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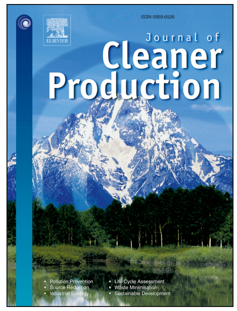

The legend about sailing ship effects – is it true or false? The example of cleaner propulsion technologies diffusion in the automotive industry

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The legend about sailing ship effects – is it true or false? The example of cleaner propulsion technologies diffusion in the automotive industry

Abstract: The global automotive industry is faced with major technological change in the field of propulsion systems. Due to low carbon emission regulations and a rising societal demand for sustainability, original equipment manufacturers (OEMs) are forced to innovate either in the conventional technology or in the technological alternatives such as electric drives or fuel cells. However, OEMs are only marginally switching to electromobility so far, but rather incrementally innovating traditional technologies. This behaviour can be described as sailing ship effect which contains the reaction of an old technology to a new technology by fostering innovation in the old technology. Firstly, the present study contributes to the discussion in literature on the sailing ship effect by combining its underlying ideas and consequences with the rationales of path dependence to demonstrate that such a behaviour may be individually economical rational. Based on these considerations, we respond to the call for further empirical investigation of the sailing ship effect. We show patent-based evidence that there has been a temporary sailing ship effect in the automotive industry concerning traditional and emerging propulsion systems and discuss implications for corporate technology strategy and policy.

Keywords: electromobility, patent analysis, path dependence, sailing ship effect; technological change; technology strategy

1 Introduction

The global automotive industry is faced with a major technology transition in the field of propulsion systems (Ren et al., 2015; Sierzchula et al., 2012; Amjad et al. 2010). Since the early 1990s, there are ongoing innovative activities regarding zero emission vehicles, although none of them has been able to achieve a significant market share so far (Dijk and Yarime, 2010). Technological change in this case – from conventional combustion engines to electric drives – is not only due to intra-industry competition but driven by societal and regulatory demand from outside the industry. The worldwide phenomenon of climate change and customers' increasing call for sustainability are two major influence factors that foster the development of electric propulsion systems (Penna and Geels, 2015; Avadikyan and Llerena, 2010).

Against this background, the present paper explores a specific strategy called sailing ship effect: In view of an emerging technology, incumbent firms increase innovative activities to enhance established technologies instead of switching to the new technology. The name refers to the innovation efforts to further improve sailing ships as a reaction to the threat of steam ships in the 19th century (Gilfillan, 1935, Rosenberg, 1972a, 1972b). Taking the current literature into account, a twofold picture can be drawn regarding the sailing ship effect. On the one hand, some studies refer to the sailing ship effect as a description of the reaction to technological threat by innovation in the old technology (see e.g. Adner and Snow, 2010; Utterback, 1996; Ward, 1967). On the other hand, some authors remark serious doubts on the existence of this effect (e.g. Howells, 2002, 2005). Due to this discussion, we want to explore a new way of thinking and combine the findings of the sailing ship effect in literature with the idea of path dependence (Arthur, 1989; Arthur, 2009; David, 1985). By this, we are able to contribute to the theory-based discussion in literature and explain that core elements of path dependence might be pivotal to the rationales of sailing ship strategy. In addition, there is a growing demand for extended empirical validation of the sailing ship effect.

Using automotive patent data as an indicator of technological development in this field, we aim at identifying empirical evidence for a sailing ship effect in the automotive industry with regard to the electrification of the drive train (Rizzi et al., 2014). Moreover, ecological innovations and particularly energy technologies such as electric propulsion systems are currently subject to and due to their limited competitiveness dependent on high governmental funding (Sierzchula et al., 2012, Cousins et al., 2007). Since customers, industrial managers and policy makers alike have an interest in optimising the transition from conventional to alternative propulsion systems, we derive policy implications that might help to improve the allocation of governmental financial support in order to maximise the reduction of CO_2 emissions in the short, medium and long term.

The paper is organized as follows: First, we refer to the well-known mechanisms of path dependence and apply these findings to the global automotive industry. By exploring the path dependent character of this industry, we create the explanatory basis for analysing the sailing ship effect. Afterwards, we demonstrate our research design, before we show that our patent data underlines the arguments of the sailing ship effect. After discussing the main findings, a conclusion summarizes the contributions and policy implications of our study.

2 Theory

2.1 Path dependence in the automotive industry

The concept of path dependence is one of the well-established theoretical foundations in the research field of technological continuity. First developed by Brian W. Arthur and Paul A. David, the literature concerning factors accruing for increasing returns and the outcomes of such processes are widely explored (see e.g. Arthur, 1989, 1994; Carayannis et al., 2012; Schreyögg and Sydow, 2011). The key element of path dependent processes is the construct of increasing returns or positive feedbacks which postulate that costs diminish due to each element of the focal technology which is produced and sold (Figure 1). This process is contradictory to classic economic thoughts of decreasing returns and finally leads from a situation of technological openness (contingency or non-ergodicity) to a lock-in situation where the focal old technology is economically superior to new technologies because of the path it has run through.

