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Do Entrants Stimulate Environmentally Friendly Research in Incumbents? Testing Incumbents? Path Dependency & Entrants? Relevant Characteristics ? An Empirical Analysis on the Automotive Industry ?

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Abstract

Evolutionary economists highlight that entrants as well as incumbents play different but essential roles in transitional processes. Entrants are claimed to spark the transition by introducing disruptive innovations. Incumbents are initially in favor of the dominant design but once motivated to pursue new technology as well, mainly they are able to achieve mass-market penetration, given their influential power, reputation, financial resources and ability to achieve process innovations that reduce costs. The incumbents? motivation is therefore crucial for the pace of technological transitions.

The present paper assumes that entrants? key role is not merely the introduction of new technologies but rather that they spur incumbents to reallocate their R&D activity towards these new technologies. This mechanism is analyzed for environmentally friendly technologies. The analysis considers R&D entry of lateral and upstream entrants as well as start-ups and spin-offs. Ordinarily, incumbents consider only a small proportion of entrants as challenging; but since these entrants are partly from different industries, they can leverage competences new to the industry and crucial for technological advances. They further stimulate the initial demand, master technologies in niche markets and eventually signal governments and incumbents the maturity of the technology for mass market adoption. At that stage, entrants are recognized by incumbents and by their innovative performance they are expected to facilitate overcoming lock-in phenomena by stimulating incumbents? R&D.

These relationships are tested for the automotive industry, which currently faces a transition from combustion engine vehicles towards electrically powered alternative technology vehicles (ATVs), providing lower or zero-emission drive systems. ATVs are claimed to become a disruptive technology which may destroy the technological and economic structure of the current vehicle system. Using global patent data, this study seeks to econometrically test whether ATV-related R&D entrants increase incumbents? R&D on ATVs. Incumbents are expected to respond heterogeneously, depending on their knowledge stock achieved in ATV technologies. The results indicate that entrants stimulate incumbents? ATV-related innovations, particularly of those incumbents that show low ATV-related patent stocks; whereas incumbents with high ATV-related patent stocks react with decreasing patenting, which is assumed to be a sign of R&D outsourcing. The findings further support the postulated hypotheses: a stronger incumbent response to international as opposed to domestic entrants and a stronger response to foreign leading entrants with greater technological expertise than to foreign following entrants with minor technological expertise.

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Do Entrants Stimulate Environmentally Friendly Research in Incumbents?

Testing Incumbents' Path Dependency & Entrants' Relevant Characteristics

– An Empirical Analysis on the Automotive Industry –

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Abstract

In the context of technological transitions, the influence of innovative entrants on incumbents is considered a major driving force. Using worldwide patent data, the present study analyzes this influence for the case of the transition from combustion engine vehicles towards electrically powered alternative technology vehicles (ATVs) that provide lower or zero-emission drive systems. Lateral entrants and start-ups play a key role in developing ATV-related patents, whereas automotive incumbents are considered as being less motivated in pursuing this new technology. The analysis investigates technology-specific incumbent responses to cross-country entrants. The results indicate that entrants' ATV-related knowledge accumulation stimulates incumbents' ATV-related innovations, particularly of those incumbents that show low ATV-related patent stocks; whereas incumbents with high ATV-related patent stocks react with decreasing patenting, which is assumed to be a sign of R&D outsourcing. The findings further suggest a stronger incumbent response to foreign as opposed to local entrants and a stronger response to foreign leading entrants with greater technological expertise than to foreign following entrants with minor technological expertise.

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1 Introduction

The crucial role of entrepreneurs in accelerating technological and industrial change is well known by Schumpeter's (1911/34) early work. Given their lack of competences in the dominant design, entrants barely face opportunities to exploit existing, rather mature technologies, but instead spark technological transitions by introducing disruptive innovations that reduce entry barriers (Tushman and Anderson, 1986; Utterback, 1994). Therefore, new markets are often shaped by new key players. 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 (Hockerts and Wüstenhagen, 2010; Schaltegger and Wagner, 2011). In contrast, incumbents are likely to establish fixed routines, which constrain them in responding appropriately to changing environments (Nelson and Winter, 1982; Teece et al., 1997). New technology may cannibalize profit from their existing products and disrupt the value of their accumulated knowledge base. Especially in later stages of the product life cycle, incumbents tend to focus on minor product improvements and process innovations. Consequently, they tend to favor the existing design, but not to promote relatively immature new technologies in early transitional phases (Gort and Klepper, 1982; Henderson and Clark, 1990; Christensen, 1997).

Hockerts and Wüstenhagen (2010) hypothesize that entrants' contributions to sustainable transitions go beyond the introduction of innovative solutions; entrants encourage incumbents' sustainable actions. 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.

Most environmental problems require disruptive innovations. Many concerned industries, however, are characterized by an oligopolistic market structure or increasing market concentration. Those market characteristics are likely to impede technological change. The incumbents' potentially defensive behavior is likely to hamper the pace of industries' sustainable development. For this reason, it is highly relevant to gain a deeper understanding of entrants' potentially catalyzing force for sustainable industrial development. The research question of the present paper therefore is to analyze the influence of entrants' environmentally friendly knowledge-stock accumulation on incumbents' environmentally friendly innovation activity.

This study assumes that entrants' key role occurs via various forces that facilitate overcoming lock-in phenomena by stimulating incumbents' research and development (R&D) on environmentally friendly technologies. The analysis considers innovative entry into the ATV research regime of lateral entrants, start-ups, and spin-offs. Ordinarily, incumbents consider only a small fraction of entrants as challenging; however, since those entrants are partially affiliated with different industries, they can provide new competences that are crucial for technological advances. 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.

To test this effect of innovative entry on incumbents, the automotive industry has been chosen for four main reasons. First, this industry is currently facing a transition towards alternative technology vehicles (ATVs).[1] Second, although this market is characterized by high entry barriers, technologies that disrupt incumbents' knowledge are providing new entry opportunities (Tushman and Anderson, 1986). ATVs are reported to have the potential to become disruptive. They may destroy not only the technological, but also the economic structure of the current vehicle system, thus allowing the industry to escape from the locked-in combustion engine technology (Cowan and Hultén, 1996; Christensen, 1997). ATVs also require new components that draw on multiple competences new to the industry, i.e. electric motors and energy storage systems.[2] These new requirements provide additional lateral entry opportunities. Third, this industry is characterized by 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 impede the pace of technological change. Lastly, given governments' growing ambition to prevent climate change, as well as the fact that the transport sector is one of the largest contributors to global emissions, the present study is also highly relevant from a policy perspective.

Entrepreneurship literature has shown that entrants positively influence incumbents' general innovative activities. Incumbents have been found to respond differently, depending on their competitive performance or the industries' technological level (Aghion et al., 2009; Czarnitzki et al., 2011; Iacovone et al., 2011). Current studies analyze the influence of entry on incumbents via quantitative entry forces, such as entry numbers or employment size, and often focus on the industry level and entrants into incumbents' domestic markets. However, this procedure has several limitations. First, incumbents are likely to react only if entrants directly interfere with their operational business field, in terms of introducing substituting technologies or providing crucial complementary knowledge, which is not necessarily the case in studies based on the

[1] Automobile firms currently focus on three different ATV vehicle types: battery, fuel cell and hybrid electric vehicles.

[2] Examples of new components in ATVs include electric motors, batteries, energy-control systems, charging systems, voltage converters, electromechanical brakes, transmission and steering-systems (Wallentowitz et al., 2010).

industry level. Second, multinational incumbents operate globally and are thus not only influenced by local but also by international entrants. Third, incumbents may not perceive the number of entrants but rather entrants' qualitative characteristics as important. It is therefore sensible that the present study firstly addresses incumbents' technology-specific responses to cross-country entry, and considers entrants' qualitative characteristics, such as the technological relevancy of entrants' knowledge-stock, while concentrating on a single technology that is potentially substituting the incumbent technology.

The paper is structured as follows. The next section highlights previous findings regarding entrants' relevancy for the transition towards environmentally friendly technologies and reviews the effect of entry on incumbents. The third section derives respective hypotheses. The methodology of the patent data analysis is described in Sections 4. Potential biases and drawbacks are presented in Section 6.

2 Literature Review

Entrants' Contribution to the Transition towards Environmentally Friendly Technologies

The rising awareness of climate change and resource shortages is shifting the focus of many actors towards finding a solution to economic and environmental challenges. Especially entrepreneurs are drawing increasing attention in academia in order to disentangle their contribution to industrial sustainable developments. This has contributed to the emergence of a new area of research regarded to sustainable entrepreneurship (Levinsohn and Brundin, 2011; Hockerts and Wüstenhagen, 2010).

The topic of sustainable entrepreneurship has been addressed from a number of perspectives. Case studies have varied from fair-trade products (Davies and Crane, 2003; Hockerts, 2006; Nicholls and Opal, 2005) to microfinance in developing countries (Christen, 2000; Cull et al., 2007). Other authors have focused on the role of sustainable entrepreneurship in national sustainable development, or have begun to categorize different types of sustainable entrepreneurship (Schaltegger and Wagner, 2011; Kardos, 2012). Hall et al. (2010) and Levinsohn and Brundin (2011) provide a comprehensive overview of recent work on the nexus of sustainability and entrepreneurship.

Hockerts and Wüstenhagen (2010) are among the first scholars to highlight complementary roles of entrants and incumbents in pushing forward the pace of sustainable developments. Both types of actors have different strengths and challenges. These authors theorize that both are crucial and essential actors to transforming industries and moving towards a higher level of sustainability. Especially in early transitional phases towards sustainability, entrants are more likely than incumbents to introduce environmentally friendly technologies. However, entrants mostly fail to reach mass-market acceptance and remain in niche markets, since they are unable to compete successfully with leading incumbents. Entrants are thus not strong enough to enforce the transition alone. Though, they instead stimulate incumbents to reallocate their resources which represents one of their key contributions to sustainable industrial developments. Hockerts and Wüstenhagen (2010) further state that, in the early stages of the transition, incumbents react merely with environmentally friendly expansions of their product portfolios. In later stages, incumbents then become motivated to leverage the technologies in question and push for mass-market adoption. Incumbents can better succeed in this by drawing on their power, influence, trustworthy reputation, and ability to reduce costs via process innovations and economies of scale. Incumbents also make use of their strong innovative power, as their extensive resources facilitate large and in-depth R&D projects.

The Effect of Entry on Incumbents – Previous Findings

Since environmentally friendly entrepreneurship is an emerging field of study, research still rests on case studies and theoretical arguments, and lacks clear definitions (Hall et al., 2010). Recent findings from the literature on more traditional entrepreneurship were therefore also incorporated to formulate the hypotheses. The most important ones of these studies are briefly discussed below. Although the effect of entry on incumbents seems to be of high importance, few studies have yet begun to disentangle entry dynamics using econometric approaches, and fundamental results on incumbents' technology-specific responses to cross-country entry are still scarce.

