

Tryggvason, Finn Jonas; Giones, Ferran

Article — Published Version

Too close for comfort: the pitfall of incumbents' knowledge search during industry evolution

R&D Management

Provided in Cooperation with:

John Wiley & Sons

Suggested Citation: Tryggvason, Finn Jonas; Giones, Ferran (2024) : Too close for comfort: the pitfall of incumbents' knowledge search during industry evolution, R&D Management, ISSN 1467-9310, Wiley Periodicals, Inc., Hoboken, NJ, Vol. 55, Iss. 1, pp. 165-184, <https://doi.org/10.1111/radm.12689>

This Version is available at:

<https://hdl.handle.net/10419/313812>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<http://creativecommons.org/licenses/by-nc/4.0/>

Too close for comfort: the pitfall of incumbents' knowledge search during industry evolution

Finn Jonas Tryggvason  and Ferran Giones 

Institute of Entrepreneurship and Innovation Science (ENI), University of Stuttgart, Stuttgart, Germany. finn-jonas.tryggvason@eni.uni-stuttgart.de, ferran.giones@eni.uni-stuttgart.de

Innovation shocks combine technology and market disruptions. They can lead to a complete overhaul of an industry. Building on prior work on firm-level responses to technological uncertainty, we propose and explore a model to explain R&D behavior under uncertainty. We theorize that industry incumbents adjust their knowledge search as the innovation shock unfolds, reacting to the perceived sources of uncertainty. We use a unique combination of two decades (2000–2020) of patent data and archival news to (1) identify the industry evolution stages as the shock unfolds and (2) map the firm's knowledge search response. Our analysis of three leading car manufacturers exposed to the emergence of the electric vehicle shows the path-dependency effects that delay the incumbents' adjustment of their innovation direction, even after the shock becomes visible. We extract insights for R&D managers by making evident the long-lasting effects of prior R&D decisions, impeding their reaction to a shock and reducing their capability to integrate newly available knowledge.

1. Introduction

Being an established player in a mature industry with high entry costs and strong economies of scale should be a rather desirable position. The large automotive firms successfully leveraged their competitive position in the last decades to gain production efficiency and global reach while successfully introducing incremental innovations—despite some technological hiccups (Bakker, 2010). In this globally efficient, razor-focused, competitive context, an attempt to build an electric roadster to cater to a small community of car enthusiasts should be neither noticeable nor significant. The surprising story of how a well-oiled mature industry gets shaken by a new entrant disrupting the core of its technological base, the engine of the car, provides a unique opportunity to understand how uncertainty interacts with

R&D decisions, its potentially dramatic effect on established firms, and to the overall industry evolution (Gustafsson et al., 2016).

Established organizations, as industry incumbents, have several options to respond to change; they can acquire new knowledge or recombine existing knowledge to adapt their product or service offering, business model, production process, or other organizational functions (Eggers and Park, 2018). They can also strategically reposition themselves considering the technological change and whether the new entrants threaten to displace the incumbents (Du et al., 2019). Although the incumbents should have the advantage, given their strategic position and resources in an established industry (Ozalp et al., 2023), there are several examples of failed transitions, even in firms well known for their innovativeness, e.g., Nokia or Kodak (Lucas and Goh, 2009; Vuori and Huy, 2016).

The introduction of an electric sports car by a new entrant should not have been the beginning of a disruption that turned the global automotive industry upside-down and jeopardized the future of leading car manufacturers. Compared to the well-known cases of Nokia or Kodak, the slow build-up of the electric vehicle niche into a mass market should have given the established players time to anticipate, prepare, respond, and benefit from the innovation. Still, the uncertainty surrounding the technology and the perceived unlikelihood of a mass market for the electric car froze, for decades, the electric vehicle R&D of established players. This puzzling situation motivates our research question: how do the incumbents' technological knowledge search evolve in response to an innovation shock?

To untangle this puzzle, we look closer at the knowledge search behaviors of established players in the automotive industry as they try to respond to the innovation shock. We leverage patent data from 20 years (2000–2020) and archival data—news articles at the firm and industry level—covering the same period. We characterize the response of each firm, identifying the knowledge they built in anticipation of the technology disruption and their knowledge search adjustments as the industry was evolving. The patent usage data (citations to other patents) gives us a unique perspective to understand how the incumbents engaged in knowledge search (Chandler and Hwang, 2015) and to find the missing pieces to match their existing resources to the new knowledge base of the industry (Agarwal et al., 2017).

Our results show a surprisingly slow uptake of the incumbents' activity in R&D of electric vehicle's key components. In our proposed theory framework, incumbents react to an innovation shock rapidly broadening their search beyond their internal knowledge. However, this is not what our data shows. Instead, we find that commercial viability doubts regarding electric vehicles, the prior setbacks with promising technologies, i.e., hydrogen car (Bakker, 2010), and the substantial differences in the architecture of combustion and electric engines (Jin and Kirsch, 2022; Murmann and Schuler, 2022; Lopez-Vega and Moodysson, 2023), promoted an unusually reactive behavior among the incumbents.

