants filed 56% of patents). 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 the ATV patent stock considered in these two variables).

These findings strongly suggest that not only experienced diversifying incumbent entrants but also new establishments influence the research of automotive incumbents. While this result contrasts Bergek et al. (2013) who generally question the postulated power of new establishments, it is in line with Schumpeter's (1911/34) idea of innovative entrepreneurs and their contribution to technological change. But what is it that young and inexperienced entrants embody that affects incumbents? Two likely explanations cross our minds: First, in accordance to Markides and Geroski (2005), young and inexperienced entrants are those firm types that are attributed to bring birth to radical innovations. We hence assume that this group might be more explorative and radical than older and

experienced entrants and therewith raise incumbents' attention, and threaten or support incumbents in a stronger manner. Secondly, given that these influential entrants are relatively inexperienced, it is likely that they are 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 for other OEMs to speed up their R&D advances and therewith the ATVs' transition (Musk, 2014).

These findings on entrants' relevant characteristics furthermore open up some new insights that have not yet been addressed. Previous studies focused mainly on relevant characteristics for survival but did not investigate relevant characteristics for entrants' influence on incumbents. Essential factors for success and survival were found inter alia in the accumulation of general organizational skills and competitive knowledge. This comes with experience and learning during market activities and increasing ages and thus provides diversifying entrants an advantage over de novo entrants when entering new markets (Geroski, 1995; Helfat and Lieberman, 2002; King and Tucci, 2002). However, for imposing an effect on incumbents these characteristics seem of minor importance. Instead, our results suggest that entrants' technology-specific expertise is crucial; while being young and pre-entry research inexperienced also complements their influence.

Having yet analysed and discussed the effects of the main explanatory variables of interest, we will next provide a few comments to more general findings. We begin with variables that were unexpectedly insignificant. None of the estimated results showed a significant effect for the global ATV patent growth rate (see Appendix, Model 1-18). It therefore seems that incumbents drive their ATV-related R&D strategies independently and do not follow a global research trend. This finding is further in support that it is rather entrants that equip the incumbents with crucial technological opportunities that can be exploited; for instance in battery technology as it was already argued in more detail in Diekhof (2015). Furthermore, the variables controlling for R&D subsidies are in all models but Model 4.1 insignificant. Aghion et al. (2012) uses the same data from the International Energy Agency to construct this indicator and test it for a similar dependent variable. Also they did not find a significant effect. They conclude that this indicator does not show an effect because the majority of these public R&D expenditures apply to fuel and energy efficiency technologies rather than to radical clean technologies such as ATVs.<sup>[f]</sup> The variable indicating vehicle registration is not significant which is not disturbing to us as it seems that the effect of this variable is vanished entirely by its firm FE that is estimated to be significant and negative (see Appendix, Model 1 to 18). It is very reasonable that

firms, once set a long term R&D strategy for a new technology, have standardized their R&D responses and always react with the same variation to changes in expected profits from the rival technology, but independently from the actual magnitude of those changes.

We further would like to highlight that the variable for global research advances on charging stations shows a constantly 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, also by policy support. The development of a sufficient ATV infrastructure will reduce the risk for investments and thus stimulate OEMs to invest in ATV research; without rapid improvement, though, the already existing infrastructure for combustion engine vehicles will further lock in conventional vehicles and makes a transition more difficult in future periods.

As using a negative binomial model, which is based on maximum likelihood estimates, we calculated the adjusted McFadden's R-squared (also known as the likelihood-ratio index) as an indicator for the model fit. For the hybrid NB models the indicators vary from 5% to 6.9% and for the FENB model we find 20.5%. McFadden's R-squared is a pseudo R-squared and cannot be interpreted as the common R-squared from an ordinary least squares regression. The McFadden's R-squared subtracts from one a ratio of the log likelihoods of the full model over the intercept-only model and the adjustment is done by penalizing the numerator in subtracting one for each predictor (Freese and Long, 2006, p.84). This indicator can thus be interpreted as the value of improvement when applying the full model instead of the intercept-only model. Hence, the higher the indicator, the better the model fit. We estimated relative small values for the McFadden's R-squared which is not disturbing as we estimated a micro model in which the fit is generally moderate. The strong difference in the hybrid NB model and the FENB model can be explained by that the R-squared calculation in the former suffers from a random effect specification whereas the latter is calculated more precisely in drawing on an inherently and correctly specified fixed effect. This finding does hence not concern us in our decision that the hybrid NB model is the more robust model and thus the main model to be interpreted.<sup>[g]</sup>

## **6 Limitations & Future Research Avenues**

The present study finds a small but significant, positive effect of the 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, as assumed in Section 3, their results can be extended as we find an asymmetric response along this variable when reacting to other market determinants, such as entry. It is not the case that firms exhibiting relatively high ATV knowledge levels react most to other market determinants. In case of domestic entry, we find a decreasing and eventually negative reaction along increasing ATV knowledge levels. As explained above in the previous Section 5, this finding indicates that during the evolution of a new technology there might exist certain development stages at which highly experienced firms find it profitable to replace their in-house research by R&D outsourcing or strategic acquisition. Hence, in case of a technological change within certain incumbent technologies, the influence of their technology-specific knowledge stock on their corresponding innovation activity may be non-linear and rather inverse u-shaped; where the turning point appears when they start outsourcing R&D. We therefore conclude that path-dependency plays an important role but might be more complex as yet considered and needs to be investigated further from various angles.