Wesseling et al. (2014) conducted one of the most related case studies. Based on a patent-count analysis, they investigated the continuation of ATV research within 15 original equipment manufacturers (OEMs) that are currently leading the 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 for the total patent pool 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 the continuation of 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 new entrants in terms of start-ups and diversifying firms are important for the development of this technology.

To examine the German manufacturing sector, Czarnitzki et al. (2008, 2011) use data from the Mannheim Innovation Panel. They test whether different 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 had 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 show a higher R&D intensity than the average firms. This strong competitive entry pressure consequently encouraged average firms to invest less in R&D, while leading firms invested more in R&D.

Other researchers have explored trade liberalization and the effect of foreign firms' entry on local incumbents. Iacovone et al. (2011) also found heterogeneous behavior 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. The authors' analysis covers a six-year period (1998–2004), which captures changes that are associated with China's entry into the World Trade Organization in 2001. Their results indicate that entry induced productive incumbents to innovate more and less productive incumbents to innovative less. They argue that this competitive pressure reinforces the differences between strongly and weakly performing firms, eventually causing heterogeneous responses to entry.

Aghion et al. (2004) also conducted a study on trade liberalization, although in this case within the United Kingdom from 1980 to 1993. The authors come to the conclusion that entry has a positive effect on incumbents' total factor productivity growth. Firm-specific fixed effects were chosen to control for permanent growth rate differences. They determined entry rates by measuring the share of industry employment held by foreign firms operating locally in the United Kingdom.[3] In a more recent analysis, Aghion et al. (2009) investigate the effect of entry also on incumbents' patenting across a number of industries. Using data from the Annual

[3] This method, however, may mean that they did not measure entry, but rather employment growth within foreign incumbent subsidiaries that had been established long before the analysis took place.

Respondents Database,[4] the authors found that the entry of foreign firms also has a positive influence on local incumbents' patenting and productivity growth, although this positive effect was only found for technologically advanced industries.

3 Basic Underlying Assumptions & Hypotheses

In line with Hockerts and Wüstenhagen's (2010) argument, the present study builds on the assumption that entrants and incumbents are essential for driving industries in a more environmentally friendly direction. An important mechanism within this transition is the influence that innovative entrants impose on incumbents that tend to stick to the existing technologies. The present analysis therefore seeks to econometrically identify whether entrants that accumulate ATV-related patents accelerate technological change within the automotive industry by increasing incumbents' ATV-related patenting. The hypotheses build on previous literature, and attempt to disentangle global industry dynamics that have not yet been addressed: incumbents' technology-specific responses to cross-country entrants' that enter the research regime of a potentially disruptive technology while concentrating on qualitative entry forces, such as technology-specific knowledge accumulation and technological expertise. Three main sets of hypotheses are derived:

A first set addresses the questions of whether incumbents react on entrants' knowledge stock and whether the entrants' origin plays a role. Previous findings have suggested that entrants impose a positive effect on general innovative activity among leading incumbents (Iacovone et al. 2011; Czarnitzki et al. 2011) operating in technologically advanced industries (Aghion et al., 2009). Hockerts and Wüstenhagen (2010) further suggest that incumbents tend to expand their product portfolios as a response to environmentally friendly entrants. Incumbents' responses in terms of new product launches should therefore also be reflected in their technology-specific patenting. Applying this reasoning to the present study—which considers leading automotive incumbents and an industry that is recognized as being technologically advanced—allows the following suggestion to be made: Since most leading OEMs (e.g., Toyota and Volkswagen) have already launched ATVs as line expansions, or have announced that they will do so in the near future, it can reasonably be assumed that this positive entry effect also holds for OEMs' ATV-related patenting. The present work thereby extends the literature which merely focused on incumbents' general innovative responses by furthermore investigating whether entrants also drive incumbents to increase patenting along a specific technological trajectory.

[4] In this study, entrants were clearly identified as international foreign firms that had not been previously operating in the United Kingdom.

The reasons why entrants influence incumbents have not yet been intensively discussed in the literature. Given the technology- and industry-specific conditions, and also the consideration of qualitative entry forces, the present paper highlights and expands several likely explanations. Entrants are expected to stimulate incumbents' ATV-related patent motivation via three forces: directly, via competitive pressure (representing the focus of previous studies) and complementary knowledge, as well as indirectly, via market initialization. The types of entrants are crucial for the assumed reasons for entrants' influence on incumbents. As for competitive entry, the present study considers patent entry and, therewith, 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 may be limited, because this industry is strongly consolidated, with a few powerful OEMs. The considered incumbents are therefore assumed to perceive, at most, a small fraction of competitive entrants that intend to sell ATVs as challenging. Despite the limited attention these entrants attract from OEMs, they are also expected to indirectly influence the OEMs' perceived profitability of ATVs, since they initialize the market in its early stages: stimulating demand, enlarging the scope of niche markets and eventually signaling to governments and incumbents the viability of ATVs for mass-market adoption.[5] As for complementary entry, the present study follows Wesseling et al.'s (2014) conclusions that both start-ups and diversifying incumbent entrants are important for achieving progress in ATV technologies. OEMs' are likely to react positively to diversifying entrants since such entities supply complementary knowledge. There is a high likelihood that many suppliers from lateral industries, such as battery or electric motor manufacturers, will enter the ATV market: they can provide new components, and thereby benefitting from new profit opportunities. Diversifying firms can draw on long-term experience and leverage crucial capabilities, which might enable them to achieve rapid technological advances. Eventually, these firms can provide OEMs with superior components or knowledge spillovers. Diversifying incumbent entrants that start ATV-related research were therefore also considered a potential influence on incumbents' patenting.

In light of these arguments, the present paper considers lateral entrants, start-ups, and spin-offs, all of whom represent new entrants into the ATV research regime. These entrants not only intend to sell ATVs on the final customer markets—which could challenge incumbents and indirectly change incumbents' perceptions of ATVs' profitability by initializing the market—but also contain suppliers that may provide complementary knowledge in the form of spillovers or superior components. Regarding these different entry forces, it can be assumed that the greater

[5] Many thanks to Frank Geels for additionally pointing out the latter indirect entry effect at the RNI Summer School 2013, Belford.

the entrants' ATV-related knowledge accumulation the stronger will be their competitive power and capacity for market penetration, and the more supportive will be their potential spillovers towards incumbents. The present study therefore hypothesize that entrants' ATV-related patent accumulation has a positive effect on incumbents' ATV-related patent activity.

Moreover, the automotive industry is not limited to national markets, but is instead characterized by globally operating incumbents. Following Aghion et al. (2012), the present study therefore expects that automotive incumbents' R&D strategies are not only influenced by domestic market conditions but also by the market conditions within relevant countries abroad. The influence of entrants is thus likely to cross national boundaries. An incumbent is expected to perceive international entrants as relevant, if the entrants origin from countries in which the incumbent is exporting to. It is thus hypothesized that not only local entrants (Hypothesis H 1.1) but also international entrants from relevant countries (Hypothesis H 1.2) positively influence incumbents' ATV-related patenting. Other entrants, originating from countries in which the incumbent is not operating in, are expected to be rather irrelevant in influencing incumbents' R&D strategies (Hypothesis H 1.3).

H 1.1: The ATV-related knowledge accumulation from local entrants of incumbents' home countries has a positive effect on incumbents' ATV-related patenting.
H 1.2: The ATV-related knowledge accumulation from international entrants of relevant countries abroad has a positive effect on incumbents' ATV-related patenting.
H 1.3: The ATV-related knowledge accumulation from international entrants of irrelevant countries abroad has no effect on incumbents' ATV-related patenting.

To investigate incumbents' responses to entrants' qualitative characteristics in further detail, the second hypothesis is related to the technological relevancy of the entrants' knowledge stock. From the incumbents' point of view, it may be of major importance *who* is entering; with which level of technological expertise, and how quick these entrants accumulate relevant knowledge. Incumbents' may not perceive entrants with minor technological expertise as challenging or supportive even if these entrants accumulate many ATV-related patents; instead, incumbents may more strongly respond to those entrants that embody a great amount of technological relevancy, regardless of these entrants' number of accumulated patents. The present study therefore hypothesize that the magnitude of the incumbent responses on entry is dependent on the entrants' level of technological relevancy (Hypotheses H 2).

H 2: The effect of entrants with high technological relevancy is stronger than the effect of entrants with low technological relevancy.

The third set of hypotheses focuses on incumbents' different responses on entry, depending on their different and individual performances. In this respect, Czarnitzki et al. (2011) conclude that a subjective perceived entry threat spurs average incumbents to invest less in R&D, but leading incumbents to invest more in R&D. Iacovone et al. (2011) also find that entry induces productive incumbents to innovate more and less productive incumbents to innovate less as a response to entry. Heterogeneous response behavior across incumbents is a relatively new finding in the literature and has not yet been explored from different perspectives. The new technology-specific perspective of the present analysis therefore opens up an opportunity to extend current literature and investigate heterogeneous responses on entry beyond incumbents' general performances—namely, their responses depending on their technology-specific performance in terms of ATV-related knowledge levels. The present paper's technology-specific perspective, however, requires the hypotheses on incumbents' heterogeneous responses to be derived from a new angle:

Automotive incumbents' responses on entry are also likely to vary across the different ATV-related knowledge levels they achieved (Hypothesis H 3.1). OEMs that already filed many ATV-related patents are likely to be too advanced to be challenged by new competitive entrants. OEMs that filed very few ATV-related patents, on the other hand, are likely to be challenged by competitive entrants or to seek support in terms of ATV-related knowledge spillovers from complementary entrants. Such OEMs are thereby likely to increase their ATV-related patenting more strongly than their more patenting counterparts. This assertion is further supported by the fact that those OEMs with few ATV-related patents also have a greater scope to increase their ATV-related patenting, as their baseline patenting has been so minimal. Based on these arguments, the present study hypothesizes decreasing incumbent patent responses on entry, along with increasing incumbent ATV-related patent stocks (Hypothesis H 3.2).

H 3.1: Incumbent responses on entry are different and dependent on their respective levels of ATV-related patent stocks.

H 3.2: With incumbents' increasing levels of ATV-related patent stocks, their responses decrease in magnitude.

4 Methodology

4.1 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' willingness to achieve innovative advances in ATV-related technologies and entrants' time of entry into the ATV research regime.

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 R&D expenditures, they are a strong indicator of firms' innovative effort and overall willingness for technology-specific investments. Patent data were therefore determined to be sufficient for analyzing technological change and long-term differences between firms' technological inventive strategies (Griliches et al., 1988), the major point of interest in the present study.