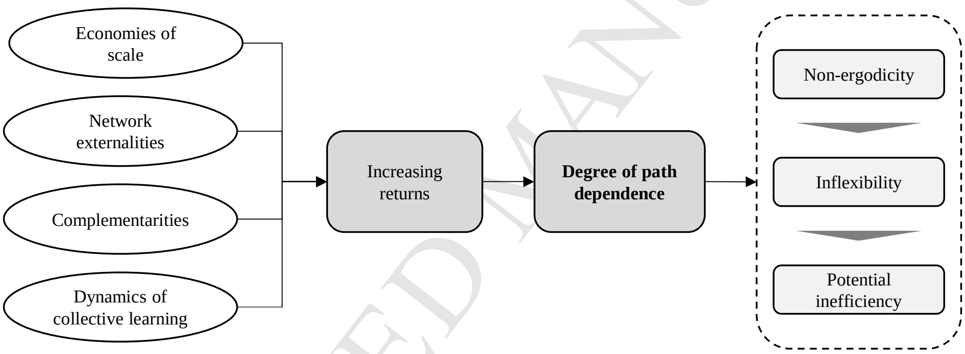

Figure 1 Sources and outcomes of path dependence.
Source: Based on Dobusch and Schüßler, 2013; Dobusch and Kapeller, 2013.

Increasing returns can lead to path dependence, which in turn has some specific outcomes (Arrow, 2000). Initially, a path-dependent process can be identified as technologically open. In the literature of path dependence, this is described as non-ergodic, which means that there is no clear mathematical function to forecast the technology that will be chosen and set as a standard (David, 1985). After this open era of ferment, the mechanisms of path dependence foster a specific technological alternative to become the quasi-standard. In the meanwhile, the state of openness and flexibility turns into a state of inflexibility. This state can be characterized as a situation where a new technology will not be able to replace the established one and this inflexibility may lead to inefficiency (Arthur, 1989). If there is a better technological alternative, and if this technology will not succeed in competing with the established technology, one can ascertain inefficiency. The different states of path dependence are driven by the mechanism of increasing returns (or positive feedbacks). This mechanism can be traced back to the effects of (1) economies of scale, (2) direct network externalities, (3) complementarities, and (4) the dynamics of collective learning processes (Dobusch and Schüßler, 2013; Dobusch and Kapeller, 2013). In the following, these four broad categories will be further explored in order to show that there are noteworthy reasons to assume that the global automotive industry is highly path-dependent.

First, economies of scale describe the fact that, in some industries, increasing outputs lead to diminishing costs per unit (Arrow, 2000; Dobusch and Schüßler, 2013). This can be reasoned by sunk costs e.g. for installed specific capacity or for building a specific brand or image. This mechanism of fix costs degression also counts for the global automotive industry. Sturgeon et al. (2008) show that significant globally concentrated production capacity with highly specific and interdependent value-chain structures exist. Along with this finding go the analyses of Orsato and Wells (2007) as well as Wells and Nieuwenhuis (2012). They provide pivotal evidence for an established business model in the automotive industry combined with widely spread distribution networks and revenue streams proven over long periods. Bohnsack et al. (2014) confirm these findings in their study on the influence of path dependence on the development of business models in the field of electric vehicles.

Second, direct network effects describe rising utility by growing usage intensity in network technologies. The classic examples for this effect are technologies such as telephone-networks in which the initial set up costs are decreasing with increased usage intensity and network size (Katz and Shapiro, 1985; Sheremata, 2004; Witt, 1997). When analysing the global automotive industry, it is also possible to identify some direct network effects, such as installed bases of fuel stations or established and specific service networks. Beside this classical argument of size constituting network externalities, Afuah (2013) suggests the impact of structure and conduct of networks on the network's value. Afuah (2013) establishes the factor structure by combining the effects of feasibility of transactions, centrality of members, structural holes, network's ties, as well as the number of roles that each member plays. The factor of conduct consists of opportunistic behaviour, reputation signalling, and perceptions of trust. In this regard, there might be even higher network effects in the global automotive industry due to highly inter-dependent and complex supply-chain structures and distribution channels. The multiplicity of roles that many actors play in this market may be another factor establishing strong network effects. The reason of this multiplicity of roles is usually the fact that OEMs are often suppliers of specific technologies for other directly competing OEMs. Another reason for role multiplicity can be seen in the complex and multivariate collaboration structures in this industry (Sick et al., 2015).

Third, the effects of technological and social complementarities that might constitute positive feedbacks have to be mentioned which ultimately lead to path dependence. Complementarities, which can also be labelled as indirect network effects, describe the effect of increasing utility while the number and the value of complementary goods and services grow (Dhebar, 1995, Farrell and Saloner, 1985; Katz and Shapiro, 1985). The effect of complementary goods and services building an indirect network around the focal technology can also be recognized in the global automotive industry (Wells and Nieuwenhuis, 2012). In this industry, manifold complementarities (e.g. platform-production systems) on the production side can be identified (Budde Christensen, 2011, Biesebroeck, 2007).