Further research is needed to determine whether this pattern of incumbents' responses, observed in the present paper, also holds for other technologies or is rather driven by technological 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 entry is stimulating existing incumbents to shift their research focus towards those new technologies.

As already presumed in Diekhof (2015), 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 entrant groups that share certain characteristics can be less in quantity but yield stronger effects on incumbents; technological leading and patent inexperienced entrants. This is an essential finding. As a consequence, studies that purely rely on indicators of entrants' quantitative forces are likely to suffer from strong distortions as assuming a linear relationship in entrant numbers and incumbent responses and omitting that not all entrants have the same effect. Also my results, however, indicate that it is neither the entrants' technology-specific patent accumulation that linearly drives the effects on incumbents (since inexperienced entrants also filed for less patents but yield stronger effects on incumbents than experienced ones). I performed a robustness check on this relation in applying a Generalized Additive Model which is very useful to identify non-linear relations (Hastie and Tibshirani, 1986). It allows to estimate different incumbent response magnitudes

with a smooth function that can vary with the value of entrants' knowledge stocks. I calculated various smooth functions for different entrant groups. They all show different functions indicating non-linear relations; most were statistically significant. I present in the Appendix (Figure 2) an example for the respective estimation for domestic entrants. As one can see, the smooth function (incumbents responses) starts slightly negative with low entrant knowledge levels and then increases up to a certain point from which the response turns and moderates when higher entrant knowledge levels are regarded. This outcome as a whole indicates a complex and non-linear relationship between entrants and their influence on incumbents; which should be treated as such in future studies. The characteristics that determine the relation between these two actors remain largely undiscovered which provides a very interesting new research direction.

Although these results support the hypotheses in many aspects, some qualifications are appropriate. Although the present findings suggest that entrants stimulate incumbents to increase ATV-related patenting, the present study is limited in its ability to provide insights on the consequences of positive incumbent patent responses. According to Gilbert and Newbery (1982), firms with monopoly power have incentives to pursue pre-emptive R&D activities. That is, they patent strategically on the substitute technology to deter entry but do not take economic advantage of these patents on the market side. These patents are also 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. As a consequence, it remains an open question whether entrants stimulate also incumbents' innovative market output. The present study therefore only represents a first step in verifying Hockerts and Wüstenhagen's (2010) proposition that incumbents react to environmentally friendly entry by launching more environmentally friendly products.

In addition, the number of patents as a response variable does not only miss the information regarding innovative market output. It is only a proxy for in-house innovative effort and thus misses various other investments that are also relevant; such as the acquirement of ATV-related licenses, ATV-related marketing investments, and ATV-related knowledge sourcing by strategic acquisitions. Those indicators would not only capture a greater amount of incumbents' overall willingness to promote ATVs but would also simplify the interpretation of incumbents' asymmetric responses to domestic and foreign entrants. Beyond these ATV-related measures, also incumbents' responses within their existing vehicle design seem relevant. In accordance to Howells (2002), incumbents' reactions to the introduction of substitutive technologies can be categorized into three

strategies: the switch to the new technology, the 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' strategic 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 incumbent responses are driven by the introduction of substituting technologies or instead by mere intra-industry competition (Howells, 2002). Although the existence of the sailing ship effect has been called into question, the possibility exists that OEMs undertake tremendous improvements of their conventional vehicles as a response to the introduction of ATVs. Since 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 within the existing vehicle design seems therefore highly relevant for future research.

With the following procedure we address the potential bias of endogeneity such as reverse causality; namely, that entrants' patenting is driven by incumbents' patenting. As explained in more detail in Section 4.1, application dates were used to retrieve incumbents' patents since it is the date of first filing and thus most closely related to their hypothesized innovative responses to entry. Using application dates also brings along another major advantage: after the initial application is made, patent offices wait 18 months to publish the patent document.<sup>28</sup> Until this publication date, the existence of the patent is kept strictly confidential. For this reason, entrants are not aware of the incumbents' patent claims in any period  $t$  in the analysis. Additionally, we used one year lag and publication dates to construct the entry variables. This procedure provides the benefit that the considered entry variables in  $t$  refer to the earliest date (the publication date) from which incumbents could be aware of entrants' patenting but the entrants' actual R&D activity (which could be influenced by incumbents) certainly took place several years before  $t$ .<sup>[h]</sup> The potential bias occurring, when this R&D activity of entrants is driven by incumbents' patenting several years before and if the latter is in turn correlated to incumbents' patenting in  $t$ , can be ruled out: implementation of autoregressive terms of the dependent variable ( $t-1$  to  $t-8$ ) indicate that all coefficients of the autoregressive terms 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 of these robustness checks are provided in the Appendix, Table 19. With this procedure of taking application and publication dates for the different entities while showing that the dependent variable is not significantly correlated by

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<sup>28</sup> An overview of this procedure can be found in OECD (1994) and in Harhoff and Wagner (2009).

incumbents' patenting several years before, we believe that we can sufficiently mitigate the potential noise of reverse causality.

For policy constructions, one needs to keep in mind that we focused on the effect of entrants on incumbents as an indirect stimulus on transitions. This study is therefore limited in its ability to draw conclusions on the efficiency of entrepreneurship supporting policies for propelling environmentally friendly transitions directly. An interesting starting point for further research would thus be to contrast the efficiency of R&D stimulating policies for different entrant types as well as incumbents.