The analysis makes use of the 2013 fall edition of the Worldwide Patent Statistical Database (PATSTAT), provided by the European Patent Office. 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, or 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.[6] Such queries better represent firms' overall 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 incumbents' overall willingness to allocate innovative effort towards ATVs to be captured more effectively; it also allows the point in time when entrants began ATV-related research to be estimated more precisely. 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[7] 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 (WIPO, 2011) and the OECD Environment Directorate (OECD, 2011); the CPC scheme is provided by the EPO and USPTO (CPC, 2014).[8] 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 the firms involved in ATV-related research. From this firm pool all the relevant incumbents and entrants that were included in the present study were extracted.

The group of relevant incumbents was defined as the 20 most successful OEMs in terms of worldwide production in 2012; this information was provided 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 currently belong to the Volkswagen group, which is one of the 20 most successful OEMs. Furthermore, OEMs' overseas establishments that also conduct R&D often develop innovation

[6] This holds for patent offices in most countries: e.g., the US, Japan, China and Europe (OECD, 1994; Hu, 2010; EPO, 2011; USPTO, 2000).
[7] Utility models, for example, are excluded from the patent count.
[8] An overview of all considered IPCs is provided in Table 1a of the Appendix.

strategies that are different from those of their parent firms focusing on country-specific R&D projects to satisfy local needs. For this reason, overseas 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 if they were part of the relevant ATV-related firm pool.[9]

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 application 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.[10] Before the patent office publishes the patent document, the application date, the patent content, and, thus, the existence of the patent, are all kept strictly confidential. For this reason, new entrants in any period t in the analysis are not aware of the incumbents' patent claims at that point in time.[11] 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.[12] 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 can be 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 respond 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, the remaining firms of the firm pool

[9] An overview of considered incumbents is provided in Table 2a of the Appendix.
[10] An overview of this procedure can be found in OECD (1994) and in Harhoff and Wagner (2009).
[11] This fact, in combination with lagged entry variables, is assumed to sufficiently rule out the possibility of reverse causality: that entrants' decision to engage in ATV-related patenting is partly driven by incumbents' ATV-related patent activity. The possibility that entrants are driven by incumbents' previous R&D investments, however, cannot be ruled out, given the lack of data on R&D investments. Thanks to an anonymous reviewer who pointed out this limitation.
[12] To further prevent double counts of inventions, the data was reviewed to ensure that each DOCDB patent family is counted only once per firm.

(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 definition and procedure allows the analysis to capture all types of entry, including lateral, downstream, and upstream entrants, as well as start-ups and spin-offs.[13]

The relevant entrants were further aggregated on the country level and assigned to different country groups for testing the hypotheses H1.1 to H1.3. Country codes provided by the PATSTAT database were used to infer incumbents' and entrants' national affiliations.[14] With this procedure, the analysis accounts for all countries ($z=1,\ldots,C$) affiliated with the relevant incumbent and entrant groups that were extracted from the firm pool, which was identified by the global ATV-related patent query. The considered incumbents originate from in 15 different countries and the considered entrants originate from 92 different countries.

The 2013 fall edition of the PATSTAT database contains accurate patent data from 1970 to 2011.[15] The period from 1970 to 1974 was excluded for constructing the 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.[16] 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 was needed to evaluate the technological relevancy of entrants' knowledge stock in t. The variable constructions are further explained in Section 4.2.

4.2 Empirical Specification: Model & Variables

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 of incumbents'

[13] Note that all remaining firms who were neither assigned to the incumbent nor entrant groups were excluded from the sample.
[14] Any firms for which there were no data regarding their national affiliation in the PATSTAT database available were excluded from the sample.
[15] 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.
[16] A lead-time of five years without any ATV-related patents was deemed sufficient, as this industry is characterized by frequent patenting.

ATV-related patenting, a negative binomial model for panel data was utilized, which also controlled for within-group correlations among multiple firm observations over time. The detailed model specification, the construction of the main variables of interest and further usage of information provided by patents to construct control variables are described below.

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-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 (NBFE), 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 NBFE model is nevertheless potentially problematic, the analysis rests on a hybrid negative binomial model in accordance with the method introduced by Allison (2005, pp. 101-105). This hybrid 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). Beyond this, the conditional NBFE model and also the random effects negative binomial model (NBRE) were additionally estimated to validate robustness.

In order to test the postulated hypotheses, three different model settings were estimated and displayed in Table 1.

Table 1: Model Settings

(1) – (3) Model: Entrants' Origin	Negative binomial model (hybrid model, NBFE, NBRE) Objective: test incumbents' ATV-related patent responses to entrants from different country origins (H1.1 – H1.3)
(4) Model: Leading Entrants (5) Model: Following Entrants	Negative binomial model (hybrid model, NBFE, NBRE) Objective: test incumbents' ATV-related patent responses to leading (*l=1, ...,L*) and following entrants (*f=1, ...,F*) regarding their technological relevancy (H2)
(6) Model: Incumbents' Path-Dependency	Negative binomial model (hybrid model, NBFE, NBRE) Objective: test incumbents' heterogeneous responses to entrants (H3.1 & H3.1)

For example, the Model (4) is expressed by Equation 1:

$$IPA_{i,t,h} = \beta_0 + \beta_1 \sum_{j\in l}\sum_{z=h} EKS_{j,t-1,z} + \beta_2 \sum_{j\in l}\sum_{z\in rc} EKS_{j,t-1,z} + \beta_3 \sum_{j\in l}\sum_{z\in ic} EKS_{j,t-1,z}$$

$$+\beta_4 IKS_{i,t-1} + \beta_5 E_{i,t} + \beta_6 PP_{i,t} + \beta_7 A_{i,t} + \beta_8 PubRD_{i,t} + \beta_9 VR_{i,t} + \beta_{10} ACS_{i,t} + \beta_{11} PGR_t + \beta_{12-30} YD_t + \epsilon_{i,t} \quad (1)$$

where: i=individual incumbent; observation period t=1980,...,2009; country of origin z = 1,…,h,…,C; incumbents' home country: h; relevant countries: rc = $\{1,C\}\backslash h+ic$; irrelevant countries ic = $\{1,C\}\backslash h+rc$; entrant j=1,...,J; leading entrant l = $\{1,J\}\backslash f$

The **dependent variable** $IPA_{i,t,h}$ describes the incumbent i's number of ATV-related patent applications filed per year for time t. The individual incumbents' yearly ATV-related patenting was tracked from t=1980 to t=2009. It needs to be noted that the incumbents' reactions to any of the entry variables are difficult to capture precisely in time. Incumbents may differ in the time they require to respond to entrants with a change in their R&D activities: some may invest in R&D one year after they observe entrants' patent activities, while others may invest after three years. Further, it is not R&D investments, but patent applications that serve as a proxy 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 relevant for observing incumbents' reactions to new entrants in the dependent variable.

The main **explanatory variables** of interest account for this imperfection. The variables that proxy the entrants' knowledge stocks, i.e. $EKS_{j,t-1,z}$, were constructed by applying Griliches' (1979) perpetual inventory method that is used in many innovation studies:

$$EKS_{j,t,z} = EPP_{j,t,z} + (1 - \delta)EKS_{j,t-1,z} \quad (2)$$

Where: j refers to the individual entrant, t refers to the time in question, z refers to the entrants' country origin

$EKS_{j,t,z}$ is calculated by accumulating the yearly number of entrant j's ATV-related patent publications ($EPP_{j,t,z}$). 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. The depreciation rate δ of entrants' previous patent stock is set to the commonly used 20% in innovation studies.[17] Depending on the hypotheses in question, the entrants' knowledge stocks were aggregated to different variables depending on their country origins (z) and type of entrant (j):

The *first model settings* regard the first hypotheses (H1.1-H1.3): whether entrants' different country origins (z) play a role for their influence on incumbents. For this purpose, the entrants were distinguished into different country groups and tested stepwise separately in three models. In Model 1, two country groups of entrants were included: those entrants that originate from the incumbents' home country (z=h) as well as those entrants that originate from all other international countries abroad (z=aic). In Model 2, the previous variable containing all international entrants (z=aic) is further split up into two new country groups: firstly, entrants from relevant countries abroad (z=rc) and, secondly, entrants from rather irrelevant countries abroad (z=ic). This classification builds on the assumption that incumbents may not be influenced by all international entrants—instead, it is likely that the market conditions abroad, including entry, of only those countries in which the incumbent is operating in are perceived as relevant from the incumbents' point of view. Each incumbent's global patent portfolio was taken to infer in which countries the incumbent is operating in. Since patenting is costly, it can be presumed that incumbents only patent in those countries abroad in which they are planning to or already do operate. Subsequently, only those entrants that originate from countries abroad in which the incumbent was patenting were aggregated to one entry variable (entrants from relevant countries) and all other entrants that originate from countries abroad in which the incumbent was not patenting were aggregated in another variable (entrants from irrelevant countries). In Model 3, the previously constructed variable containing entrants from the group of relevant international countries (z=rc) was also split up into two new country groups: firstly, entrants that originate from those three most relevant countries abroad (z=mrc) in which the incumbent was

[17] Different values of the depreciation rate were used to validate robustness.

filing most of its international patents and, secondly, entrants from all other remaining relevant countries abroad (z=rrc) in which the incumbent in question was patenting in.

The *second model settings* regard the second hypothesis (H2): whether entrants' technology-specific qualitative characteristics play a role for their influence on incumbents. For this purpose, all entrants (j=*1,...,J*) were distinguished in two groups: leading *(l=1,…,L)* and following *(f=1,…,F)* entrants in accordance to their patents' technological relevancy. These two groups were tested separately in two models; Model 4 and 5, respectively. The technological relevancy of entrants' inventions is measured by means of forward citations. Taking citations for this purpose rests on the argument that the more often a certain patent was cited in following periods, the more relevant its contribution was perceived for subsequent inventions. Citations are frequently used as a proxy to measure inventions' technological relevancy and thereby the quality of firms' patent portfolios.[18] The entrants' ATV-related technological relevancy (ETR) in each period t is calculated for each entrant j as follows:

$$ETR_{j,t} = \sum_{x=t_{1st\,P}}^{x=t} \left[\frac{\sum_{w=1}^{w=3} C_{j,x+w}}{\sum_{j=1,\dots,J} \sum_{w=1}^{w=3} C_{j,x+w}} \right] \qquad (3)$$

The considered periods for evaluating j's ATV-related patents range from j's first patent publication ($x=t_{1st\ P}$) until the time in question ($x=t$-1).The numerator $\sum_{w=1}^{w=3} C_{j,x+w}$ represents the total number of patent citations that j receives, within a three-year citation window *(w=1,2,3)*, for all its ATV-related patents filed until time x.[19] This number of citations is divided in each of these considered periods by the total number of entrants' citations. Relative citation numbers were taken to smooth out the potential bias of ATV-related patent trends that may have yield to an incomparably high number of citations in respective periods. An equal three-year citation window for each patent accounts for the bias that earlier applied patents would have otherwise gained more citations than recently applied patents.[20] The present study assumes that the higher the entrants' technological relevancy, the greater their challenging or supportive potential with which they can affect incumbents. Entrants are classified into leading entrants (*l*), if their $ETR_{j,t}$ value is among the highest 10%; all remaining entrants are classified as following entrants (*f*). Since this classification was undertaken in each period *t*, this procedure allows for a dynamic

[18] There is an obvious bias for patents filed at the USPTO. In USPTO's citation procedure the examiner at the patent office, instead of the applicant, commonly adds the citations to the patent document. This procedure ordinarily leads to more citations compared to other patent offices than the USPTO. This bias does not only hold for US firms but also for international firms filing patents at the USPTO. The robustness of the analysis will be examined carefully in estimating the entry effects a second time whilst excluding all US firms and patents filed at the USPTO.
[19] For an accurate classification, it is important to capture all citations which are associated to the same invention. This requires the citation count to not only count citations to the first priority application but also citations on later filed patents referring to the same invention, which is indicated by the DOCDB patent family. The patent family links together all patents belonging directly to the same invention. To rule out any bias occurring due to the firms' tendency to cite their own patents from the same patent family, citations from the same patent family were excluded.
[20] The citation window is set to three years as it is a common citation interval (Harhoff and Wagner, 2009) and to keep the truncation of time periods at the end of the data sample to a low number of periods.

evaluation of their performance as they can switch in each period from one group to another in case their $ETR_{j,t}$ value is changing drastically.