We contribute to industry evolution research by showing how proximal incumbent firms, both in space and knowledge, might be particularly ill-positioned to respond to a niche emergence in their industry. In these situations, the incumbents' scaling-up of search scope and depth is too slow to match the accelerated industry evolution driven by the new entrant's technological innovation (Klepper, 1997; Moeen et al., 2020). We identify that in these settings,

firms with a secondary role in the industry can benefit from the emergence of the niche, they can gain centrality—becoming hub firms—as the industry's underlying innovation ecosystem gets restructured.

The article starts with a theory background section summarized in a conceptual framework to explain the incumbent's response to an innovation shock. We then present our research design to collect and analyze data on the recent changes in the automotive industry to assess how well our framework explains the observed changes. We finalize the article by reflecting on the incumbents' response to innovation shocks, their ability to understand and disambiguate the technological and market impact of a shock and discuss why they might not always be able to respond successfully. We present implications for the connection between innovation shocks and industry evolution research and insights for R&D managers engaged in similar transitions.

2. Theory background

2.1. Innovation shock and uncertainty

The most prominent cause for industry-level disruptions is technology evolution. Other factors, such as a change in regulation or cultural values, can threaten the existing industry but are often easier to influence or absorb if you are an established player (Gustafsson et al., 2016). New technologies that gain market acceptance can lead to an innovation shock: a “pioneering new product design [...], the demand for which surges in an unanticipated way” (Argyres et al., 2015, p. 216). An innovation shock can occur even when the new technology does not instantaneously disrupt the whole market (S. L. Cohen and Tripsas, 2018), temporally preserving the existent the industry structure (N. R. Furr and Eisenhardt, 2021). Established players try to maintain their status quo, identifying options to contain and respond to the effects of the shock (Wenzel et al., 2021).

The disruption created by the innovation shock puts the industry structure in a flux phase, where uncertainty is high (Lam et al., 2010; Vith et al., 2019). Incumbents' options include to exit the market, to imitate the new products and services, or to reposition their offerings considering the threat of new entrants (Nelson and Winter, 1982; Argyres et al., 2015). The option to exit the industry is not often considered, leaving most organizations with the option to find the right imitation response (Ozalp and Kretschmer, 2019) or to accelerate their internal development efforts to outplay the new entrant (Giustiziero et al., 2019). The reaction time depends on the incumbent's adjustment costs, transaction costs, and opportunity costs (Bigelow et al., 2019).

In this technology-focused response, incumbents need suitable internal technical knowledge to assess the threat that the new technology poses. The technology has not yet been proven in the market, so it is not clear to what extent is it a successful market rival or potential competitor (Giustiziero et al., 2019). If the incumbent does not hold the knowledge internally, it can try to acquire it from external sources (Helfat and Raubitschek, 2000).

2.2. External search for knowledge

Acquiring and integrating the necessary external knowledge is not an easy process for incumbents responding to a new entrant (Eggers and Park, 2018). A common challenge to adapt to technology changes is incumbents' overreliance on their internal knowledge (T. E. Stuart and Podolny, 1996); they struggle to obtain knowledge that requires crossing technological or organizational boundaries (Rosenkopf and Nerkar, 2001; Lopez-Vega et al., 2016), and might find difficult to decode the technology features of the product—in particular when they are complex technological systems (Rivkin, 2000).

Possible ways to overcome this shortcoming are to form alliances, promote inventor mobility between firms (Rosenkopf and Almeida, 2003), or acquire knowledge through hiring (J. Song et al., 2003) among other options (Giustiziero et al., 2019). However, integrating external knowledge remains challenging, often requiring a specific and appropriate strategy (Peeters and Martin, 2017), and internal learning capabilities to increase the absorptive capacity of the organization (Lewin et al., 2011).

Most of the prior research on innovation performance and external knowledge stresses how critical it can be to identify and acquire the knowledge needed to sustain the firm competitiveness and overall industry position (Spithoven et al., 2010; West and Bogers, 2014; Roper and Love, 2018). However, incumbents face multiple sources of uncertainty, it unclear whether and when the new technology will outperform the current technology (Adner and Kapoor, 2016), and it remains unclear whether there is a real need to accelerate internal knowledge to outplay the new entrant's technology or if it is better to imitate their products as they eventually gain traction in the market (Giustiziero et al., 2019; Ozalp and Kretschmer, 2019).

2.3. Niche emergence as an innovation shock

To better understand how this reaction process unfolds, we introduce the literature on new industry emergence to describe the progressive evolution of

the innovation shock. The development path of a new industry and its evolutionary stages have received substantial attention (Gort and Klepper, 1982; Agarwal and Bayus, 2002; Moeen and Agarwal, 2017). Scholars suggest three distinct stages, an incubation stage, a prefirm take-off stage, and a pre-sales take-off stage (Moeen et al., 2020). Moeen et al. (2020) propose to separate the different stages by key market events. An incubation trigger initiates the incubation stage, the first commercialization signals the beginning of the prefirm take-off stage, while the final pre-sales stage starts once a significant number of firms have entered the market.