Lastly, the present study underpins that incumbents' reactions need to be interpreted differently in accordance to entrants' business types (the supply chain position of entry; e.g. downstream as supplier or same position as competitor). This aspect is largely disregarded in similar studies (e.g., Aghion et al., 2004, 2009). More detailed data on entrants would allow researchers to better interpret incumbents' responses. Nevertheless, we would like to highlight that it is problematic to access adequate records on entrants; as criticized by many other researchers (e.g., Andersson et al., 2012). Regarding their business types, the common separation across industries is too broad for our purpose as we need to distinguish between component supplier, R&D equipment supplier, and competitive end user supplier. Some diversifying entrants even act as both component and end user supplier in early development phases of an industry. By nature, entrants are very heterogeneous. Diversifying entrants and parent-company ventures are managed by incumbents whereas de novo entrants are founded by private persons that might as well be educated in running a firm while it is difficult to get global aggregated data on the founding entities. In later phases of emerging industries subsidiaries are founded and merges and acquisitions take place, causing frequent renaming and management changeovers that are difficult to track. As a consequence, a straight forward identification of entrants does not exist but causes insurmountable difficulties (Andersson et al., 2012). We believe that under the consideration of the particularities of ATVs, the automotive industry, and the data that is at our disposal a diversification of patenting entrants in different age groups as well as existing versus non-existing pre-entry patent experience are useful measures. Firstly, in taking patenting entrants, we know that we are dealing with innovative entrants. Secondly, this diversification helps us to distinguish at least diversifying incumbent entrants from new establishments (de novo entrants and parent-company ventures). Even though parent-company ventures bear knowledge and financial support from their parent firms and are therefore still very different from de novo entrants, it is a first step towards providing an idea about the entry types that influence incumbents.

## **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. This work as well contributes to a deeper understanding of market dynamics in the transition towards a more environmentally friendly transport system. We assume that incumbents' motivation in promoting ATVs is crucial for the transition since incumbents are likely to be more successful than entrants in mass-market penetration. In contrast, entrants are more likely than incumbents to launch ATV-related technologies and to initialize niche markets until also incumbents perceive ATVs as profitable. The results indicate that entrants exhibit a research-stimulating function, motivating incumbents to increase their ATV-related patenting. We expect these technological advances of incumbents to accelerate technological change and thereby to provide opportunities to escape from the locked-in combustion engine trajectory.

Our findings affirm that entrants' countries of origin play an important role in their effect on incumbents. Entrants from relevant foreign countries (in which incumbents are expected to operate) had a stronger influence on incumbents' patenting than domestic entrants; whereas entrants from any other foreign country (in which incumbents are not expected to operate) were found to have no effect. Future studies investigating global markets and multinational firm responses to entry therefore need to take into account the different effects of domestic and foreign entrants to represent more accurately the overall effect of entry.

The incumbents' responses were found to be asymmetric and dependent on the level of their ATV-related knowledge stocks. Regarding the effect of domestic entrants, incumbents' responses were decreasing as their ATV-related knowledge increased, moving from positive towards negative responses, representing about 97% and 1% of the incumbent firm sample, respectively. We assume that entrants stimulate patenting in incumbents that exhibit low ATV-related patent stocks: complementary entrants from lateral industries provide crucial knowledge, and competitive entrants challenge these incumbents to keep up with the technology frontier, or influence them indirectly via market penetration. Incumbents with relatively high ATV-related patent stocks reacted negatively on entry. We presume that their knowledge is already too advanced to be challenged by competitive entrants. Instead, such incumbents are likely to start replacing their

in-house R&D by sourcing new components or licenses from entrants, or by investing in strategic acquisition of entrants, leading to a decrease in these incumbents' ATV-related patenting. Given that we find this negative effect only when domestic entrants are considered while bearing in mind that OEMs tend to cooperate merely with domestic suppliers, this further supports the interpretation of R&D outsourcing. Entrants from relevant foreign countries yielded reverse response patterns: incumbents reacted stronger, the higher their ATV-related knowledge stocks. This is expected to be a sign of competitive responses to few but outstanding competitive entrants or to competitive foreign automotive incumbents that improved their ATV-related performance as being themselves stimulated by domestic entry.

The explicit entry forces that cause these incumbent reactions are still unknown. We expect entrants to stimulate incumbents via three forces: directly, via competitive pressure and complementary knowledge, as well as indirectly, via market initialization as entrants stimulate initial demand and master ATVs in niche markets until ATVs become profitable also for incumbents. Current literature focuses almost exclusively on the competition effect. Investigating the channels through which entrants influence incumbents in further detail would be a fruitful area for future studies.

To put the outcomes of the present study into perspective, they basically suggest that environmentally friendly entrants reinforce environmentally friendly innovation activities, especially in incumbents that previously had a relatively low R&D commitment to achieve advances in environmentally friendly technologies. This effect of entrants might be key to encouraging a transition as a whole. 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-place. This possibility limits conclusions that can be drawn regarding the impact of increased incumbent patenting for the technological change on the market level. Further research is required to determine whether entrants' not only increase incumbents' patenting but also influence incumbents' innovative market output.