The remaining factor establishing positive feedbacks are the dynamics of collective learning (Arrow, 1962; Christiano, 1997; Malerba, 1992). Given that the buyers and users of certain technologies get used to these technologies over time, they establish specific technological expertise. Besides this tactile aspect of collective learning, other more tacit aspects can be identified, such as social preferences or behavioural patterns that influence buying and using decisions. Applying these concepts to the global automotive industry, manifold artefacts can be seen which allow the assumption that a tendency towards old technologies exists. Regarding the tactile aspects of this dimension, Graham-Rowe et al. (2012) show in their qualitative in-depth study that customers have serious doubts regarding the effectiveness of new technologies and that customers are relying on established vehicles. In a similar vein, Caperello and Kurani (2012) show the social and cultural factors obstructing mainstream-households leaving their established technologies. Steg et al. (2001) and Steg (2005) show the socio-psychological importance of the combustion engine propelled car in modern societies. These aspects can be seen as tacit in this regard, but nevertheless important when analysing dynamics of collective learning in situations of technological transitions.

In sum, the aforementioned characteristics might have constituted a long series of positive feedbacks in the global automotive industry (van den Hoed, 2007). This series of positive feedbacks has most likely in turn led to a situation of technological lock-in. In this situation, it might be economically rational to stick to the traditional technology with its diverse increasing returns instead of switching to a new technology with no or little returns so far.

2.2 Sailing ship effect

This lock-in situation might lead to the effect that the OEMs react to the threat of new technologies by improving old technologies. This intentional innovation effort as a direct reaction to the threat of new technologies is characterized by the sailing ship effect. The sailing ship effect refers to the technological competition between sailing ships and the newly developed steam ships in the 19th century. The term goes back to Gilfillan's historical representation of the development of ship technology (Gilfillan, 1935). Although Gilfillan might count as the original source for this effect, accurate economic meaning and application was gained by the contributions of Nathan Rosenberg (Rosenberg, 1972a, 1972b). Rosenberg showed several cases in which old technologies gained innovation effort after the introduction of competing new technologies. Building up on these early logics little but significant literature about the sailing ship effect can be found.

The literature can be divided into two broad categories, whereas these are not mutually exclusive. The first strand of literature shows a strong background of economic history and is dominated by qualitative research approaches. Several historic examples are mentioned that demonstrate an increasing innovation effort in old technologies after the emergence of new competing technologies. The exemplary list varies from the aforementioned ships (Geels, 2001, 2005a; Ward, 1967), horse-drawn carriage to motorcycles (Geels, 2005b), steam locomotives and diesel-electric powered trains (Cooper and Schendel, 1976; Cooper and Smith, 1992). Furthermore, chemical processes in the alkali industry and the iron industry energy transition in the 19th century (Howells, 2002; Rothwell and Zegveld, 1985) as well as the British coal industry were studied (Turnheim and Geels, 2012).

The second strand of literature concerning the sailing ship effect focuses on micro-economic theorizing, modelling and simulating. Particularly, the recent approaches of De Liso und Filatrella are capable to show competition effects when the technological monopoly is challenged by an entrant with a new technology (De Liso and Filatrella, 2008). They demonstrate that relative investments in research and development (R&D) in an old technology maximize the incumbent's profits. De Liso and Filatrella (2010) extend the neo-classical profit maximization assumption. They show that even in cases where a rather heuristic approach than a clear profit maximization function is leading the actions of the model market, participants' innovation competition consistent with the sailing ship effect exists. In their most recent article, De Liso and Filatrella (2011) try to incorporate more factors, such as complementary products, regulations or experience, into their model environment. They show the advantages of old technologies due to their broader base of built and sold products. A different approach for modelling the sailing ship effect is used by Windrum and Birchenhall (2005). They focus explicitly on consumer's decisions influenced by the emergence and development of a new technology in order to adopt new or old technology in network markets. These decisions are influenced by service and price characteristics, whereas the old technology service characteristics are determined by R&D spending. Depending on the innovation potential of the technologies and the innovation ability of the technology suppliers, the succession of the new technology may be delayed or even cancelled. Schiavone (2014) recently added insight from the photography industry presenting an approach called "technology reverse", where old and new technologies are combined to extend the lifetime of the old technology.

Nevertheless, Howells states serious doubts about the existence of the sailing ship effect (Howells, 2002, 2005). His sceptics concentrate on two central arguments. Firstly, Howells sees manifold empirical shortcomings regarding the sailing ship effect in the existing literature as they are subject to somewhat ambiguous interpretations. In his re-analysis of the cases of sailing ships and alkali-technology, Howells shows different interpretation patterns for the observed reaction behaviour. Secondly, he interprets the reaction strategy according to the sailing ship effect as irrational and doubts that this irrational strategy was really intended by the corporations under study. He calls for additional empirical investigations of the effect. We contribute to this discussion by adding empirical investigations in form of patent analyses. Regarding Howells irrationality claim, we combine the arguments of path dependence theory with the findings of the sailing ship effect to find out if the observed reaction behaviour is individually rational. The following Figure 2 summarizes the relation between path dependence and the sailing ship effect. The old technology has gone through a path dependent process over the last decades and is now finally in a state of lock-in (Phase III, above). Against this background, a new technology emerges which is still in its open phase (Phase 1, below). The innovation competition might take place between the locked-in old and the contingent new technology. Thus, the key research question of our approach is: Can we identify evidence for the sailing ship effect in the automotive industry based on patent data? Specifically, is there measurable evidence for a rising innovation effort in the old propulsion technology in response to new and clean technologies?