While the study of industry evolution anchored in Klepper's work on industry lifecycles initially treated new industries as independent (Klepper, 1997), more recent contributions suggest that the dynamics in a niche could impact the overall industry structure and evolution (Bhaskarabhatla and Klepper, 2014). Using the case of the laser industry, Bhaskarabhatla and Klepper (2014) explain how developments in a market segment result in substantial changes in the whole industry, suggesting that technology developments that in the onset are only aimed at a particular group of customers can spread to the entire industry. The likelihood of a broad impact on the industry can be explained by the severity of the technological change and the market segment's interdependence with the rest of the industry (Bhaskarabhatla and Klepper, 2014).

The emergence of a niche is interconnected with the technological regime in the industry (Smith and Raven, 2012). When the niche appears around a novel technology, it is likely to benefit from the inability of the dominant technological regime to match the features or benefits that the technology offers (Schot and Geels, 2007), it becomes complex to imitate (Rivkin, 2000). As the niche emerges and starts entering the main markets in the industry, its development gets in sync with the industry evolution, eventually leading to industry shakeouts (Sanderson and Simons, 2014), where some established firms exit or have to reinforce their position to stay in the industry (Agarwal et al., 2015).

3. Theoretical framework

We connect the prior literature on innovation shocks, knowledge search by incumbents, and niche emergence around a new technology to propose a theoretical framework (see Figure 1). We theorize on the knowledge search behavior of incumbents as they react to the niche emergence that triggers an industry evolution. We differentiate

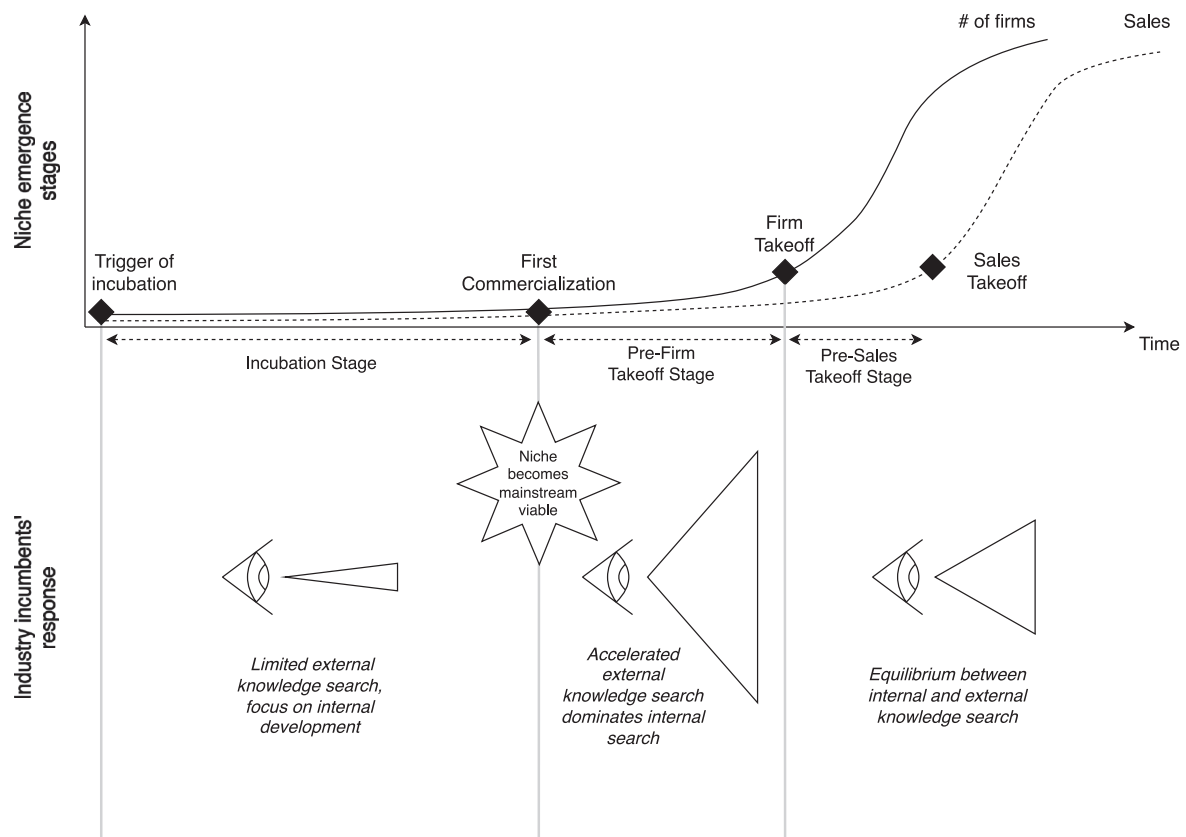


Figure 1. Theoretical framework on niche emergence and incumbents' knowledge search response, based on Moeen et al. (2020).

between the early stage, where the uncertainty is on the technology capabilities, and the later stages where the uncertainty shifts to the market acceptance of the technological product introduced by the new entrant. We follow the new industry emergence phases to offer a parsimonious elaboration of the incumbents' response.