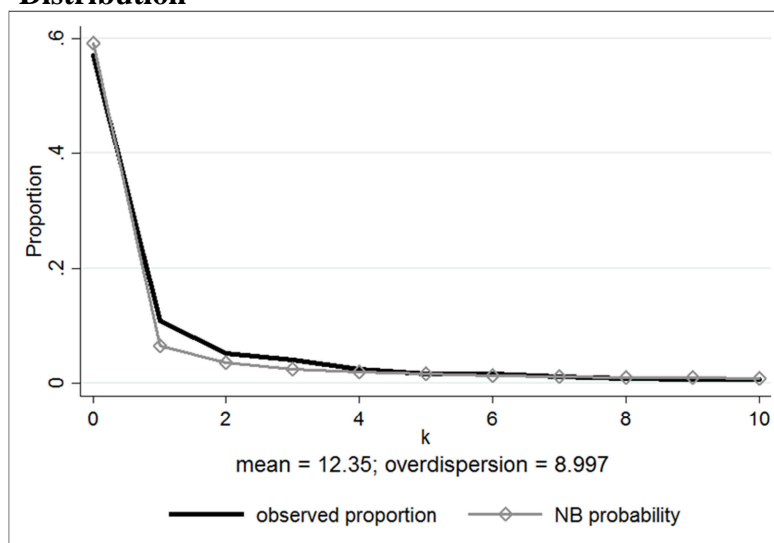
Entrants are deterred by high entry barriers and survival challenges, especially in the energy and transport sector that show high firm concentrations. Their potential key role is therefore likely to be limited in such markets, suggesting that policy interventions may be supportive in reaping the full benefit of entrants' potential to catalyze transitions. The outcome of the present study is 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. The present findings further suggest that policies directed at supporting entrants are likely to not only encourage entrants but also to stimulate innovative advances of incumbent actors; namely of those ones that have yet been relatively uncommitted to the new technology at hand and need to be stimulated to catch up. Joint research projects could be funded to further speed up 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.

Another policy implication can be drawn from our findings. When it comes to the question of targeting policies to certain actors, one might want to know which actors are in great need of support but simultaneously highly influential on incumbents. In this regards, we found that young and pre-entry patent-inexperienced entrants greater stimulated incumbents' research 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 and thereby receive more attention by incumbents. Given liability of newness, though, 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 since we found that a small group of technological leading entrants (13% of the sample that received citations on their ATV patents) had a stronger effect on incumbents than the remaining following entrants altogether (87% of the sample that received no citations). 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.

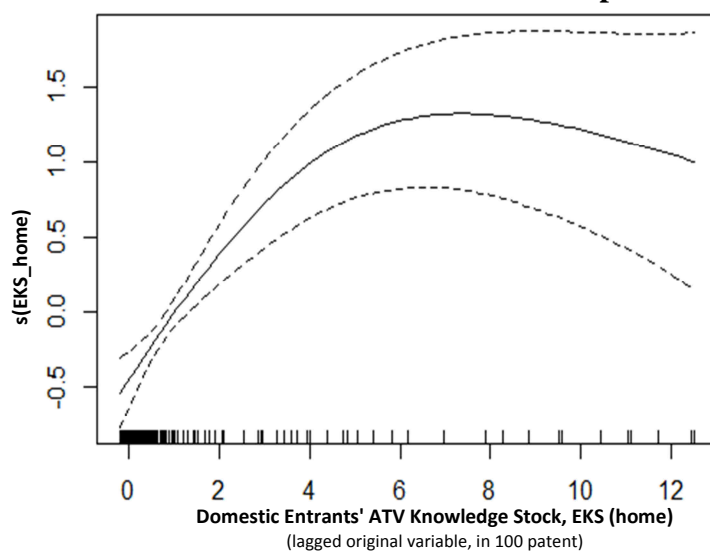
## 8 Appendix

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



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

**Figure 2: Incumbents' Non-Linear ATV Patent Responses to Entrants**

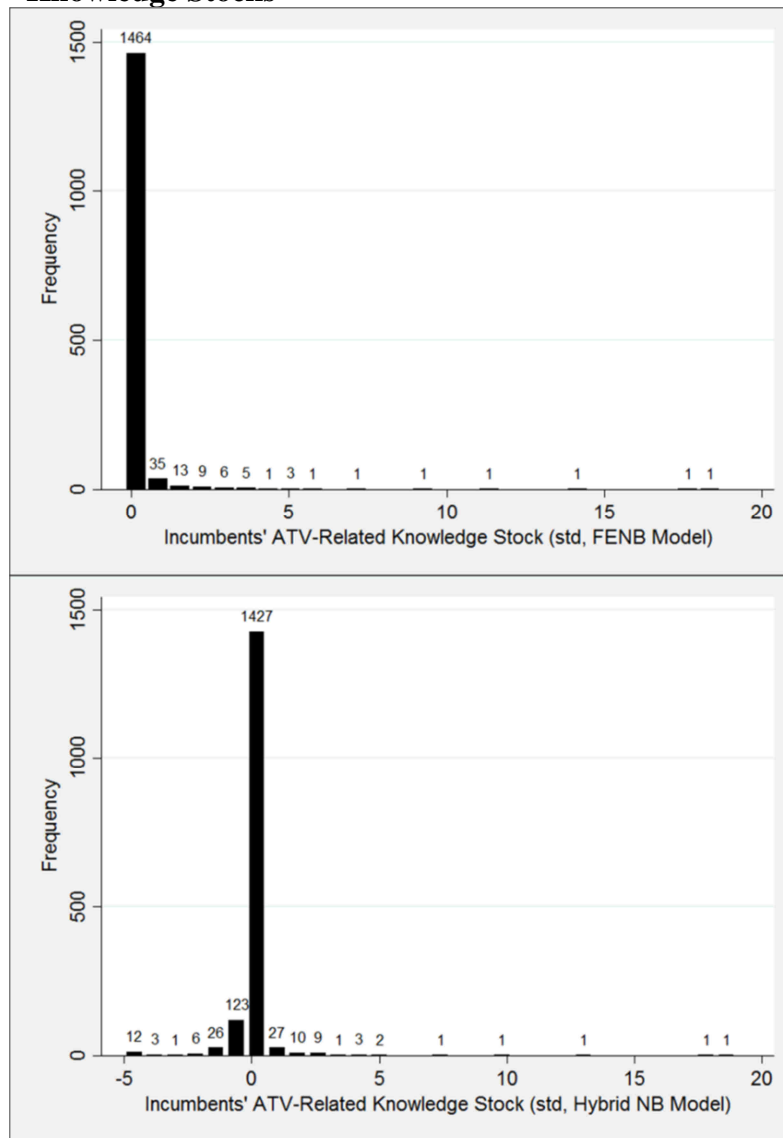


	edf	Ref.df	Chi.sq	p-value
s(EKS_home)	2.858	3.601	42.06	1.72e-08 ***

Note: \*p<0.10, \*\* p<0.05, \*\*\* p<0.01.