The *third model settings* regard the third hypotheses (H3.1 & H3.2): whether the incumbents' responses on entry are different and dependent on their respective levels of ATV-related knowledge stocks. For this purpose, the entry variables were interacted with a variable that proxies the incumbents' ATV-related knowledge stocks ($IKS_{i,t}$). These interaction terms were tested with Model 6. The $IKS_{i,t}$ variable also builds on Griliches' (1979) perpetual inventory method. It was thus constructed similarly to the entrants' knowledge stocks ($EKS_{j,t,z}$), but instead of the patent publications, it rests on the accumulation of patent applications as explained in Section 4.1, see Equation 3:

$$IKS_{i,t} = IPA_{i,t} + (1 - \delta)IKS_{i,t-1} \quad (4)$$

Aghion et al. (2012) also constructed this variable in a similar way and tested its influence on a similar dependent variable (the automotive firms' yearly number of ATV-related triadic patent grants). Their analysis shows that the ATV-related patent stock is an important and significant determinant. Following their work, this variable was also implemented as control variable in all the six models. The remaining **control variables** were computed as follows:

Incumbents' previous experience in ATV-related R&D is a potential source of bias. First, extensive previous experience facilitates firms' ability to create follow-up inventions, and therewith increases those firms' likelihood to patent. Second, an experienced firm is more likely to anticipate technological bottle necks, and can target its R&D at these points. Third, experienced firms have a higher patent likelihood for those specific technological advances that take a long time to solve. Previous experience was accounted for by implementing a variable that determines the number of years the firm *i* was involved in ATV-related research. The variable for ATV-related R&D experience ($E_{i,t}$) was calculated by subtracting the year of *i*'s first ATV-related patent application from the year *t* in question.

The present analysis also aims to rule out the noise from different firm-specific patenting propensities and strategies, which are not necessarily constant but vary over time with different reactions to market trends or changes in firms' financial situations or leaderships. Firms that succeed in innovation projects and that file for more patents than other firms in their field may also file more patents for ATV-related technologies. There are also a number of reasons why some firms may tend to file patents less often than other firms, despite identical levels of technological advancements; possible reasons include a new management that prefers secrecy, that tends to patent only major advancements or that is characterized by a relatively stronger cost-saving attitude. Since those aspects should be reflected in an incumbent's overall patent activity compared to other incumbents, i's relative number of yearly filed patent applications across all technological fields 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. Such 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. For these reasons, it is likely that older firms will file more patents than younger firms. Incumbents' ages were approximated by subtracting the year of a firm's first patent application from the year t in question.

In addition, it can be expected that the incumbents' ATV-related R&D strategy is also dependent on other market characteristics beyond entrants. First, governments' support in form of R&D subsidies regarded to ATV-related research is likely to yield a positive influence. The data of public R&D expenditure was taken from the OECD Statistical Service (2014a) that rests on data from the International Energy Agency. Second, the incumbents' expected profit from sales of the competitive dominant vehicle design, namely, the commercial vehicle that is propelled with an internal combustion engine is likely to yield a negative effect on the incumbents' ATV-related R&D decisions. In order to control for this potential influence, the yearly number of new vehicle registrations, was taken as a proxy for incumbents' profit expectations. The data was drawn from the OECD Statistical Service (2014b). Third, the advances in charging stations can be associated with the markets' effort to ease ATV adoption from end users, which is in turn likely to positively influence incumbents' R&D decisions. The yearly numbers of patents that correspond to IPC codes for charging stations were withdrawn from the PASTAT data base to proxy advances in charging stations. These three control variables (new vehicle registrations ($VR_{t,z}$), public R&D spending ($PubRD_{t,z}$) and advances in charging stations ($ACS_{t,z}$)) are originally provided at the country level. The dependent variable, however, varies on the firm level which is beneficial to exploit. Similar to the argument regarding the influence of entrants abroad, also international market conditions are likely to be perceived as relevant from incumbents point of view, particularly the conditions in those countries in which they are operating in. In line with Aghion et al. (2012), the extent to which a firm considers the local market condition of a country at hand as relevant is approximated with the firm's patent share filed in the corresponding country. Since patent protection is costly, it is likely that firms seek property protection only in those countries in with they currently do or plan to sell their products. The firms' global patent portfolio is therefore useful to infer where the firms' main markets they wish to exploit are located geographically. Furthermore, a firm's country-specific patents relative to other countries are also likely to reflect its sales expectation within this country and should thus also indicate the relevancy of the countries' market condition for the firm.[21] Subsequently, the firm-specific country weights ($w_{i,t,z}$) were constructed in taking the fraction of i's accumulated patent filings within a specific country z over i's total patent filings in all other countries considered (C):

$$w_{i,t,z} = \sum_{t_0}^{t} \frac{number\ of\ i's\ patent\ filings\ in\ country\ z}{total\ number\ of\ i'spatent\ filings\ in\ all\ countries\ C} \tag{5}$$

This country weights[22] were used to weigh the country level data individually for each incumbent. The three weighted control variables that were included in the econometrical approach were constructed as follows:

$$PubRD_{i,t} = \sum_z w_{i,t,z} * PubRD_{t,z}\ , \qquad VR_{i,t} = \sum_z w_{i,t,z} * VR_{t,z}\ , \qquad ACS_{i,t} = \sum_z w_{i,t,z} * ACS_{t,z} \tag{6-8}$$

Beyond firm-specific and individually weighted country-specific control variables, it seems necessary to also control for research trends that are technology specific. The global yearly growth rate in ATV-related patenting (PGR_t) is added to the model to account for the following potentially distortional aspects. It is likely that incumbents' ATV-related patents merely steadily increase over time since ATV-related technology requires continuously new advances and therewith provides many patent opportunities as is commonly associated with early research phases of newly emerging technologies. Also other likely research trends can be controlled for with the growth rate, such as global patent increases due to significant advances achieved or global patent decreases due to appearing technological bottle-necks.

The present analysis also accounts for unobservable determinants, not only by implementing firm fixed effects, but also in introducing a full set of time dummies (YD_t) as the Wald test indicated that time fixed effects are present and the year dummies' coefficients were significantly different from zero. Beyond controlling for firm and time fixed effects, the necessity to control for other observational levels could be rejected. For the country and subsidiary levels, Anova results indicated a significantly stronger within-group than between-group variation and negligible values of intra-class correlations.

[21] Aghion et al. (2012) additionally shows for five OEMs that their patent distribution among countries is well correlated to their sales share in the respective countries.
[22] Note that the difference to Aghion et al.'s (2012) country weight construction is that the present study allows the firm-specific weights to be time variant since it is likely that over a long time period the incumbents' perception of a countries' relevancy changes. For example, it can be expected that 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, there is the possibility that both incumbents and entrants are equally driven by an external factor (e.g., technological opportunities) that is not controlled for directly in the model. Entrants of environmentally friendly products are often individualistic, and are not only driven by profit aspects, but also by the desire to create social or ecological value (Schaltegger and Wagner, 2011). The motivation behind patenting may therefore differ greatly between OEMs and truly new startups. Further, diversifying lateral incumbent entrants are likely to be exactly those firms that provide OEMs with technological opportunities to be exploited. Previously, missing technological opportunities was considered to have been one of the major obstacles that hampered radical improvements on the internal combustion engine trajectory (Dosi, 1988). The current emergence of ATVs is often assumed to be mainly driven by recent significant technological advances, especially in battery technology (Barkenbus, 2009).[23] This tremendous progress in battery performance, however, rests on battery manufacturers' efforts. It is therefore suppliers that equip the incumbents with crucial technological opportunities. Diversifying incumbent suppliers that start patenting on automotive batteries, as an energy source for propelling ATVs, are captured in the data sample of entrants. It can be therefore argued that technological opportunities are indirectly represented in the model via the entry variables.

5 Preliminary Results

For testing the first set of hypotheses that were regarded to the question whether entrants' country of origins (z) play a role in influencing incumbents' ATV-related patenting, the entrants were distinguished into different country groups and tested stepwise separately in three models. Table 2 displays the results thereof when using the negative binomial hybrid model.

In all three models, the effect of entrants from incumbents' home country ($z=h$) was positive and significant, supporting hypothesis H1.1. In the estimations from Model 2, the entrants originating from relevant countries ($z=rc$), in which the corresponding incumbents are operating in, also showed a positive and significant effect on incumbents' ATV-related patenting. In contrast, the entrants originating from irrelevant countries ($z=ic$) did not lead to significant incumbent responses (Model 2 and 3). These findings are in line with hypothesis H1.2 and H1.3. Interestingly, when this separation into relevant and irrelevant country groups is absent, the variable containing all the international entrants from abroad ($z=aic$) was not significant (Model

[23] For example, patent applications on battery energy storage rose 17% per year (1999–2008), twice as much as in the decade before, and faster than overall patent growth during that time period (Dinger et al., 2010).

1). This indicates that the classification into relevant and irrelevant country groups was meaningful.

The additional separation into entrants from the most relevant countries abroad (z=mrc) and the remaining relevant countries abroad (z=rrc) does not seem to be meaningful. Although both variables yield in fact a positive and significant effect whereas the entrants from irrelevant countries (z=ic) do not yield a significant effect, one would have expected that the effect of the most relevant entrants is highest compared to other entrants, but as can be seen from Model 3: instead, the effect of entrants from remaining relevant countries (z=rrc) remains the highest among the entry variables. Therefore, only the first split up of entrants into relevant and irrelevant country groups is considered to be sensible.[24]

Table 2: Incumbents' Response to Entrants from Different Countries of Origin.