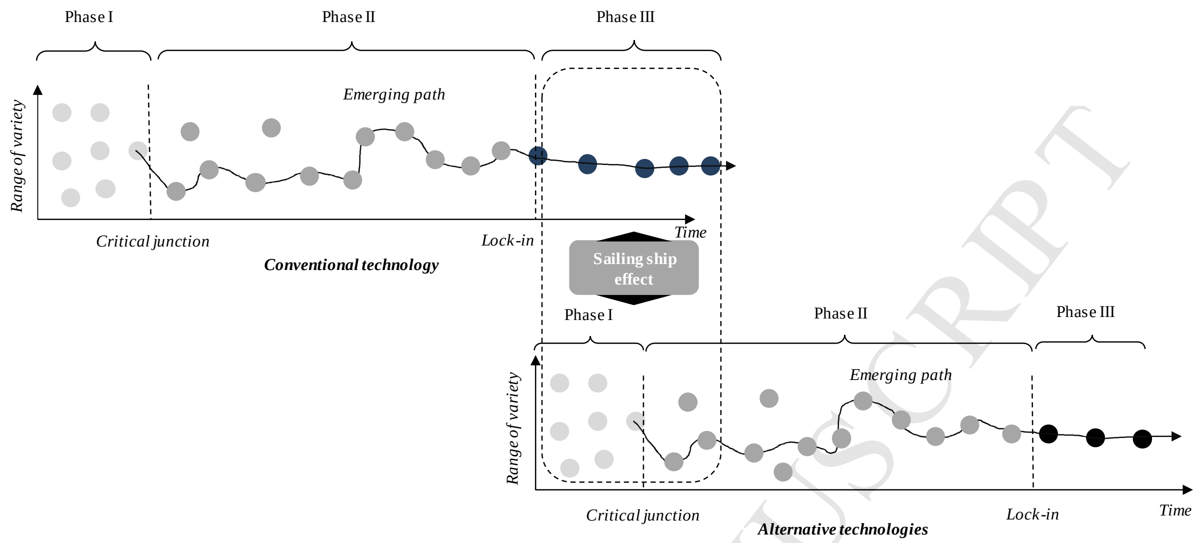

Figure 2 Sailing ship effect between two path dependent technological trajectories.
Source: Based on Sydow, Schreyögg and Koch, 2009.

3 Data and methods

We conduct a patent analysis in PatBase, a global patent database which provides access to more than 36 million patents from 95 issuing authorities. PatBase is based on patent families, containing all single patents belonging to one invention. This feature makes PatBase especially suitable for our analysis as duplicates can be avoided and all relevant patent information on different technologies in the automotive industry can be pooled. The patent retrieval took place in February 2015.

The search was conducted using exclusive key word combinations (e.g. “ELECTRIC VEHICLE NOT HYBRID NOT FUEL CELL NOT INTERNAL COMBUSTION ENGINE”) in titles, abstracts and claims of the patents. We searched for traditional propulsion technologies (internal combustion engines, ICE) and clean alternatives such as battery electric vehicles (BEV), hybrid electric vehicles (HEV), and fuel cell vehicles (FCV). This type of retrieval strategy guarantees a broad inclusion of patents related to the focused technologies and is independent of patent classification issues. We chose a timeframe of the priority date from 1985 until 2012 for our patent search. The priority date is defined as the day when the invention is initially submitted for application to a patenting authority. Hence, the priority date is the date which is the closest to the innovation processes in the applying corporations (Ernst, 2001; OECD, 2009). 1985 was set as a starting point because first regulatory standards were implemented in 1990 by the California Air Resources Board (CARB) with the Zero Emission Vehicle (ZEV) regulation as part of the Low Emission Vehicle (LEV) program (Lloyd, 2000, Dijk et al., 2013). Although it might give the impression of a regionally limited program implemented by just one state, this regulation, as Berg (2003: 178f.) observes, can be taken as “the event which changed the world not only in the field of auto emission control but as well in the corresponding technology section”. Furthermore, we had to limit our search to 2012 since patents undergo a delay of 18 months until publication. We tested if 2013 could be included in the sample, but came to the conclusion that most of all patents available in 2013 had been applied in the first half of the year. Thus, an inclusion of the year 2013 into the sample would distort the results, particularly with respect to analyses on the basis of yearly patent data.