**Figure 3: Histogram of the Variable indicating the Incumbents' ATV Knowledge Stocks**



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

Note: The first histogram depicts the Incumbents' ATV-related knowledge stock (IKS) used in the conditional fixed effects negative binomial model (Models 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)
<b>Alternative Technology Vehicles</b>	
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 electromobility: 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 Environment Directorate (2011); WIPO (2011); CPC (2014).

**Table 7: Patent Classes and Description (2)**

Description	International Patent Classification (IPC) & Cooperative Patent Classification (CPC)
<b>Alternative Technology Vehicles</b>	
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
<b>Charging Stations</b>	
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 Environment Directorate (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 YUUII
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 form PATSTAT database.

**Table 9: Descriptive Statistics**

Variable	Original Variables				Standardized Variables				
	Max	Min	Mean	SD	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
<b>Hybrid NB Model</b>									
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
<b>Fixed Effect NB Model</b>									
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	0.49	-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 entry variables. The only control variable that is disturbingly high correlated to entry 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. We can therefore rule out the presence of multicollinearity in our estimations. 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 entry variables were among the highest correlations and thus most worrisome (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
<b>Model (5)</b>						
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
<b>Model (8)</b>						
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
<b>Model (9)</b>						
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** (2.06)	0.171** (2.39)	0.171** (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 (0.68)	0.0748 (0.69)
ATV Knowledge Stock (DM) $t_{-1}$	0.0172 (1.09)	0.0273* (1.67)	0.0273* (1.67)
Patent Propensity (DM) $t_{-1}$	0.085*** (3.20)	0.078*** (2.95)	0.078*** (2.94)
Age (DM) $t_{-1}$	-0.0189 (-0.13)	-0.228 (-1.43)	-0.227 (-1.42)
R&D Subsidies (DM) $t_{-1}$	0.0005 (0.01)	0.0069 (0.16)	0.0077 (0.18)
Vehicle Registration (DM) $t_{-1}$	0.0382 (0.92)	0.0330 (0.79)	0.0333 (0.80)
Charging Station Advances (DM) $t_{-1}$	0.125*** (3.17)	0.124*** (3.08)	0.125*** (3.06)
ATV Patent Growth (DM) $t_{-1}$	-0.0481 (-1.13)	-0.0453 (-1.04)	-0.0455 (-1.05)
ATV Knowledge Stock (M)	0.121* (1.68)	0.132* (1.85)	0.132* (1.85)
Patent Propensity (M)	0.0937 (1.14)	0.118 (1.41)	0.118 (1.42)
Age (M)	0.512*** (4.94)	0.439*** (4.18)	0.439*** (4.18)
R&D Subsidies (M)	-0.0549 (-0.67)	-0.0381 (-0.46)	-0.0385 (-0.47)
Vehicle Registration (M)	-0.300** (-2.29)	-0.258** (-1.99)	-0.257** (-1.99)
Charging Station Advances (M)	0.431*** (3.95)	0.355*** (3.39)	0.355*** (3.39)
ATV Patent Growth (M)	0.0163 (0.18)	0.0397 (0.44)	0.0397 (0.44)
Constant	-0.838*** (-4.62)	-0.958*** (-5.20)	-0.959*** (-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** (2.06)	1.186** (2.39)	1.186** (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 (0.68)	1.078 (0.69)
ATV Knowledge Stock (DM) $t_{-1}$	1.017 (1.09)	1.028* (1.67)	1.028* (1.67)
Patent Propensity (DM) $t_{-1}$	1.089*** (3.20)	1.081*** (2.95)	1.081*** (2.94)
Age (DM) $t_{-1}$	0.981 (-0.13)	0.796 (-1.43)	0.797 (-1.42)
R&D Subsidies (DM) $t_{-1}$	1.001 (0.01)	1.007 (0.16)	1.008 (0.18)
Vehicle Registration (DM) $t_{-1}$	1.039 (0.92)	1.034 (0.79)	1.034 (0.80)
Charging Station Advances (DM) $t_{-1}$	1.133*** (3.17)	1.132*** (3.08)	1.133*** (3.06)
ATV Patent Growth (DM) $t_{-1}$	0.953 (-1.13)	0.956 (-1.04)	0.955 (-1.05)
ATV Knowledge Stock (M)	1.129* (1.68)	1.141* (1.85)	1.141* (1.85)
Patent Propensity (M)	1.098 (1.14)	1.125 (1.41)	1.126 (1.42)
Age (M)	1.668*** (4.94)	1.551*** (4.18)	1.552*** (4.18)
R&D Subsidies (M)	0.947 (-0.67)	0.963 (-0.46)	0.962 (-0.47)
Vehicle Registration (M)	0.741** (-2.29)	0.773** (-1.99)	0.773** (-1.99)