Dependent Variable: Incumbents' Number of ATV-related Patents

	NB Hybrid Model		
Parameter	(1)	(2)	(3)
Entrants' ATV Knowledge Stock (home country)	0.302***	0.677***	0.410***
Entrants' ATV Knowledge Stock (all international countries)	0.203		
Entrants' ATV Knowledge Stock (relevant international countries)		1.715**	
Entrants' ATV Knowledge Stock (3 most relevant international countries)			0.359***
Entrants' ATV Knowledge Stock (remaining relevant international countries)			0.447***
Entrants' ATV Knowledge Stock (irrelevant international countries)		0.637	-0.171
ATV Knowledge Stock	0.0299	0.0393**	0.0428**
ATV Experience	-3.175***	-3.534***	-3.489***
Patent Propensity	0.103***	0.109***	0.105***
Age	3.510***	3.430***	3.376***
Public R&D Expenditure	-0.0101	0.0363	0.0140
Vehicle Registration	0.162***	0.167***	0.161***
Advances Charging Stations	0.142***	0.167***	0.153***
ATV Patent Growth Rate	-0.0677	-0.0619	-0.619**
Constant	-0.907***	0.236	-1.129***
N	1658	1658	1658

Note: *p<0.10, ** p<0.05, *** p<0.01; Models 1, 2 and 3 only show the corrected fixed effects estimates from the hybrid model (based on Allison (2005)); the mean variable estimates thereof are omitted in the table above; the results for the Models 1,2, and 3 that rest on the full hybrid model, the NBFE and NBRE are provided in the Appendix (Table 3a).

Moreover, the effect of relevant international entrants on incumbents' patenting was in all cases (Model 2 and 3) higher than the effect of local entrants. This outcome underlines the previously asserted importance of cross-country entry for firms operating on global markets. When analyzing the response of multinational firms to entry forces, not only entrants into the firms'

[24] For this reason, all the other models are also tested with this entry group separation into home, relevant and irrelevant countries.

domestic markets, but also international entrants should therefore be considered to ensure a comprehensive analysis of the overall influence of entry.

For testing the second hypothesis that were regarded to the question whether entrants' technological relevancy plays a role in influencing the incumbents' ATV-related patenting, the entrants were distinguished into two different groups (leading and following entrants) and tested in two separate models, Model 4 and 5, respectively. Table 2 displays the results thereof when using the negative binomial hybrid model.

Table 3: Incumbents' Response to Entrants with Different Technological Expertise

Dependent Variable: Incumbents' Number of ATV-related Patents

	Leading Entrants	Following Entrants
	NB Hybrid Model	NB Hybrid Model
Parameter	(4)	(5)
Entrants' ATV Knowledge Stock (home country)	0.352***	0.553***
Entrants' ATV Knowledge Stock (relevant international countries)	0.686***	0.522***
Entrants' ATV Knowledge Stock (irrelevant international countries)	-0.128	-0.243
ATV Knowledge Stock	0.0440**	0.0394**
ATV Experience	-3.391***	-3.522***
Patent Propensity	0.104***	0.107***
Age	3.305***	3.417***
Public R&D Expenditure	0.0228	0.0241
Vehicle Registration	0.155***	0.170***
Advances Charging Stations	0.164***	0.135***
ATV Patent Growth Rate	-0.139	-0.0874
Constant	-1.514***	-1.454***
N	1658	1658

Note: *p<0.10, ** p<0.05, *** p<0.01; Models 4 and 5 only show the corrected fixed effects estimates from the hybrid model (based on Allison (2005)); the mean variable estimates thereof are omitted in the table above; the results for the Models 4 and 5 that rest on the full hybrid model, the NBFE and NBRE are provided in the Appendix (Table 4a).

Similar to the previous results from Table 2, neither the leading nor the following entrants from irrelevant countries do yield an effect on incumbents' patenting. In contrast to this, local and international entrants from relevant countries significantly increase the incumbents' ATV-related patenting and this holds for both leading and following entrants. As asserted in Hypothesis H2, the effect of leading entrants from relevant countries is stronger than the effect of following entrants, and also shows the highest magnitude among all other entry variables across these two models. This suggests that OEMs' responses on the international level is in fact determined not only by whether the entrants' originate from countries in which the OEM is operating, but also, with which technological expertise entrants enter accumulate new knowledge. This does not hold, however, for their responses on the domestic level. In this case, following entrants were found to influence incumbents stronger than leading entrants. This result is puzzling and difficult to explain. On the one hand, it may be driven by the data sample construction: in most periods, incumbents are faced with very few leading domestic entrants while following entrants represent a fast majority. On the other hand, forward patent citations may also be an inappropriate indicator for incumbents' reaction on the entrants' technological expertise. Incumbents may not evaluate the importance for them based on how relevant the technology was perceived for other technological advanced, but rather judge the entrants' technological relevancy based on their market value. Further investigation regarding this coherence needs to be undertaken to interpret these results.

The Models 6 was estimated to test the third set of Hypothesis (H3.1 and H3.2), which concerns heterogeneous incumbent responses that were expected to depend on their levels of ATV-related patent stocks and also to decrease as this this level increases. The results of Model 6 when applying the negative binomial hybrid model are presented in Table 4.

Table 4: Incumbents' Response on Entry Depending on their ATV Knowledge Stock

Dependent Variable: Incumbents' Number of ATV-related Patents

Parameter	NB Hybrid Model (6)
Entrants' ATV Knowledge Stock (home country)	0.380***
Entrants' ATV Knowledge Stock (home country)*IKS	-0.135***
Entrants' ATV Knowledge Stock (relevant international countries)	0.698***
Entrants' ATV Knowledge Stock (relevant international countries)*IKS	0.0514*
Entrants' ATV Knowledge Stock (irrelevant international countries)	-0.117
ATV Knowledge Stock	0.358***
ATV Experience	-3.656***
Patent Propensity	0.0918***
Age	3.453***
Public R&D Expenditure (weighted)	0.0687*
Vehicle Registration (weighted)	0.145***
Advances Charging Stations (weighted)	0.225***
ATV Patent Growth Rate	-1.349***
Constant	-0.723***
N	1658

Note: *p<0.10, ** p<0.05, *** p<0.01; Model 6 only shows the corrected fixed effects estimates from the hybrid model (based on Allison (2005)); the mean variable estimates thereof are omitted in the table above; the results for the Model 6 that rest on the full hybrid model, the NBFE and NBRE are provided in the Appendix (Table 5a).

The interaction terms between incumbents' ATV-related knowledge stocks with both, the entry variables from home and from relevant countries are positive significant[25] and thus indicate that incumbents in fact do react differently on entry in dependence on their knowledge stock achieved. This outcome supports Hypothesis H3.1. In line with both previous result tables, the variable of entrants from irrelevant countries abroad is insignificant but was although implemented in all models to verify consistency.

To investigate incumbents' heterogeneous responses in further detail, based on Model 6, the marginal effects of both entry variables were calculated for the different levels of incumbents' ATV-related knowledge stocks, while holding the other explanatory variables constant at their mean values, see Table 5.

Table 5: Entrants' Marginal Effects for Different Levels of Incumbents' ATV Knowledge

Level of Incumbents' ATV Knowledge Stock	Entrants' ATV Knowledge Stock (home country)	Entrants' ATV Knowledge Stock (relevant international countries)
	based on: NB Hybrid Model (6)	based on: NB Hybrid Model (6)
-4,9	1.040***	0.446*
-4,1	0.932***	0.487**
-3,3	0.825***	0.528**
-2,5	0.717***	0.569***
-1,7	0.609***	0.610***
-0,9	0.501***	0.651***
-0,1	0.394***	0.692***
0,7	0.286***	0.734***
1,5	0.178**	0.775***
2,3	0.0704	0.816***
3,1	-0.0373	0.857***
3,9	-0.145	0.898***
4,7	-0.253**	0.939***
5,5	-0.361***	0.980***
6,3	-0.468***	1.021***
7,1	-0.576***	1.062***
7,9	-0.684***	1.103***
8,7	-0.792***	1.144***
9,5	-0.899***	1.185***
10,3	-1.007***	1.227***
11,1	-1.115***	1.268***
11,9	-1.223***	1.309***
12,7	-1.330***	1.350***
13,5	-1.438***	1.391***
14,3	-1.546***	1.432***
15,1	-1.654***	1.473***
15,9	-1.761***	1.514***
16,7	-1.869***	1.555***
N	1658	1658

Note: * p<0.10, ** p<0.05, *** p<0.01; the results are based on the hybrid model estimates of Model 6 from Table 4. Entrants' marginal effects for all three variants of Model 6 are presented in the Appendix (Table 6a).

[25] Note that the entry and interaction variables in Models 6 were summed up to arrive at the pure effect of entry.

The first column indicates the bandwidth of the incumbents' standardized patent stock variable (ranging from -4.9 to 16.7). The number of firm observations within the data sample for each level of this variable is provided in the Appendix, in Figure 2a. A rather small step length of 0.8 was chosen to compare the marginal effects of entry for the different knowledge levels; this choice was made to provide precise results, especially for the first levels, since most observations cluster at very low productivity levels. The marginal effects of local and international entrants for the respective levels of incumbents' ATV-related patent stocks are shown in the second and third column, respectively. The results indicate that local and international entrants yield very different heterogeneous response patterns among incumbents.