A validation of the sample was conducted based on an analysis of the International Patent Classifications (IPC) on group level, whereby we checked if the most relevant IPCs can be assigned to propulsion technologies for vehicles. The most relevant IPC groups over all technologies are:

- B60 (VEHICLES IN GENERAL),
- F01 (MACHINES OR ENGINES IN GENERAL; ENGINE PLANTS IN GENERAL; STEAM ENGINES),
- F02 (COMBUSTION ENGINES; HOT-GAS OR COMBUSTION-PRODUCT ENGINE PLANTS),
- F16 (ENGINEERING ELEMENTS OR UNITS; GENERAL MEASURES FOR PRODUCING AND MAINTAINING EFFECTIVE FUNCTIONING OF MACHINES OR INSTALLATIONS; THERMAL INSULATION IN GENERAL),
- H01 (BASIC ELECTRIC ELEMENTS), and
- H02 (GENERATION, CONVERSION, OR DISTRIBUTION OF ELECTRIC POWER).

In order to provide more detailed insight into the dataset, we additionally present the numbers of the three most relevant IPC groups for the respective technologies in Table 1. In addition to the overall fit of IPC groups to propulsion technologies, the high degree of selectivity of the search string for single technologies is confirmed here. F02 as a distinct group for combustion engines clearly dominates ICE and appears as second largest group for HEV, which contain combustion engines as well – in contrast to BEV and FCV. Apart from B60 as general vehicles group, the most relevant groups for BEV are H02 and H01, referring to electric elements and the electric power conversion, which is the most obvious differentiation to ICE. Furthermore, FCV patents are predominantly classified to H01 basic electric elements, underlining the relevance and integration of the fuel cell into the vehicle. On this basis, we can confirm that the retrieved patent sample excellently represents conventional as well as electric propulsion technologies for vehicles.

Table 1 Absolute numbers of the three most relevant IPC groups for single propulsion technologies.

ICE	*BEV*	*HEV*	*FCV*
F02: 3,301	B60: 3,262	B60: 4,208	H01: 1,035
B60: 1,583	H02: 1,857	F02: 1,432	B60: 934
F01: 1,543	H01: 888	F16: 912	H02: 96

4 Results and discussion

We received a total of 62,422 patent families in the field of conventional and alternative propulsion technologies, whereby ICE as conventional technology represents about half of all patent families (Table 2). Concerning alternative technologies, BEV follow with 33%, while HEV account for less than half of the amount of patent families with about 14%. Patent families referring to FCV hold the smallest share with a total of about 2% of the sample.

Table 2 Patent data for conventional and alternative propulsion technologies in absolute and relative numbers.

	ICE	*BEV*	*HEV*	*FCV*	*Total*
Absolute	31,614	20,675	8,797	1,336	62,422
Relative	50.65%	33.12%	14.09%	2.14%	100.00%

One important matter in our approach is the classification of HEV as an alternative technology. HEV contains electric components as well as traditional combustion technology elements. Hence, it is difficult to determine whether they are new or old technology. In most recent approaches, hybrids are labelled as new technology, therefore we follow this classification. From a technological viewpoint, serial and parallel hybrids could be differentiated. In the case of parallel hybrids both, the combustion engine as well as the electric engine is connected to the wheels in order to propel the car. In the case of serial hybrids, the electric engine is the central propulsion unit which is supplied with energy from a battery. If this battery is low, a small combustion engine with no connection to the wheels is used to create electric energy. On this technological basis parallel hybrids can be defined as old technology and serial hybrids as new technology. However, this distinction is difficult to be done in our data set because it has to be done for each patent individually and manually. Thus, we decided to take a conservative perspective and label hybrids as new technology.

Figure 3 shows the absolute number of patent families on a yearly basis from 1985 until 2012. A clear dominance of the old technology can be seen until 2008, when the number of ICE-related patent families (2,445) still doubles the number of BEV-related patent families (1,019). While the number of patent families is approaching in 2009, the emergent BEV-technology takes over leadership in patenting activity in 2010 and rises steeply until 2012, whereby the number of ICE-related patent families moves sideways. In contrast to the public and scientific discussion (e.g. Bakker, 2010; Bakker et al., 2012), the number of FCV-related patent families is still on a very low level with a maximum of 168 patent families per year in 2008. The HEV-technology, however, shows higher patenting activity with a steeper increase from 2006 onwards.

Irrespective of the boost in patenting activities concerning BEV, it has to be noted that from the mid-1990s until 2008, R&D activities for the conventional ICE technology had been intensified. Since the first regulatory standards for lower carbon emissions (ZEV regulations by CARB) were implemented in 1990, followed by further regulations and program approaches (e.g. by CARB or the European Union), the intensified patenting activity afterwards may be a response to these regulations in order to incrementally improve ICE efficiency. As R&D efforts to promote HEV and BEV technologies only started 15 years delayed in 2005, the automotive industry obviously decided to concentrate on enhancing the old technology instead of promoting alternative technologies. On the other hand, the number of yearly BEV-related patent families clearly outweighs the number of ICE-related patent families since 2009. In conjunction with the aforementioned intensification of ICE-related patenting activities between 1995 and 2008, this can be taken as a first hint towards the existence of a temporary sailing ship effect in the automotive industry. Dijk (2014) and Dijk et al. (2015) support our finding pointing out that after 1995, alternative technologies entered into a phase of decreasing growth rates with some models even being withdrawn from the market. In addition to the diminished interest in BEV and HEV, they observe intense efforts in improving conventional diesel engines during that phase, which underlines our proposition of a temporary sailing shop effect.