3.1. Incubation stage and early potential indication

During the incubation stage of the niche, the technological uncertainty is at its highest (Moeen et al., 2020). Fleming (2001) argues that experimentation with unfamiliar components and recombination of components can significantly lower the technological uncertainty during that phase and increasing the search breadth of knowledge sources is beneficial to the firm's innovation output (Leiponen and Helfat, 2010). However, to successfully integrate external knowledge into the firm, continuous internal learning efforts and previous internal knowledge are required (W. M. Cohen and Levinthal, 1990; Vega-Jurado et al., 2008).

At this stage, incumbents in the mainstream market perceive the niche as too small to be relevant

(Schot and Geels, 2007), or as a distant signal to their core activities (Shankar et al., 2023). They do not explore the new technological knowledge in the niche, and they do not actively engage in external search for knowledge or related innovation activities.

3.2. Prefirm take-off stage and shift to external knowledge

The first commercialization of a product in the niche marks a critical change (Moeen et al., 2020). It is an indication that there is a potential mainstream viability for the product in the industry. Incumbents in the mainstream market do not generally anticipate the first successful commercialization. It is perceived as a shock—still of unclear intensity—and will consequently expand their reach to access external knowledge (Schilling, 2015) as the niche is now visible.

At this point, the incumbent can assess alternative reactions. Accelerating their internal R&D activities to surpass the technology in the niche, or aiming to imitate the offered solution (Lee and Lim, 2001). Imitation has shown to be a successful strategy for incumbents trying to catch-up (Bi et al., 2017) and inspiration can be drawn from unrelated fields beyond the existing industry

(Enkel and Gassmann, 2010). However, sustained internal R&D efforts are a necessary complement to external knowledge acquisition (Cassiman and Veugelers, 2006).

In this stage, incumbents might also start to transition from imitating to innovating with the technology/ies that the niche players have introduced. For this, access to external knowledge becomes imperative and precedes reliance on internal knowledge (C. Y. Wu and Mathews, 2012). Consequently, the incumbent firms will attempt to catch up with the niche market leader and expand their external knowledge search, searching for the most appropriate solutions.

3.3. *Presales take-off stage and rebalancing of knowledge search*

Finally, in the presales take-off stage, which captures mass-market adoption, the primary focus shifts from product refinement to optimizing scalability and cost-effectiveness (Moeen et al., 2020). Additionally, at this stage, the restructured innovation ecosystem starts to consolidate, actors take purposeful actions to ensure they establish a position to capture value in the new ecosystem structure (Adner, 2012; Dattee et al., 2018). Some incumbents might fail in the catch-up efforts, being forced to consider profiting of their existing competencies while the old regime lasts and start retreating from the market (N. Furr and Kapoor, 2018). Others might find a path to leverage their internal assets, recombine them with the new knowledge, and effectively exploit their competencies to appropriate value in the new technology regime (Khanagha et al., 2018). Consequently, in this stage, we expect incumbents to reduce their reliance on external knowledge search, compared to the previous stage, and to increasingly find answers in the external knowledge they have now internalized and started to integrate into their knowledge resource base.

This results in our theoretical framework (see Figure 1), where we adapt (upper section) Moeen et al.'s (2020) model to show the niche emergence stages, and we describe the expected response of industry incumbents (lower section) adjusting their external knowledge search as the innovation shock of the niche emergence unfolds.

4. Research design

4.1. *Setting*

We evaluate the theoretical framework's examining the response of the automotive industry incumbents to the innovation shock of the electric vehicle

emergence, from niche to mass market. To study the incumbent's response, we select a group of German automotive firms with considerable geographical and cultural proximity but catering to different segments of the automotive industry—mass-market cars, luxury cars, and sports cars. By doing this, we expected to identify distinct responses based on their differences in market and technology positions, capturing the uncertainty effects as the innovation shock became evident. The car manufacturing sector is deeply rooted in Germany's economy and a crucial export good, with three German car manufacturers being within the top 10 of the biggest car manufacturers worldwide by market capitalization (Companies Market Cap, 2022), namely Volkswagen (VW), Mercedes-Benz (MB) and Bayerische Motoren Werke AG (BMW).

The innovation shock is the electric vehicle emergence. Technological advances in battery technology, climate change and environmental awareness, as well as regulatory changes created a fertile environment for change in the automotive industry. Embodied in the rise of the firm Tesla, electric vehicles gained traction and eventually shook the whole industry (Stringham et al., 2015). After an initial dismissal of the niche as a temporal market hype, established manufacturers acknowledged it as a crucial future market (Stringham et al., 2015).