Firstly, as to **entrants from home countries**, the incumbents' reaction to marginal variation in the entrants' patent stocks decreased, moving from positive to negative responses, as incumbents' firm-specific ATV-related knowledge stock increased. Those incumbents with very low patent stocks significantly increased their ATV-related patenting, while incumbents with very high patent stocks significantly reduced their ATV-related patenting in response to marginal increases in the entrants' knowledge stocks. The incumbents with more moderate knowledge levels did not react significantly to entrants. Subsequently, Hypothesis H3.2 finds support regarding entrants' from incumbents' home country. The overall positive entry effect from local entrants (shown in Table 2, 3and 4) can be explained by the fact that a vast majority (about 99%) of the observed incumbents in the present date sample have very low levels of patent stocks and are thus those firms that reacted positively to entrants (seen in the nine rows more towards the top of column two). The estimated negative marginal effects (seen in the 16 rows more towards the bottom of column two), however, only hold for very few observations (about 0.8%) in the present data sample.[26] As a result, Hypothesis H1.1 (suggesting a positive incumbent reaction) holds only for the overall effect, as well as for those incumbents who have relatively low firm-specific ATV-related patent stocks. Considering the underlying technology- and firm-specific characteristics, the three different response patterns of incumbents can be explained as follows:

First, incumbents that are characterized by very high ATV-related knowledge stocks were estimated to respond to entrants with a decrease in ATV-related patenting. Given that these incumbents filed already a high number of ATV-related patents, they are unlikely to perceive competitive entrants as challenging. In contrast, this negative incumbent response is likely to be driven by entrants from complementary fields. OEMs ordinarily begin ATV-related research with prototypes that are self-constructed; this entails producing small quantities of new

[26] The number of firm observations along the bandwidth of the productivity variable is provided in the Appendix, Figure 2a.

intermediate components, testing equipment, and laboratory devices, which are mainly used to optimize the electrical powertrain. This R&D effort may, if successful, result in new patent applications. Before incumbents can start to source new components, production, and R&D equipment from suppliers, they need to reach a certain stage of development, characterized by a sufficient knowledge threshold and long-term management targets for future ATV production. As this group of incumbents have filed already a high number of ATV-related patents, they are likely to have reached this stage. When many technologically superior suppliers enter the ATV research regime, these incumbents' may begin to source intermediate components, patents or licenses from those suppliers, thereby partially replacing their previous in-house R&D. This scenario would explain the decrease in such incumbents' patenting. This negative effect only appears in the case of local entrants, supporting the preceding R&D outsourcing explanations, since OEMs ordinarily tend to source from suppliers that are located in their home country. Furthermore, as can be seen from Table 2, 3 and 4, the variable of ATV-related research experience (measured in years) is in all models significant but negatively associated with incumbents patenting. This further supports the interpretation that incumbents' tend to begin to outsource certain R&D activities the longer they are involved in ATV-related R&D. Moreover, Wesseling et al. (2014) found that although incumbents do increase their patents related to electric vehicles, the incumbents' share of the global patent stock related to electric vehicles has been decreasing over time. The authors concluded that incumbents cannot keep pace with the progress that has been achieved in electric vehicle technologies. R&D outsourcing may be an alternative explanation for the decrease in incumbents' global patent share in electric vehicle technologies.

Second, incumbents with relatively low ATV-related patent stocks were estimated to react positively to entrants. This outcome may be driven by complementary entrants that provide crucial capabilities from lateral industries, thereby supporting innovation advances in these incumbents. Given that these incumbents only filed a small number of ATV-related patents, they are also likely to perceive competitive entrants that are technologically advanced as challenging, and may therefore increase their innovation effort to keep up with the ATV technology frontier. Additionally, such entrants can also indirectly stimulate these incumbents: Over time, these competitive entrants pioneer the market: they set up the initial demand, advance the technology and increase the scope of niche markets. Once these entrants manage to initialize the necessary condition for incumbents to perceive ATVs as profitable, incumbents may realize the potential and accelerate their ATV-related R&D. Further, incumbents with very few ATV-related patents generally have more potential and a greater scope to increase their ATV-related patenting, as compared to other incumbents who already have many ATV-related patents.

Third, incumbents characterized by moderate ATV-related patent productivity did not react significantly on entrants in the present study. This indicates that they kept to their existing R&D strategies, independently from entering firms. One explanation for this lack of a change in patenting could be that these incumbents' knowledge-stock on ATV-related technology might be too advanced to either benefit from any knowledge spillovers from complementary entrants or to feel challenged by competitive entrants. On the other hand, these incumbents' knowledge-stock might still be too small to outsource their R&D and source goods from entering suppliers.

Secondly, as to **entrants from relevant international countries abroad**, the incumbents' reaction to marginal variation in the entrants' patent stocks increased with increasing levels of incumbents' firm-specific ATV-related knowledge. These findings are controversial to Hypothesis H3.2. This particular incumbent response pattern, although, could be explained with two likely scenarios:

On the one hand, their response might be of competitive nature. Most entrants in the present data sample are lateral entrants from complementary fields. The considered international entrants originate from countries in which the incumbent *i* is operating, hence, the local OEMs in those countries are competitors for incumbent *i*. Taking this point further in combination with the argument that OEMs tend to cooperate merely with suppliers from their domestic markets, it becomes likely that the effect is rather an indirect effect of entry imposed by foreign entrants' local market activities; namely, the support they provide to their local OEMs to which the incumbent *i* reacts in a competitive way. For example, in case the German OEM Volkswagen reacts in a competitive way with increased patenting to Chinese OEMs (e.g. Changan Automobile, Dongfeng Motor) who were able to improve their ATV-related competitiveness by receiving valuable knowledge spillovers from their own domestic suppliers (that are new to the ATV-research regime (e.g. BYD) and thus included in the present data sample).

On the other hand, given that ATVs draw on many technologies that are firstly, new to OEMs who just recently began to acquire knowledge in this field (e.g., battery technologies and electric motors) and secondly, already mastered by other firms for different applications, the following scenario becomes likely as well. If new specialized suppliers are superior, known globally, rare, and from the incumbents' point of view perceived as an obligatory knowledge source, incumbents may exceptionally take the effort and seek complementary support also from international suppliers abroad. If successful, these knowledge spillovers can facilitate incumbent

ATV-related R&D progress and may therefore increase their patenting. For example, in case the German OEM Volkswagen exceptionally seeks to receive research enhancing knowledge spillovers from Chinese battery suppliers (new to the ATV-research regime) because the Chinese battery industry is well-known globally for their high quality batteries and also because of a lack in such knowledge sources in Volkswagen's home country Germany.

Although these results support the hypotheses in many aspects, some qualifications are appropriate. Even though the present findings suggest that entrants stimulate the majority of incumbents to increase ATV-related patenting, the possibility exists that OEMs only patent to prevent rivals from achieving further technological advances, as opposed to monetizing these newly obtained inventions for industrial applications. According to Gilbert and Newbery (1982), firms with monopoly power have incentives to pursue pre-emptive R&D activities, strategically patenting substitute technologies to deter entry. The patents for such inventions, which are not commercialized in the form of product launches or licensing, are often referred to as sleeping patents. The present study is therefore limited in its ability to provide any insight into the consequences of positive incumbent patent responses, i.e., whether entrants stimulate incumbents to also increase their innovative market output in terms of the number and quality of the ATVs they offer to end users. The present study therefore only represents a first step in verifying Hockerts and Wüstenhagen's (2010) proposition that incumbents react to environmentally friendly entrants with more environmentally friendly product portfolio expansions.

Moreover, whether the results presented in this chapter also hold for alternative indicators of incumbents' responses and entrants' determinants requires further research. The variables of interest could be represented more accurately in future studies, allowing for richer databases. One direction for future research could be choosing other proxies for incumbents' responses: The number of patents does not represent overall ATV-related efforts, but is only a proxy for in-house innovation effort. Other investments, such as patent purchases, the acquisition of licenses, ATV-related marketing investments and ATV-related knowledge sourcing by strategic mergers and acquisitions should also be considered to capture incumbents' overall willingness to promote ATVs. Another fruitful direction for future research could be to obtain other variables that prescribe the entrants' characteristics, such as their market value or R&D experience in other fields.

The results of the present study indicate that entrants perform a research-catalysing function, motivating the majority of incumbents to increase their ATV-related patenting. The incumbents' respective patented technological advances are expected to accelerate the pace of the automotive industry’s technological change towards environmentally friendly vehicles. However, the present study indicates that incumbents’ reactions may vary according the type of entrant, and are specific to the automotive industry. More detailed data on entrants’ business types would allow researchers to shed more light on the influence of entrants, and to better interpret incumbents’ responses. Further research is also needed to determine whether the pattern of incumbents’ responses observed in the present paper also holds for other industries.

6 Concluding Remarks

This study examined the effect of innovative entrants on automotive incumbents’ innovation activity related to alternative technology vehicles (ATVs). This work contributes to a deeper understanding of the market dynamics in the transition towards a more environmentally friendly transport system and extends current literature by investigating incumbents’ technology-specific responses to cross-country entrants while considering entrants’ qualitative characteristics. The present paper assumes that incumbents’ motivation in promoting ATVs is crucial for the pace of this transition, since incumbents are likely to be more successful than entrants in mass-market penetration. Incumbents’ ATV-related technological advances, stimulated by entry, are expected to accelerate technological change and thereby provide opportunities to escape from the locked-in combustion engine trajectory.

The results indicate that entrants’ country of origin played an important role in their effect on incumbents. Entrants from rather relevant countries abroad (in which incumbents are operating in) had a stronger influence on incumbents’ patenting than domestic entrants; whereas entrants from any other countries abroad (in which incumbents are not operating in) were found to have no effect on incumbents’ patenting. Future studies investigating global markets and multinational firms’ responses to entrants therefore need to take into account the different effects of international and local entrants to represent the overall effect of entry and to minimize distortion of the results.

The incumbents’ responses on entry were further found to be of heterogeneous manner and dependent on their ATV-related knowledge stocks. Regarding the effect of local entrants, incumbents’ responses were decreasing as their ATV-related knowledge increased, moving from positively reacting towards negatively reacting incumbents, representing about 99% and 1% of the incumbent firm sample, respectively. This study assumes that entrants stimulate patenting in incumbents with 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 initialization. Incumbents with high ATV-related patent stocks are assumed to react negatively on entry, since their knowledge is likely to be already too advanced to be challenged by competitive entrants. Instead, such incumbents are likely to start replacing their inhouse R&D by sourcing new components or licenses from entering firms that provide complementary capabilities, leading to a drop in these incumbents' ATV-related patenting. Considering that OEMs tend to cooperate merely with domestic suppliers, this interpretation of R&D outsourcing is further supported in that this negative effect holds only for domestic entrants. Entrants from relevant countries abroad yield to reverse response patterns: incumbents reacted stronger, the higher their ATV-related knowledge stocks; which is assumed to be rather a sign of competitive responses to international market actors.

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 environmentally friendly technological advances. This effect of entrants might be key to encouraging a transition as a whole. However, the present study was only able to conclude that entrants have an influence on incumbents' patenting; given the possibility of strategic patenting, these incumbents do not necessarily immediately commercialize their achieved technological advances on the market-place. This possibility limits conclusions that can be drawn regarding the impact of increased incumbent patenting for technological change on the market level. Further research is required to determine whether entrants' not only increase incumbents' patenting, but also influence incumbents' innovative output on the market. The explicit entry forces that cause these incumbent reactions are still unknown; possibilities include direct influences via competitive pressure and complementary knowledge, or indirect influences via market initialization as entrants stimulate initial demand and master new technologies in niche markets until ATVs become profitable enough to interest incumbents. Investigating what entrant characteristics determine incumbent reactions would be a fruitful area for future study.

As entrants are discouraged by high entry barriers and survival challenges, their potential key role is likely to be limited, suggesting that policy interventions may be supportive in reaping the full benefit of entrants' transition-catalyzing function. The outcome of the present study is therefore expected to be helpful in deriving policy implications for governments that intend to achieve environmental goals and target to increase the research level 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 supporting entrants are likely to not only be effective in encouraging entry but also in enhancing innovative technological advances of other actors within the industry. However, this study is limited in its ability to draw further conclusions on the underlying efficiency of those policies. An interesting starting point for further research would be exploring the efficiency of different policies in supporting entrants versus incumbents to increase their environmentally friendly R&D.