Charging Station Advances (M)	1.539*** (3.95)	1.427*** (3.39)	1.427*** (3.39)
ATV Patent Growth (M)	1.016 (0.18)	1.041 (0.44)	1.040 (0.44)
Constant	0.432*** (-4.62)	0.384*** (-5.20)	0.383*** (-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** (2.28)	0.132* (1.83)
Entrants' ATV Knowledge Stock (home) x IKS $t_{-1}$	-0.100*** (-5.91)	-0.134*** (-8.22)
Entrants' ATV Knowledge Stock (relevant foreign) $t_{-1}$	0.470*** (3.29)	0.398*** (3.23)
Entrants' ATV Knowledge Stock (relevant foreign) x IKS $t_{-1}$	0.0327 (1.03)	0.0509 (1.49)
ATV Knowledge Stock (IKS) (DM) $t_{-1}$	0.303*** (10.87)	0.449*** (10.62)
Entrants' ATV Knowledge Stock (irrelevant foreign) $t_{-1}$	0.120 (1.05)	0.190 (1.46)
Patent Propensity (DM) $t_{-1}$	0.0497** (2.49)	0.251*** (6.34)
Age (DM) $t_{-1}$	-0.293* (-1.87)	0.217*** (2.59)
R&D Subsidies (DM) $t_{-1}$	0.0798** (2.05)	-0.0346 (-0.60)
Vehicle Registration (DM) $t_{-1}$	0.0539 (1.30)	-0.0744 (-1.31)
Charging Station Advances (DM) $t_{-1}$	0.114*** (3.52)	0.230*** (4.59)
ATV Patent Growth (DM) $t_{-1}$	0.00380 (0.09)	-0.0260 (-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*** (-3.22)	-1.147*** (-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** (2.28)	1.141* (1.83)
Entrants' ATV Knowledge Stock (home) x IKS $t_{-1}$	0.904*** (-5.91)	0.874*** (-8.22)
Entrants' ATV Knowledge Stock (relevant foreign) $t_{-1}$	1.600*** (3.29)	1.488*** (3.23)
Entrants' ATV Knowledge Stock (relevant foreign) x IKS $t_{-1}$	1.033 (1.03)	1.052 (1.49)
ATV Knowledge Stock (IKS) (DM) $t_{-1}$	1.354*** (10.87)	1.566*** (10.62)
Entrants' ATV Knowledge Stock (irrelevant foreign) $t_{-1}$	1.128 (1.05)	1.209 (1.46)
Patent Propensity (DM) $t_{-1}$	1.051** (2.49)	1.286*** (6.34)
Age (DM) $t_{-1}$	0.746* (-1.87)	1.242*** (2.59)
R&D Subsidies (DM) $t_{-1}$	1.083** (2.05)	0.966 (-0.60)
Vehicle Registration (DM) $t_{-1}$	1.055 (1.30)	0.928 (-1.31)
Charging Station Advances (DM) $t_{-1}$	1.121*** (3.52)	1.258*** (4.59)
ATV Patent Growth (DM) $t_{-1}$	1.004 (0.09)	0.974 (-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*** (-3.22)	0.318*** (-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*** (5.87)	0.158** (2.18)	-0.2	-5	0.306 (1.38)	0.387*** (3.10)	-0.2
-4.2	0.576*** (5.69)	0.0643 (0.91)	0.5	-4.2	0.332 (1.64)	0.423*** (3.52)	0.5
-3.4	0.496*** (5.41)	-0.0298 (-0.42)	1.2	-3.4	0.359* (1.93)	0.459*** (3.82)	1.2
-2.6	0.415*** (5.00)	-0.124* (-1.72)	1.9	-2.6	0.385** (2.25)	0.494*** (3.97)	1.9
-1.8	0.335*** (4.41)	-0.218*** (-2.89)	2.6	-1.8	0.411*** (2.59)	0.530*** (3.97)	2.6
-1	0.254*** (3.60)	-0.312*** (-3.89)	3.3	-1	0.437*** (2.93)	0.565*** (3.88)	3.3
-0.2	0.174** (2.56)	-0.406*** (-4.70)	4	-0.2	0.463*** (3.22)	0.601*** (3.75)	4
0.6	0.0937 (1.38)	-0.500*** (-5.35)	4.7	0.6	0.489*** (3.43)	0.637*** (3.59)	4.7
1.4	0.0133 (0.19)	-0.594*** (-5.86)	5.4	1.4	0.516*** (3.53)	0.672*** (3.44)	5.4
2.2	-0.0670 (-0.89)	-0.688*** (-6.26)	6.1	2.2	0.542*** (3.53)	0.708*** (3.29)	6.1
3	-0.147* (-1.79)	-0.782*** (-6.57)	6.8	3	0.568*** (3.45)	0.743*** (3.16)	6.8
3.8	-0.228** (-2.51)	-0.877*** (-6.82)	7.5	3.8	0.594*** (3.33)	0.779*** (3.04)	7.5
4.6	-0.308*** (-3.07)	-0.971*** (-7.02)	8.2	4.6	0.620*** (3.18)	0.814*** (2.94)	8.2
5.4	-0.389*** (-3.51)	-1.065*** (-7.19)	8.9	5.4	0.646*** (3.04)	0.850*** (2.84)	8.9
6.2	-0.469*** (-3.85)	-1.159*** (-7.32)	9.6	6.2	0.672*** (2.89)	0.886*** (2.76)	9.6
7	-0.549*** (-4.12)	-1.253*** (-7.43)	10.3	7	0.699*** (2.76)	0.921*** (2.68)	10.3
7.8	-0.630*** (-4.33)	-1.347*** (-7.52)	11	7.8	0.725*** (2.65)	0.957*** (2.61)	11
8.6	-0.710*** (-4.51)	-1.441*** (-7.60)	11.7	8.6	0.751** (2.54)	0.992** (2.55)	11.7
9.4	-0.790*** (-4.65)	-1.535*** (-7.66)	12.4	9.4	0.777** (2.44)	1.028** (2.50)	12.4
10.2	-0.871*** (-4.77)	-1.629*** (-7.72)	13.1	10.2	0.803** (2.36)	1.064** (2.45)	13.1
11	-0.951*** (-4.87)	-1.723*** (-7.76)	13.8	11	0.829** (2.28)	1.099** (2.40)	13.8
11.8	-1.032*** (-4.96)	-1.817*** (-7.81)	14.5	11.8	0.856** (2.21)	1.135** (2.36)	14.5
12.6	-1.112*** (-5.03)	-1.912*** (-7.84)	15.2	12.6	0.882** (2.14)	1.170** (2.32)	15.2
13.4	-1.192*** (-5.10)	-2.006*** (-7.87)	15.9	13.4	0.908** (2.09)	1.206** (2.29)	15.9
14.2	-1.273*** (-5.15)	-2.100*** (-7.90)	16.6	14.2	0.934** (2.04)	1.242** (2.26)	16.6