4.2. *Data*

4.2.1. *Patent data*

To study the evolution of knowledge search and the actual knowledge exchanges between firms in the industry, patent data provides an excellent window to these dynamics (T. Stuart, 1999), and has been used successfully to study the automotive industry innovation (Lin et al., 2011). We use the European Patent Office's API (EPO, 2022) to access patents and patent applications filed in Germany, consistent with our research design. Focusing on German patents allows us to eliminate the effect of different international patenting reach and intellectual property strategies of the different companies. Furthermore, considering patent applications rather than only granted patents gives us more nuanced insights into the innovation efforts of each of the companies. Patents and patent applications from 2000 until 2020 were considered, capturing the relevant timespan of the emergence of electromobility technologies and the electric vehicle niche. The search was narrowed down to the patent subclass B60L (USPTO, 2022), concerned with the "propulsion of electrically-propelled vehicles" to ensure the fit of the patents with our electromobility focus.

4.2.2. Archival data

To identify the niche emergence stages and structure the patent data analysis, we use key events of each company, including announcements and releases related to the electrification of their products. In addition to the three major car companies (VW, MB, and BMW), the events associated with Tesla were included as they are the primary influence in electromobility. We conducted a search on *LexisNexis* using the string “electric AND (vehicle OR car) AND (Mercedes OR Tesla OR BMW OR Volkswagen OR VW) AND (announce* OR present* OR show* OR release),” limiting the search to articles released in *The New York Times* or *Financial Times* as generalist newspaper that follow industry business updates. Afterwards, a search was conducted within the article sample using the new car’s names, i.e., “Model S” or “i3”, to narrow down the results. To ensure that we did not miss pivotal events in our study context, we did an additional search of articles in the leading economic news newspaper, the *Frankfurter Allgemeine*, covering the same period and topics. We complemented the data with inputs from industry experts, including new sources when necessary.

4.3. Methods

Given the explorative nature of this work, case-based methods are most appropriate (Eisenhardt, 1989; De Massis and Kammerlander, 2020). We follow a longitudinal case design to capture the temporal, unfolding nature of the shock. To thoroughly capture the dynamics of the case and judge the suitability of the proposed theoretical framework, we conduct a three-step analysis following a conceptualized composition approach (see Song et al., 2024), summarized in Figure 2. The following sub-sections explain our steps to evaluate and conduct our data analysis.

4.3.1. Step 1: identifying the industry stages

We identify the critical events in the recent history of electromobility. Specifically, the initial commercialization in the niche market and when the three major German car manufacturers entered the electromobility market. We complement this data with the electromobility patenting behavior of each firm as an indicator of their overall knowledge activity. We identify the crucial events by recording the dates of official announcements. We determine the niche market entering the mainstream market, as the first commercialization happens, makes the niche visible, and the accumulation of sales signals the firm take-off. Finally, we used the sales data (units) of electric vehicles in the German market (Statista, 2023) to determine the sales take-off.

4.3.2. Step 2: identifying the focus of innovation efforts

In the second step, we analyze the number of patent applications in electromobility for each international patent class. We identify the five most relevant subclasses for each industry evolution stage and company to unveil the focus of the knowledge search and innovation efforts. The longitudinal view of the activity in each subclass gives us a nuanced view of how the incumbents shifted or maintained their focus, helping us to understand whether they relied on external knowledge.

4.3.3. Step 3: mapping the knowledge flows

In this step, we take a closer look at the source of the knowledge. Patent citations have been the predominant indicator for knowledge flows (Jaffe et al., 1993; Thompson and Fox-Kean, 2005; Agarwal et al., 2009; Natalicchio et al., 2019). While patent citations might not capture all types of collaborations, they indicate informal knowledge flows (Corsino et al., 2019). We use the inventor’s citations as they better capture the actual knowledge flows (Criscuolo and Verspagen, 2008) and are not exposed to the modification introduced by the examiner’s requests (Alcácer and Gittelman, 2006).

We categorize the source of knowledge into internal and external sources. Self-citations of the respective company depict internal knowledge sourcing. The external sources are further subdivided based on their proximity to the current technological regime. We also consider whether the knowledge stems from known market competitors and suppliers. Existing suppliers are characterized by a clear focus on traditional car manufacturing components (internal combustion engines), not specific to electric vehicles. External knowledge sources have a clear focus on electric vehicle-specific components. We also look at other actors, complementors, or suppliers of generic goods and services, that are not directly related to car manufacturing, e.g., infrastructure and software providers. Private applicants and holding companies without affiliations were not assigned to any groups. We use tables (see Tables 2–4) and network plots (see Figures 5–7) to present this information. The tables provide a structure to present and quantify the behaviors; the network plots allow us to visually represent the patent citation dependencies and how they change in each of the stages.