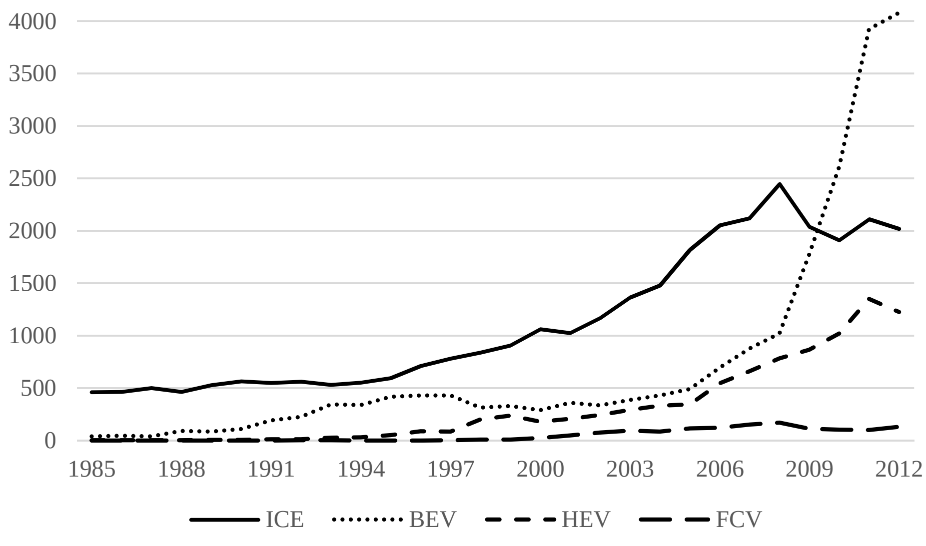

Figure 3 Number of patent families for conventional and alternative propulsion technologies.

The cumulated number of patents confirms the dominance of the old technology, at least until 2008 (Figure 4). The old technology still totals until 2012 for about double the amount of patent families than all alternative technologies. When thinking of the intensified innovation activities since the mid-1990s, it has to be added that the high share of patent families cannot be traced back to long time ago patenting activities but to the increase between 1995 and 2008. In contrast, it has to be noted that a considerable hump together with a slowdown of cumulated ICE patenting activity can be observed in 2008. At the same time, the cumulated number of BEV-related patent families undergoes a steep rise from 2008 onwards, counteracting the heretofore dominance of conventional propulsion technologies. This goes along with intensified climate protection policies and programmes in the aftermath of the economic and financial crisis of 2007, stimulating R&D activities as well as market opportunities for alternative propulsion technologies, particularly BEV (Dijk et al., 2013). These findings underline the conclusion drawn from the development of the absolute patent data that a sailing ship effect has been taken place in the field of propulsion technologies. At least on patent and thus technological level, the effect seems to be limited to the timeframe between 1995 and 2008. We received clear evidence that innovation activities in recent years begin to focus on new technologies, particularly concerning battery electric vehicles, while activities in the old technology stay on a constant level.

Very interesting to see in this context is the time lag between technological and market level: Although the dominance of conventional technologies on technological level due to the sailing ship effect ended in 2008, this development is not yet reflected on market level. To date, there is a total of 400,000 electric cars registered worldwide, in contrast to about 700,000,000 vehicles with conventional propulsion systems (ZSW, 2014; Statista, 2015). Although the number of electric vehicles showed growth rates of 100% per year during the last three years, the share of electric vehicles is still extremely small. We can conclude that the dynamics in patenting and innovation activities for alternative propulsion technologies are reflected in the market, but that the absolute numbers are still on a very low level.

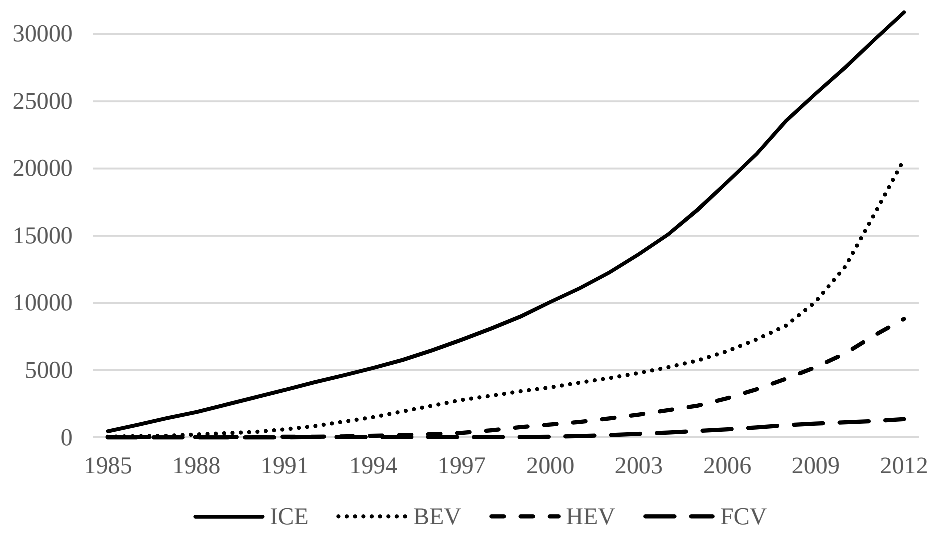

Figure 4 Cumulated numbers of patent families for conventional and alternative propulsion technologies.