15	-1.353*** (-5.20)	-2.194*** (-7.93)	17.3	15	0.960** (1.99)	1.277** (2.23)	17.3
15.8	-1.433*** (-5.25)	-2.288*** (-7.95)	18	15.8	0.986* (1.94)	1.313** (2.20)	18
16.6	-1.514*** (-5.29)	-2.382*** (-7.97)	18.7	16.6	1.012* (1.90)	1.348** (2.17)	18.7
17.4	-1.594*** (-5.32)			17.4	1.039* (1.87)		
18.2	-1.675*** (-5.35)			18.2	1.065* (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*** (4.20)	0.383*** (4.57)	0.418*** (4.25)	0.567*** (5.89)	0.433*** (4.33)	0.571*** (6.02)
ATV Knowledge Stock (DM) $t_{-1}$	0.0321** (2.08)	0.0305** (1.97)	0.0299* (1.94)	0.0364** (2.38)	0.0306** (1.99)	0.0357** (2.29)
Patent Propensity (DM) $t_{-1}$	0.0710*** (2.81)	0.0709*** (2.80)	0.0724*** (2.87)	0.0636** (2.52)	0.0723*** (2.86)	0.0622** (2.48)
Age (DM) $t_{-1}$	-0.239 (-1.57)	-0.270* (-1.80)	-0.259* (-1.68)	-0.401*** (-2.71)	-0.264* (-1.73)	-0.435*** (-2.89)
R&D Subsidies (DM) $t_{-1}$	0.0118 (0.28)	-0.00730 (-0.17)	-0.000311 (-0.01)	-0.00682 (-0.16)	-0.00128 (-0.03)	-0.00633 (-0.15)
Vehicle Registration (DM) $t_{-1}$	0.0302 (0.73)	0.0243 (0.59)	0.0321 (0.78)	0.0277 (0.66)	0.0325 (0.79)	0.0262 (0.63)
Charging Station Advances (DM) $t_{-1}$	0.125*** (3.22)	0.119*** (3.08)	0.123*** (3.17)	0.125*** (3.21)	0.124*** (3.21)	0.120*** (3.07)
ATV Patent Growth (DM) $t_{-1}$	-0.0460 (-1.06)	-0.0488 (-1.11)	-0.0475 (-1.09)	-0.0460 (-1.03)	-0.0470 (-1.08)	-0.0470 (-1.05)
ATV Knowledge Stock (M)	0.127* (1.79)	0.150** (2.10)	0.131* (1.84)	0.160** (2.26)	0.135* (1.90)	0.153** (2.19)
Patent Propensity (M)	0.147* (1.75)	0.0946 (1.15)	0.127 (1.53)	0.130 (1.56)	0.128 (1.54)	0.128 (1.55)
Age (M)	0.430*** (4.68)	0.454*** (4.87)	0.459*** (4.94)	0.388*** (4.23)	0.451*** (4.86)	0.403*** (4.38)
R&D Subsidies (M)	-0.0270 (-0.35)	-0.0350 (-0.45)	-0.0302 (-0.39)	-0.0561 (-0.73)	-0.0299 (-0.39)	-0.0627 (-0.81)
Vehicle Registration (M)	-0.258** (-2.04)	-0.236* (-1.87)	-0.244* (-1.92)	-0.206* (-1.65)	-0.243* (-1.91)	-0.197 (-1.57)
Charging Station Advances (M)	0.333*** (3.16)	0.351*** (3.34)	0.337*** (3.16)	0.280*** (2.85)	0.332*** (3.13)	0.274*** (2.79)
ATV Patent Growth (M)	0.0220 (0.24)	0.0287 (0.32)	0.0237 (0.26)	0.0320 (0.36)	0.0238 (0.26)	0.0356 (0.39)
Constant	-0.553*** (-3.32)	-0.574*** (-3.29)	-0.560*** (-3.27)	-0.547*** (-3.24)	-0.549*** (-3.23)	-0.587*** (-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*** (4.20)	1.467*** (4.57)	1.520*** (4.25)	1.764*** (5.89)	1.542*** (4.33)	1.771*** (6.02)
ATV Knowledge Stock (DM) $t_{-1}$	1.033** (2.08)	1.031** (1.97)	1.030* (1.94)	1.037** (2.38)	1.031** (1.99)	1.036** (2.29)
Patent Propensity (DM) $t_{-1}$	1.074*** (2.81)	1.074*** (2.80)	1.075*** (2.87)	1.066** (2.52)	1.075*** (2.86)	1.064** (2.48)
Age (DM) $t_{-1}$	0.788 (-1.57)	0.763* (-1.80)	0.772* (-1.68)	0.669*** (-2.71)	0.768* (-1.73)	0.647*** (-2.89)
R&D Subsidies (DM) $t_{-1}$	1.012 (0.28)	0.993 (-0.17)	1.000 (-0.01)	0.993 (-0.16)	0.999 (-0.03)	0.994 (-0.15)
Vehicle Registration (DM) $t_{-1}$	1.031 (0.73)	1.025 (0.59)	1.033 (0.78)	1.028 (0.66)	1.033 (0.79)	1.027 (0.63)
Charging Station Advances (DM) $t_{-1}$	1.133*** (3.22)	1.127*** (3.08)	1.130*** (3.17)	1.133*** (3.21)	1.132*** (3.21)	1.127*** (3.07)
ATV Patent Growth (DM) $t_{-1}$	0.955 (-1.06)	0.952 (-1.11)	0.954 (-1.09)	0.955 (-1.03)	0.954 (-1.08)	0.954 (-1.05)
ATV Knowledge Stock (M)	1.136* (1.79)	1.162** (2.10)	1.140* (1.84)	1.173** (2.26)	1.145* (1.90)	1.165** (2.19)
Patent Propensity (M)	1.159* (1.75)	1.099 (1.15)	1.135 (1.53)	1.139 (1.56)	1.137 (1.54)	1.136 (1.55)
Age (M)	1.538*** (4.68)	1.574*** (4.87)	1.582*** (4.94)	1.474*** (4.23)	1.569*** (4.86)	1.496*** (4.38)
R&D Subsidies (M)	0.973 (-0.35)	0.966 (-0.45)	0.970 (-0.39)	0.945 (-0.73)	0.971 (-0.39)	0.939 (-0.81)
Vehicle Registration (M)	0.772** (-2.04)	0.790* (-1.87)	0.783* (-1.92)	0.814* (-1.65)	0.784* (-1.91)	0.821 (-1.57)
Charging Station Advances (M)	1.395*** (3.16)	1.420*** (3.34)	1.401*** (3.16)	1.323*** (2.85)	1.394*** (3.13)	1.315*** (2.79)
ATV Patent Growth (M)	1.022 (0.24)	1.029 (0.32)	1.024 (0.26)	1.033 (0.36)	1.024 (0.26)	1.036 (0.39)
Constant	0.575*** (-3.32)	0.564*** (-3.29)	0.571*** (-3.27)	0.579*** (-3.24)	0.578*** (-3.23)	0.556*** (-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								
Parameter	Hybrid NB Model Estimates							
	(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.