5. Results

The results are presented following the steps presented in the method section. We use graphical

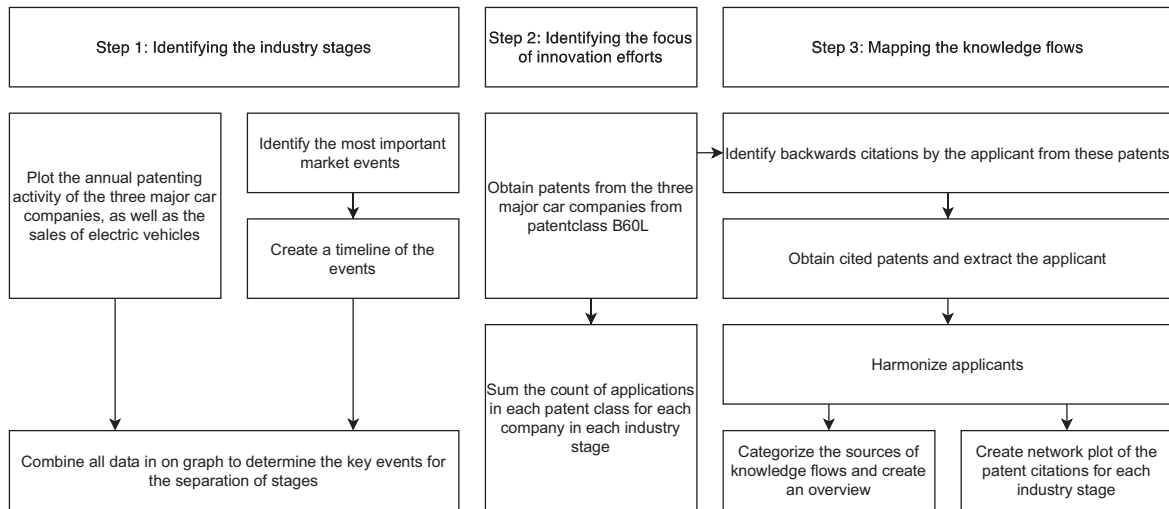


Figure 2. Overview of the study method and steps followed in the analysis of the data.

representations to aid in the visualization of the data to assess our theoretical framework.

5.1. Step 1: identifying the niche emergence and industry evolution stages

We plot the innovation efforts using the annual patent applications data. Figure 3, shows all three companies' annual patenting activity in electromobility in relation to the Germany-wide trend. The plot shows that the three companies started their patenting activity around 2006. After a gradual increase in patenting up to 2017, the annual patenting activity spikes. All

three companies follow very similar uptake in their patenting activity trajectory.

Using the news articles, we built a timeline of the most important events regarding product launches, releases, and announcements, summarized in Table 1.

These identified events are combined with the patenting and annual sales plot to create the rich timeline drawn in Figure 4, where each event is placed on the horizontal axis as per their actual date.

5.1.1. The key emergence events: from niche to firm take-off

Identifying the first commercialization for an electric car is not straightforward. Early electric cars

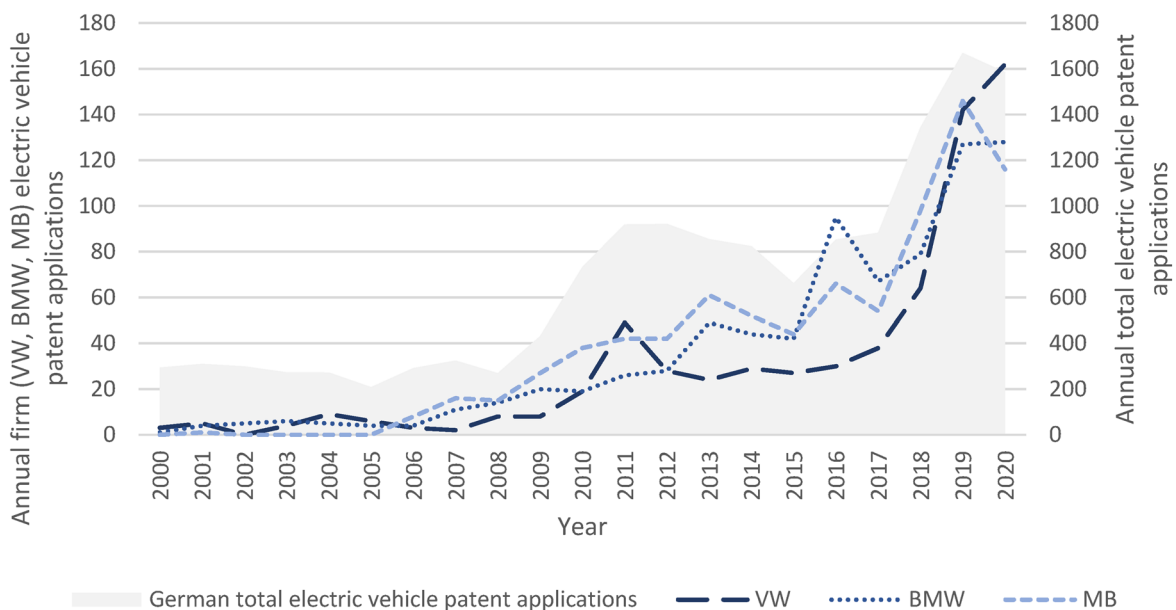


Figure 3. Summary of all patenting activities. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