When considering the relative shares of the technologies under study, the temporary sailing ship effect gets even more obvious, particularly when comparing ICE- and BEV-related patent families (Figure 5). From 1985 to 1995, the share of ICE-related patent families decreased from more than 90% to about 60% while the share of BEV-related patent families grew from less than 10% to nearly 40%. After a short period of lateral movement at the beginning of the 1990s, patent activity for ICE was intensified again, holding shares between 60% and 70% of all propulsion patent families until 2008. At the same time, the share of BEV-related patent families dropped to about 20%. Since the mid-1990s, HEV-related patent families increased to shares between 10% and 20% while FCV-related patent families constantly hold shares lower than 10%. Even though part of the drop in BEV-related patent families may be explained by rising activities in the area of HEV, the opposite development of patent shares of old and new technologies shows evidence for the intensification of innovation activities in the old technology at the expense of new technologies.

Although the effort in developing alternative technologies started in the early 1990s, the old technology reacted after a first phase of euphoria in the new technology by mid-1990s. An explanation for the stability of ICE technologies from 1995 to 2008 might be the relative technological power of the conventional ICE technology. After a first phase of technological pressure and euphoria due to the CARB regulations in 1990, the automotive industry started initiatives to improve ICE based on increasing innovation activities. This can be seen as another hint towards the proposed sailing ship effect as at least the lifetime of the old technology has been prolonged significantly. On the other hand, in 2009, the share of alternative patent families exceeds the share of ICE-related patent families and constantly rises until 2012. Particularly BEV-related patent families undergo a steep increase and hold a share of about 50% of all patent families from 2010 onwards, while HEV- and FCV-related patent families hold quite constant shares during this period. This development is probably due to the dominance of battery technologies and particularly lithium-based batteries in R&D for alternative propulsion systems since 2008 (Golembiewski et al., 2015; Wagner et al., 2013). In addition, the fact that the automotive industry tends to give priority to incremental innovations such as fuel efficient ICE instead of radical innovations such as battery-electric and fuel cell vehicles might contribute to the sailing ship effect (Zapata and Nieuwenhuis, 2010, van den Hoed, 2007).

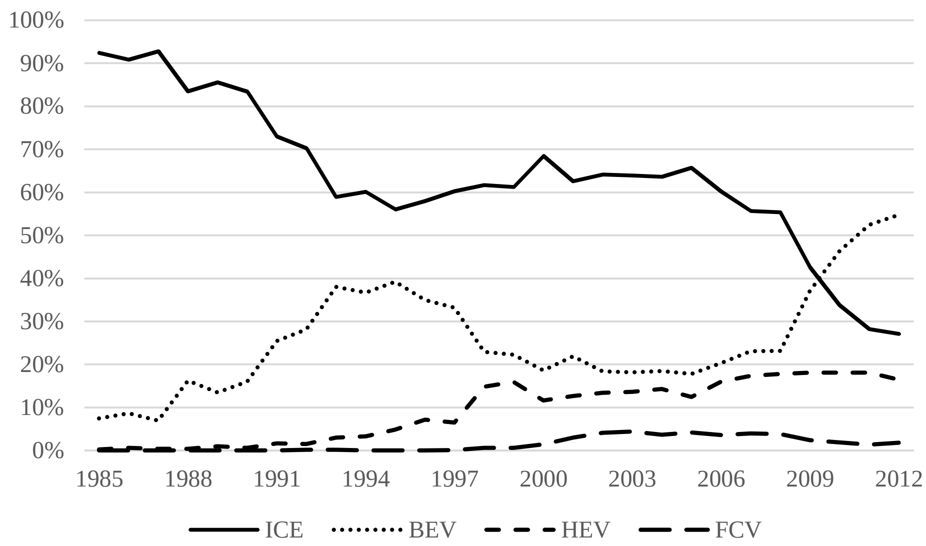

Figure 5 Relative shares of conventional and alternative propulsion technologies.

5 Conclusions

In sum, our analyses confirmed the existence of a sailing ship effect in the automotive industry in terms of conventional and alternative propulsion technologies. We found patent-based evidence for a temporary sailing ship effect on technological level between 1995 and 2008. Our results show several implications for (1) the study of technological change (theoretical perspective), for (2) players in the automotive sector (industry perspective), and for (3) policy makers (policy perspective).