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8 Appendix

Table 1a: International Patent Classes for Alternative Technology Vehicles

Description	International Patent Classification (IPC) & Cooperative Patent Classification (CPC)
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; including control of fuel cells	B60W 10/28
#CPC classes to be insert here#	

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

Table 2a: Overview of Considered Incumbents in the Firm Sample

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

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

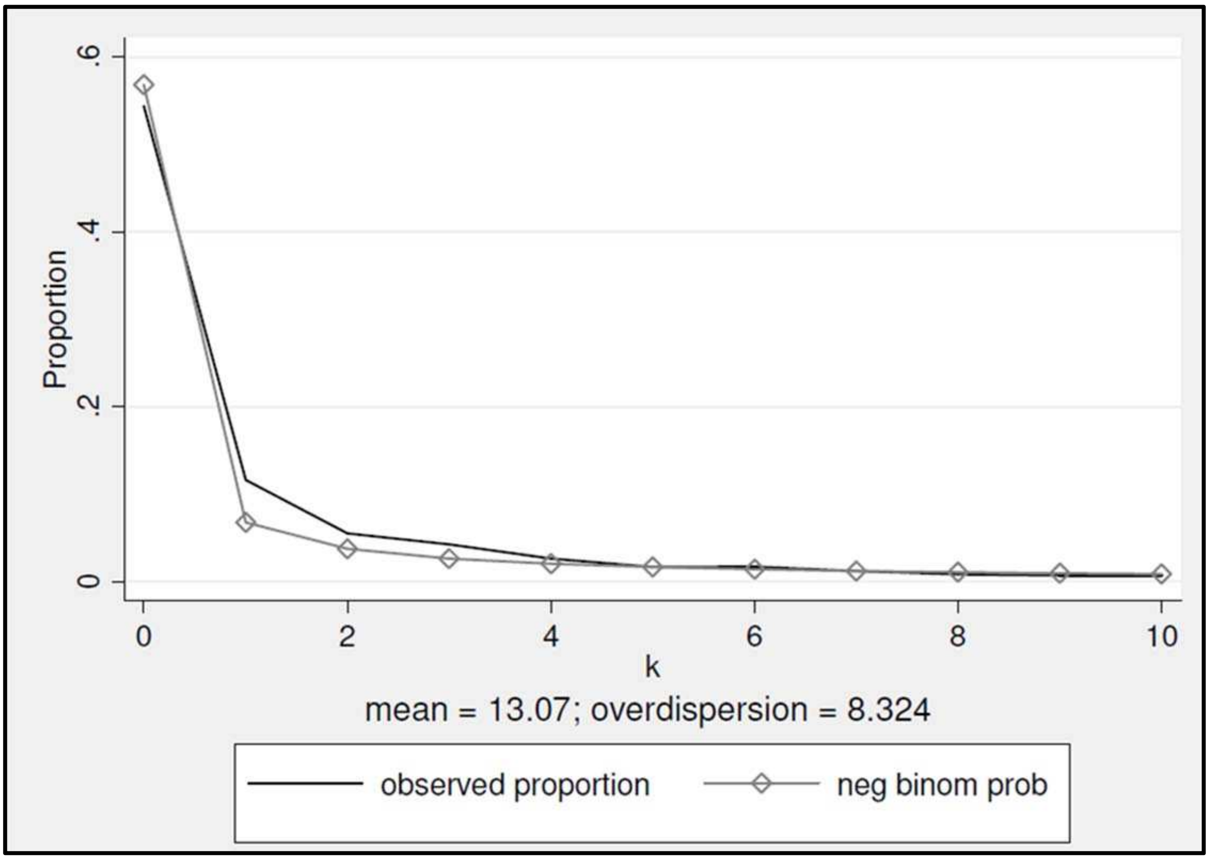

Figure 2a: Distribution of Incumbent Firm Frequency along the Bandwidth of the ATV-Related Patent Stock Variable

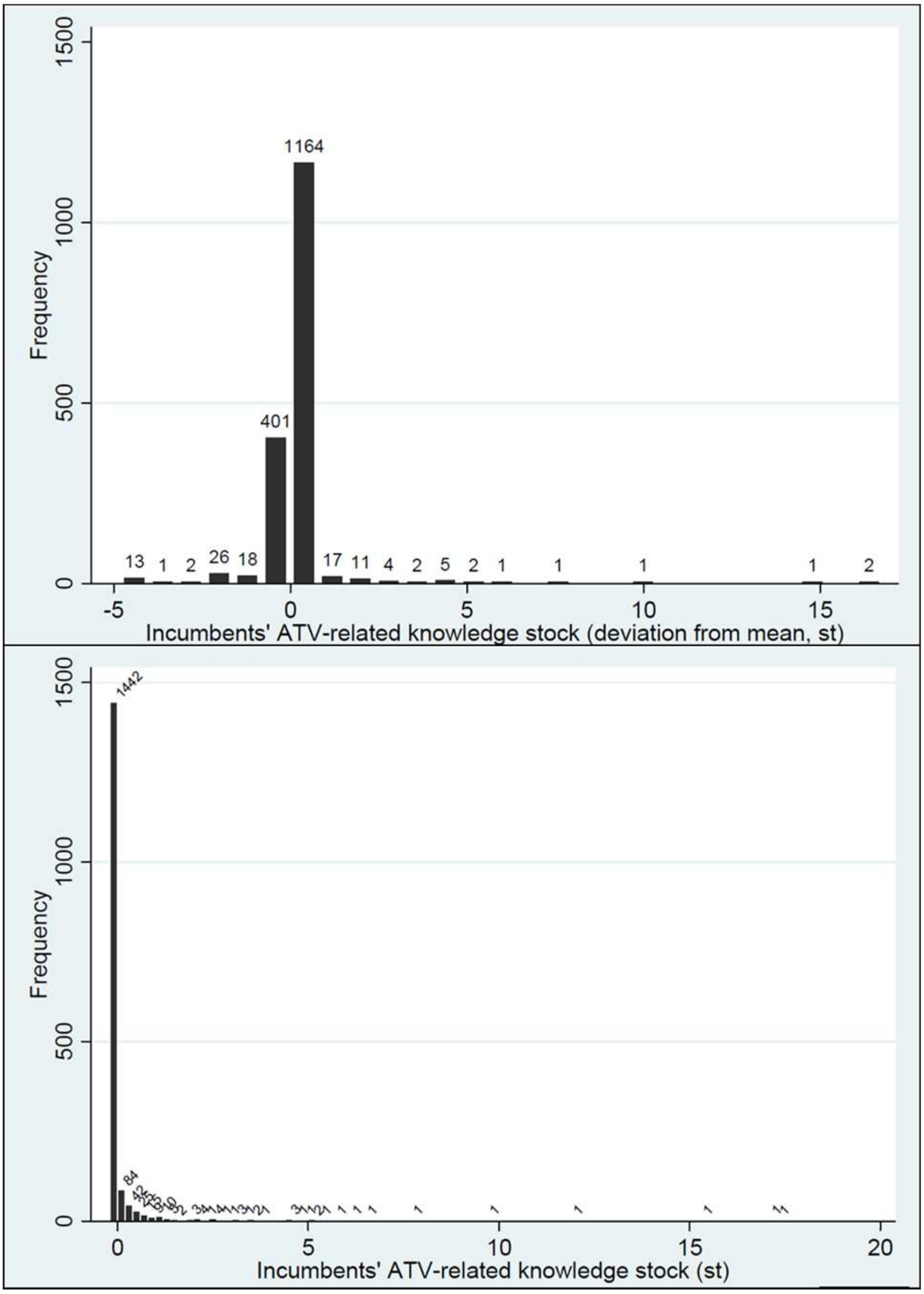

Table 3a: Incumbents' Response to Entrants from Different Countries of Origin

Dependent Variable: Incumbents' Number of ATV-related Patents

Parameter	NB Hybrid Model (1)	NBFE Model (1)	NBRE Model (1)	NB Hybrid Model (2)	NBFE Model (2)	NBRE Model (2)	NB Hybrid Model (3)	NB FE Model (3)	NB RE Model (3)
EKS (home country)	0.302***	0.131**	0.141**	0.677***	0.169***	0.174***	0.410***	0.175***	0.180***
EKS (all international countries)	0.203	0.315***	0.294***						
EKS (relevant international countries)				1.715**	0.343***	0.349***			
EKS (3 most relevant international countries)							0.359***	0.179***	0.180***
EKS (remaining relevant international countries)							0.447***	0.233***	0.237***
EKS (irrelevant international countries)				0.637	-0.131	-0.117	-0.171	-0.126	-0.111
ATV Knowledge Stock	0.0299	0.0157	0.0189	0.0393**	0.0166	0.0201	0.0428**	0.0191	0.0225
ATV Experience	-3.175***	-0.995***	-0.740***	-3.534***	-1.104***	-0.841***	-3.489***	-1.115***	-0.851***
Patent Propensity	0.103***	0.280***	0.279***	0.109***	0.265***	0.265***	0.105***	0.265***	0.265***
Age	3.510***	1.323***	1.074***	3.430***	1.283***	1.002***	3.376***	1.296***	1.013***
Public R&D Expenditure	-0.0101	-0.0771*	-0.0736*	0.0363	-0.0832*	-0.0752*	0.0140	-0.0908**	-0.0829*
Vehicle Registration	0.162***	0.0794*	0.0743*	0.167***	0.0881**	0.0864**	0.161***	0.0918**	0.0903**
Advances Charging Stations	0.142***	0.154***	0.145***	0.167***	0.164***	0.152***	0.153***	0.155***	0.143***
ATV Patent Growth Rate	-0.0677	-0.0435	-0.0448	-0.0619	-0.0457	-0.0458	-0.619**	-0.0425	-0.0429
M_ATV Knowledge Stock	-0.00109			0.0884			0.0549		
M_ATV Experience	0.345**			0.272			0.270		
M_Patent Propensity	0.139			0.115			0.133		
M_Age	0.181			0.0699			0.0872		
M_Public R&D Expenditure	-0.0513			0.00531			-0.0500		
M_Vehicle Registration	-0.472***			-0.350***			-0.325***		
M_Advances Charging Stations	0.415***			0.244**			0.240**		
Year Dummy 1981	0.105			0.139			0.260		
Year Dummy 1982	0.280			0.323			-0.410		
Year Dummy 1983	0.498*			0.507*			-0.215		
Year Dummy 1984	0.0343			0.0619			-0.515		
Year Dummy 1985	0.241			0.227			-2.185*		
Year Dummy 1986	0.0739			0.0394			0.416		
Year Dummy 1987	-0.169			-0.221			-0.749		
Year Dummy 1988	0.0400			0.00814			-0.0914		
Year Dummy 1989	-0.0301			-0.0845			-0.570		
Year Dummy 1990	0.0723			0.00766			0.420		
Year Dummy 1991	-0.00559			-0.0867			0.586		
Year Dummy 1992	0.162			0.0232			0.0475		
Year Dummy 1993	0.400			0.143			0.849**		
Year Dummy 1994	0.264			-0.0992			0.891**		
Year Dummy 1995	0.213			-0.224			0.385		
Year Dummy 1996	0.287			-0.240			0.722*		
Year Dummy 1997	0.193			-0.490			0.533		
Year Dummy 1998	0.330			-0.533			1.209**		
Year Dummy 1999	0.360			-0.650			1.437***		
Year Dummy 2000	0.0749			-1.212			0.688**		
Year Dummy 2001	0.246			-1.398			0.492		
Year Dummy 2002	0.576**			-1.547			0.0690		
Year Dummy 2003	0.277			-2.172			0.744***		
Year Dummy 2004	0.0979			-2.682			0.163		
Year Dummy 2005	0.282			-2.981			-0.233		
Year Dummy 2006	0.186			-3.514			0.674***		
Year Dummy 2007	0.196			-4.159			0.372**		
Year Dummy 2008				-4.972					
Constant	-0.907***	-0.593***	-0.621***	0.236	-0.658***	-0.672***	-1.129***	-0.659***	-0.673***
N	1658	1549	1658	1658	1549	1658	1658	1549	1658