Table 1. Description of key events in the electric vehicle (EV) innovation shock

Key events in the industry related to the electric vehicle			
Event	Date		Source
Tesla unveils “Roadster”	Q3	2006	Wald (2006)
Tesla unveils “Model S”	Q1	2009	Financial Times (2009b)
MB reveals electric “SLS AMG”	Q3	2009	The New York Times (2009); Zöllter (2009)
MB buys 10% stake in Tesla	Q2	2009	Financial Times (2009a); Frankfurter Allgemeine (2009)
BMW inaugurates Germany’s first factory for electric cars	Q4	2010	Meck (2010); The New York Times (2010)
BMW unveils prototypes for “i3” and “i8”	Q3	2011	Appel (2011); The New York Times (2011)
Tesla shows first production version of “Model S”	Q4	2011	Financial Times (2011)
Tesla shows prototype of the third vehicle “Model X”	Q1	2012	The New York Times (2012)
BMW starts delivery of “i3” in US	Q2	2014	The New York Times (2014)
BMW delivers first “i8” in Germany	Q2	2014	BMW (2018); Loveday (2014)
Tesla adds “Model X” to its line-up	Q4	2015	The New York Times (2015)
VW reveals first “ID” concept car	Q3	2016	Appel and Schmidt (2016a); Financial Times (2016)
MB announces all-electric EQ division	Q4	2016	Appel and Schmidt (2016b); Bhatt (2016)
Tesla unveils Semi Truck	Q4	2017	The New York Times (2017)
“Cybertruck” unveiled by Tesla	Q4	2019	The New York Times (2019)
BMW announces “iX” SUV	Q4	2020	Lardinois (2020); Peitsmeier (2020)

date back as far as 1888 (Schrader, 2002); however, treating this as the first commercialization would not be accurate. According to Moeen et al. (2020), the first commercialization must indicate viability in the mainstream market. Consequently, the event signaling the first commercialization should have significant market resonance. While the first electric car from Tesla appeared in 2006 with the Roadster (Wald, 2006), we argue that this is not the first commercialization milestone for the industry. Instead, the announcement of the Model S in 2009 is more appropriate. It is the first time a car addressed to the mainstream market was introduced, receiving significant pre-orders, and eventually successfully commercialized in a high volume.

We identify the firm take-off when the incumbents start to join the niche, triggering an industry evolution. BMW was the first incumbent to launch a response with their i3 and i8 cars in 2014 (The New York Times, 2011). Both MB and VW committed to electromobility at the end of 2016, supported by an uptake in patent activity, suggesting firm take-off at the end of 2016.

Finally, the sales take-off stage becomes evident in the electric vehicle sales uptrend. Sales of electric vehicles in the German market grew slowly from 2016 onwards until increasing by almost 400% from 2019 to 2020, characteristic of the

sales take-off stage in a new industry (Golder and Tellis, 1997).

Consequently, we separate the industry stages into the incubation stage 2000–2009, the prefirm take-off stage 2010–2016, and the pre-sales take-off stage 2017–2020. We make these stages visible in Figure 4.

5.2. Step 2: identifying the focus of innovation efforts

The results of the analysis of the knowledge search efforts are shown in the list the five most important IPC classes by company and stage. Each IPC class receives a short title that summarizes its long description. All three companies follow a similar trend (see Table 2), focusing on fuel cells and related components in the first two stages of the industry evolution. In the third stage, fuel cells are no longer the priority; it becomes evident that it is not the technology behind the innovation shock. Instead, the focus rapidly shifts toward electric engines, charging, and batteries.

5.3. Step 3: mapping the knowledge flows

Finally, we use the backward citations to map the source of the knowledge flows. Table 3 shows the total number of patents, the number of citations, and