Firstly, we present evidence for the existence of a sailing ship effect. By our empirical setting, we followed the call of Howells (2002, 2005) for an empirical test of the propositions of the sailing ship effect. Our results could be taken into account when forecasting diffusion or adoption patterns of new technologies. Furthermore, we could conclude that it is not – as sometimes explicitly or implicitly stated – irrational. By connecting the sailing ship effect with the well-established mechanisms of path dependence, the individual rationality of such behaviour becomes more evident. It is not irrational herd- or inertia-based behaviour but rather rational in the face of internal (sunk costs, know-how) and external (customer loyalty to the old technology, complementary products and services) influence factors.

Secondly, our results show that major part of the innovation behaviour in the automotive industry is subject to the sailing ship effect which should be considered in strategic technology planning. There are some recent cases that show the manifold pitfalls for industry players in this area. For instance, the battery manufacturer A123 filed bankruptcy (New York Times, 2012a) and Chevrolet set out the production of its HEV “Volt” due to stagnating sales numbers (New York Times, 2012b). Additionally, Toyota retrenched its plans to start the wide-spread sale of the BEV “eQ” due to a misperception of its market potential (New York Times, 2012c). Business model innovation regarding new technologies (Budde Christensen et al., 2012) might create possibilities for new technologies in market niches that might evolve quickly. Overall, our findings may be helpful in order to better evaluate technology and market development as well as competitors' behaviour in times of far-reaching technological change.

Thirdly, in countries of major automotive production and consumption as for instance China, France, Germany, India or the United States, manifold initiatives to subsidize old technologies can be identified (e.g. Altenburg et al., 2012). These subsidization strategies seem to be highly inefficient in light of the sailing ship effect. When the old technology still holds efficiency and pollution reduction potential, the promotion of alternative technologies may lead to 'dead ends'. Considering our findings, a standard-based regulation that focuses on certain CO_2-limits seems to be more appropriate since it leaves the innovation process open to competition. A solely favouritism of new technologies hinders reasonable innovation in the old technology since scarce R&D resources are allocated to the new technologies. From an ecological perspective, the exclusive development of alternative technologies does not seem to be too effective concerning the mitigation of climate change, too. First, even in optimistic scenarios, the electric driven alternatives will only reach minor market shares in the next decades. As Fouquet (2010) as well as Pearson and Foxon (2012) already concluded in their studies on the transition to a low carbon economy, a rapid and easy diffusion of ecological innovations and thus a short- to mid-term replacement of existing energy technologies cannot be presumed. Second, the ecological impact of electric cars depends strongly on the sources of electricity. If the energy creation is sustainable and renewable (e.g. wind or photovoltaic energy), the well-to-wheel emission balance of energy propelled cars is positive. If the energy comes mostly from fossil fuel powered energy plants, the emissions reduction effect of electric vehicles is a solely local one with no or even a negative overall reduction effect (Christ, 2012; Hawkins et al., 2012). In contrast, incremental adjustments of the old technology will have even greater overall effects regarding CO_2-reductions (Schäfer et al., 2006; Öko-Institut et al. 2011).

Although our findings show major contributions to the discussion of the sailing ship effect, some limitations have to be stated. Firstly, a selection bias cannot be excluded in our data set. We tried to reduce this effect in conducting a very broad search ex ante and validating our data ex post. Secondly, the distinction between direct sailing ship effect behaviour and other influencing developments, such as political regulations and fuel prices, remains methodologically difficult and seems to be a worthwhile endeavour for further research. Thirdly, after a thorough discussion, we characterised hybrids as new technology, being well aware that summarising parallel and serial hybrids might affect the selectivity of the data set. Another option could be to analyse hybridisation of the propulsion system as a separate strategy of OEMs to deal with the transition from conventional to electric power trains (Raven, 2007). Alongside with the presented sailing ship effect, there may be other effects that hinder the diffusion of alternative technologies in the automotive sector: for instance, the widely researched rebound effect (Brännlund et al., 2007; Small and Van Dender, 2007). This effect could be even fostered by efficiency gains due to the sailing ship effect. Another manifestation of the sailing ship effect might also be traceable in the domain of process innovations (Pistorius and Utterback, 1995, 1997). This specific occurrence of the sailing ship effect seems to be a valuable question for future research.

Finally, further approaches to detect and measure the sailing ship effect in the automotive industry could be applied in future studies. One question for example might be if the sailing ship effect is strategically intended by automotive executives as a distinct strategic option or if it presents an unconscious outcome of different dynamics. Moreover, it seems to be very promising to qualitatively analyse the strategic decision-making process regarding technological change of automotive executives. A survey with R&D managers might even be supportive for a deeper insight into decision dynamics in times of technological change. Furthermore, a calculation based on market data might be another approach to analyse the sailing ship effect. Therefore, new products and pre-market-stage innovations (prototypes, fleet trials) might be collected over time and analysed regarding possible action-reaction patterns between two competing technological trajectories.

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Highlights JCLEPRO-D-16-01031

- Elements of path dependence are pivotal to the rationales of sailing ship strategy.
- It can be rational to stick to an old technology instead of switching to a new one.
- Our analyses confirm this innovation behavior in the automotive industry.
- Patent-based evidence shows a temporary sailing ship effect between 1995 and 2008.