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## Endnotes

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<sup>[a]</sup> In this context, I would like to highlight 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). Similar to Markides and Geroski, we prefer to use 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 vehicles and therefore 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 markets, 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).

<sup>[b]</sup> As we regard this work to a technology (ATV) which is considered to be more environmentally friendly than the dominant design (combustion engine vehicles), we occasionally also 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.

<sup>[c]</sup> In this context it is helpful to know that an early definition for sustainable development stems from the Brundtland report (WCED, 1987, p.54): "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 World Summit of the United Nations 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 friendly than the dominant design (combustion engine vehicles). We thus contribute only broadly to the sustainability debate itself; indirectly touching the economic and environmental dimension. Though, 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 of our case.

<sup>[d]</sup> 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.

<sup>[e]</sup> This data contains public expenditure 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; diesel engines (OECD Statistical Service, 2014a; Aghion et al., 2012).

<sup>[f]</sup> 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. For this reason the variable could theoretically also be significant for firms' ATV-related patent activities. Given that this variable is insignificant in most cases, though, 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.

<sup>[g]</sup> The strong difference in the R-squared calculation stems from the following construction: hybrid NB models are specified as random effects models in which FEs are integrated via additional variables and the likelihood estimation is therefore (incorrectly) based on the between variation and thus shows relatively higher values, leading to lower McFadden's R-squared indicators. In contrast, in the FENB model, the actual within variation is (correctly) considered in the likelihood estimation which is therefore lower, leading to higher McFadden's R-squared indicators.

<sup>[h]</sup> For example, in year  $t=2009$  entrants' accumulated patents were considered up to  $t=2008$ . Entrants' ultimate patents in  $t=2008$  refer to the publication date, that means 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 the entrant's actual investment in R&D has happened in  $t=2005$ . Note that only the actual investment in R&D could be an entrant's response to incumbent patenting. However, we used incumbents' patent applications as dependent variable. Hence, in  $t=2005$  the entrants are not aware of incumbents' patent applications in  $t=2005$ ; instead, in  $t=2005$  entrants can only be aware of incumbents' patent applications from  $t=2003$  (because of 18 month confidentiality). In sum, the entrants' actions, measured with the variable implemented in  $t=2009$ , could be at best a reaction to incumbents' patent application from  $t=2003$ . Consequently, the entry variable in  $t$  could at best be a reaction to the dependent variable 6 years before. Therefore, the correlation between the dependent variable and the autoregressive terms not from  $t-1$  but from later years matter.