Table 4a: Incumbents' Response to Entrants with Different Technological Expertise

Dependent Variable: Incumbents' Number of ATV-related Patents

	Leading Entrants			Following Entrants		
	NB Hybrid Model	NBFE Model	NBRE Model	NB Hybrid Model	NBFE Model	NBRE Model
Parameter	(4)	(4)	(4)	(5)	(5)	(5)
EKS (home country)	0.352***	0.123**	0.124**	0.553***	0.343***	0.353***
EKS (relevant international countries)	0.686***	0.353***	0.357***	0.522***	0.293***	0.305***
EKS (irrelevant international countries)	-0.128	-0.108	-0.0883	-0.243	-0.169*	-0.169**
ATV Knowledge Stock	0.0440**	0.0215	0.0248	0.0394**	0.0190	0.0236
ATV Experience	-3.391***	-1.107***	-0.837***	-3.522***	-1.157***	-0.893***
Patent Propensity	0.104***	0.264***	0.263***	0.107***	0.280***	0.280***
Age	3.305***	1.325***	1.040***	3.417***	1.264***	0.975***
Public R&D Expenditure	0.0228	-0.0735	-0.0647	0.0241	-0.0794*	-0.0745*
Vehicle Registration	0.155***	0.0942**	0.0916**	0.170***	0.0867**	0.0855**
Advances Charging Stations	0.164***	0.166***	0.156***	0.135***	0.124***	0.108***
ATV Patent Growth Rate	-0.139	-0.0443	-0.0449	-0.0874	-0.0315	-0.0309
M_ATV Knowledge Stock	0.0271			0.116		
M_ATV Experience	0.274			0.245		
M_Patent Propensity	0.159			0.0930		
M_Age	0.137			0.0544		
M_Public R&D Expenditure	-0.0430			-0.00642		
M_Vehicle Registration	-0.297**			-0.401***		
M_Advances Charging Stations	0.243**			0.267***		
Year Dummy 1981	0.193			0.149		
Year Dummy 1982	0.317			0.298		
Year Dummy 1983	0.592**			0.498*		
Year Dummy 1984	0.210			0.118		
Year Dummy 1985	0.607			0.388		
Year Dummy 1986	0.347			0.222		
Year Dummy 1987	0.284			0.0126		
Year Dummy 1988	0.477			0.300		
Year Dummy 1989	0.585			0.274		
Year Dummy 1990	0.755*			0.464		
Year Dummy 1991	0.639			0.401		
Year Dummy 1992	0.906**			0.606		
Year Dummy 1993	1.103***			0.865**		
Year Dummy 1994	0.911**			0.721**		
Year Dummy 1995	0.983**			0.652*		
Year Dummy 1996	1.041***			0.769**		
Year Dummy 1997	1.054**			0.679*		
Year Dummy 1998	1.175***			0.860**		
Year Dummy 1999	1.083***			0.915***		
Year Dummy 2000	0.786**			0.638**		
Year Dummy 2001	0.896***			0.589**		
Year Dummy 2002	1.124***			0.951***		
Year Dummy 2003	0.769***			0.660**		
Year Dummy 2004	0.485**			0.590**		
Year Dummy 2005	0.639***			0.715***		
Year Dummy 2006	0.477**			0.538**		
Year Dummy 2007	0.291*			0.281*		
Constant	-1.514***	-0.631***	-0.644***	-1.454***	-0.707***	-0.725***
N	1658	1549	1658	1658	1549	1658

Table 5a: Incumbents' Response on Entry Depending on their ATV Knowledge Stock

Dependent Variable: Incumbents' Number of ATV-related Patents

Parameter	NB Hybrid Model (6)	NBFE Model (6)	NBRE Model (6)
Entrants' ATV Knowledge Stock (home country)	0.380***	0.162***	0.153***
Entrants' ATV Knowledge Stock (home country)*IKS	-0.135***	-0.133***	-0.141***
Entrants' ATV Knowledge Stock (relevant international countries)	0.698***	0.240***	0.253***
Entrants' ATV Knowledge Stock (relevant international countries)*IKS	0.0514*	0.0247	0.0362
Entrants' ATV Knowledge Stock (irrelevant international countries)	-0.117	-0.212**	-0.185**
ATV Knowledge Stock	0.358***	0.440***	0.451***
ATV Experience	-3.656***	-1.083***	-0.781***
Patent Propensity	0.0918***	0.252***	0.252***
Age	3.453***	1.228***	0.907***
Public R&D Expenditure	0.0687*	-0.0520	-0.0438
Vehicle Registration	0.145***	0.0639	0.0588
Advances Charging Stations	0.225***	0.241***	0.230***
ATV Patent Growth Rate	-1.349***	-0.0524	-0.0527
M_ATV Knowledge Stock	0.371***		
M_ATV Experience (years)	0.415**		
M_Patent Propensity	0.317**		
M_Age	-0.0886		
M_Public R&D Expenditure (weighted)	-0.0364		
M_Vehicle Registration (weighted)	-0.357***		
M_Advances Charging Stations (weighted)	0.190**		
Year Dummy 1981	0.567		
Year Dummy 1982	-1.310***		
Year Dummy 1983	-1.215***		
Year Dummy 1984	-1.261***		
Year Dummy 1985	-5.244***		
Year Dummy 1986	0.462		
Year Dummy 1987	-2.161***		
Year Dummy 1988	-0.299		
Year Dummy 1989	-1.796***		
Year Dummy 1990	0.572		
Year Dummy 1991	0.815**		
Year Dummy 1992	-0.362		
Year Dummy 1993	1.243***		
Year Dummy 1994	0.969***		
Year Dummy 1995	-0.0428		
Year Dummy 1996	0.874**		
Year Dummy 1997	0.300		
Year Dummy 1998	2.135***		
Year Dummy 1999	2.321***		
Year Dummy 2000	0.329		
Year Dummy 2001	0.232		
Year Dummy 2002	-0.878**		
Year Dummy 2003	0.320		
Year Dummy 2004	-0.550**		
Year Dummy 2005	-1.149***		
Year Dummy 2006	0.672***		
Year Dummy 2007	0.234		
Constant	-0.723***	-0.537***	-0.547***
N	1658	1549	1658

Table 6a: Entrants' Marginal Effects for Different Levels of Incumbents' ATV Knowledge Stock

	Entrants' ATV Knowledge Stock (home country)			
IKS Level	NB Hybrid Model (6)	NBFE Model (6)	NBRE Model (6)	IKS Level
-4,9	1.040***	0.189***	0.181***	-0,2
-4,1	0.932***	0.0693	0.0546	0,7
-3,3	0.825***	-0.0502	-0.0722	1,6
-2,5	0.717***	-0.170***	-0.199***	2,5
-1,7	0.609***	-0.289***	-0.326***	3,4
-0,9	0.501***	-0.409***	-0.453***	4,3
-0,1	0.394***	-0.528***	-0.579***	5,2
0,7	0.286***	-0.648***	-0.706***	6,1
1,5	0.178**	-0.767***	-0.833***	7
2,3	0.0704	-0.887***	-0.960***	7,9
3,1	-0.0373	-1.007***	-1.087***	8,8
3,9	-0.145	-1.126***	-1.213***	9,7
4,7	-0.253**	-1.246***	-1.340***	10,6
5,5	-0.361***	-1.365***	-1.467***	11,5
6,3	-0.468***	-1.485***	-1.594***	12,4
7,1	-0.576***	-1.604***	-1.721***	13,3
7,9	-0.684***	-1.724***	-1.847***	14,2
8,7	-0.792***	-1.843***	-1.974***	15,1
9,5	-0.899***	-1.963***	-2.101***	16
10,3	-1.007***	-2.082***	-2.228***	16,9
11,1	-1.115***	-2.202***	-2.355***	17,8
11,9	-1.223***			
12,7	-1.330***			
13,5	-1.438***			
14,3	-1.546***			
15,1	-1.654***			
15,9	-1.761***			
16,7	-1.869***			
N	1658	1549	1658	

	Entrants' ATV Knowledge Stock (relevant international countries)			
IKS Level	NB Hybrid Model (6)	NBFE Model (6)	NBRE Model (6)	IKS Level
-4,9	0.446*	0.235***	0.246***	-0,2
-4,1	0.487**	0.257***	0.278***	0,7
-3,3	0.528**	0.280***	0.311***	1,6
-2,5	0.569***	0.302***	0.343***	2,5
-1,7	0.610***	0.324***	0.376***	3,4
-0,9	0.651***	0.346***	0.408***	4,3
-0,1	0.692***	0.368***	0.441***	5,2
0,7	0.734***	0.391***	0.474***	6,1
1,5	0.775***	0.413***	0.506***	7
2,3	0.816***	0.435**	0.539***	7,9
3,1	0.857***	0.457**	0.571***	8,8
3,9	0.898***	0.480**	0.604***	9,7
4,7	0.939***	0.502**	0.636***	10,6
5,5	0.980***	0.524**	0.669**	11,5
6,3	1.021***	0.546*	0.702**	12,4
7,1	1.062***	0.569*	0.734**	13,3
7,9	1.103***	0.591*	0.767**	14,2
8,7	1.144***	0.613*	0.799**	15,1
9,5	1.185***	0.635*	0.832**	16
10,3	1.227***	0.657*	0.864**	16,9
11,1	1.268***	0.680*	0.897**	17,8
11,9	1.309***			
12,7	1.350***			
13,5	1.391***			
14,3	1.432***			
15,1	1.473***			
15,9	1.514***			
16,7	1.555***			
N	1658	1549	1658	