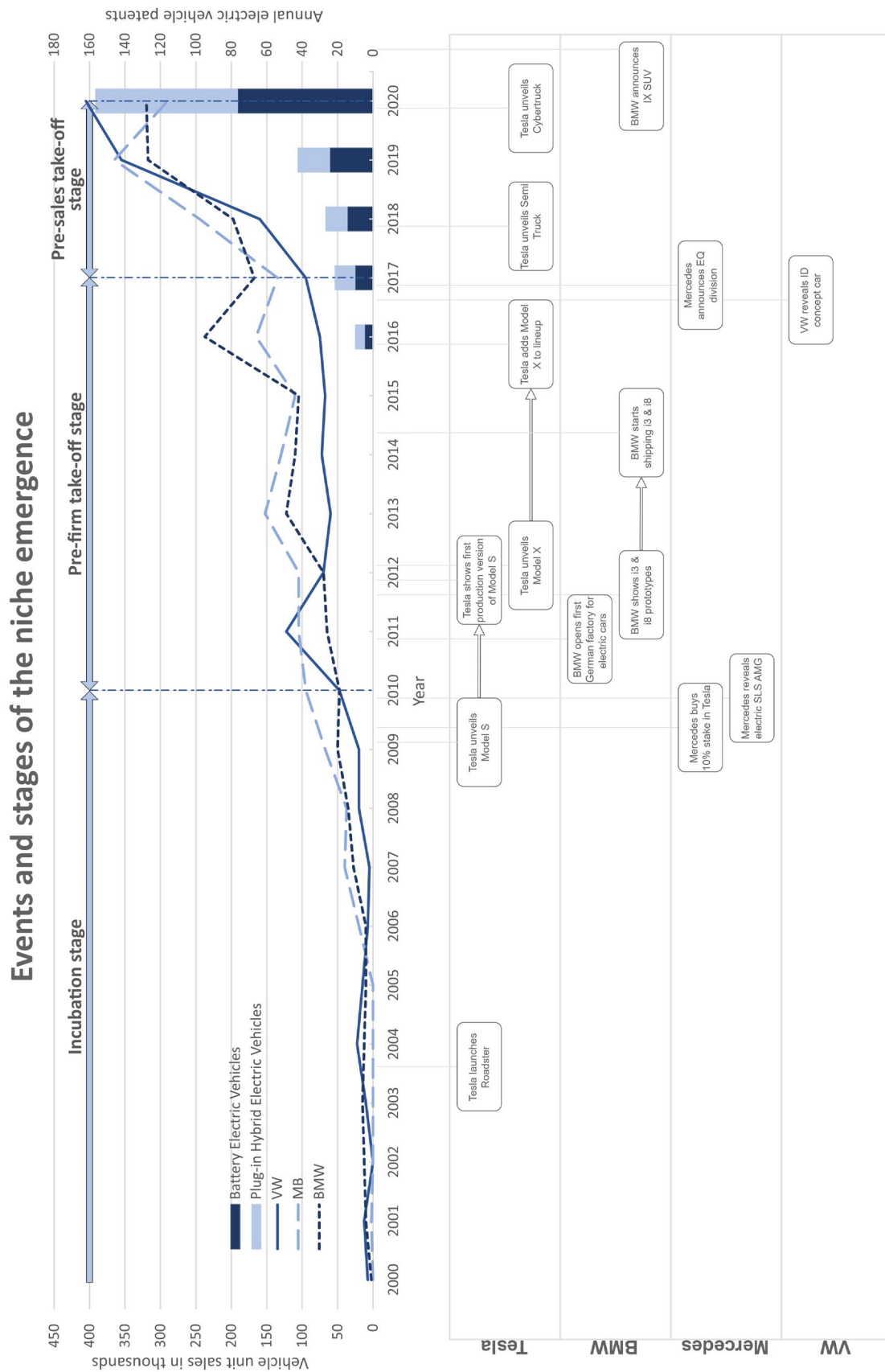


Figure 4. Full timeline, merging the sales and patent activity plot with the key events in the niche and indicating the three phases. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

Table 2. IPC class counts by stage and company
IPC classes by stage and company

Stage 1			Stage 2			Stage 3		
IPC code	Name	Count	IPC code	Name	Count	IPC code	Name	Count
BMW	B60L50/15	20	B60L11/18	Electric propulsion by fuel cells	218	B60L50/64	Batteries	112
	B60L11/18	13	H02J7/00	Battery charging	131	B60L50/60	Electric propulsion by battery	63
	B60W20/00	9	B60L3/00	Safety monitoring	41	H01M10/625	Batteries for vehicles	49
	B60L1/00	8	B60R16/03	Circuits	22	H02J7/00	Battery charging	48
	B60L7/24	6	B60L50/15	Electric propulsion	21	B60L50/50	Electric engines	47
	B60W10/08	6	B60R16/033	Circuits	18	H01M50/20	Auxiliary parts for fuel cells	38
MB	B60L11/18	26	B60L11/18	Electric propulsion by fuel cells	283	B60L11/18	Electric propulsion by fuel cells	64
	B60L50/15	16	H02J7/00	Battery charging	137	H02J7/00	Battery charging	64
	H01M8/04	8	B60L3/00	Safety monitoring	50	B60L50/60	Electric propulsion by battery	54
	H02J7/00	7	H01M8/04	Hydrogen fluid control	36	B60L3/00	Safety monitoring	46
VW	B60W20/00	6	B60R16/03	Circuits	33	B60L53/16	Charging of electric vehicles	46
	B60L1/00	6	H02J17/00	Inductive power transfer	25	B60L50/64	Batteries	39
	B60L50/15	15	B60L11/18	Electric propulsion by fuel cells	146	B60L50/64	Batteries	76
	B60W10/08	13	H02J7/00	Battery charging	77	B60L50/60	Electric propulsion by battery	47
	B60W20/00	13	B60L3/00	Safety monitoring	32	B60K1/04	Quick Battery replacement	43
	B60L11/18	9	B60R16/03	Circuits	21	H02J7/00	Battery charging	41
	B60W10/06	8	H02J1/00	Circuits	15	B60L50/50	Electric engines	34
	B60W10/26	7	B60R16/033	Circuits	15	B60L53/16	Charging of electric vehicles	32

Table 3. Identified patents by company and number of citations

Identified patents			
Company	Patent count	Citations	Matched applicants
BMW	819	514	507
MB	884	937	932
VW	691	1,021	1,015

the matched applicants. We use this data to present the source of the knowledge.

Our data had a total of 518 unique applicants after harmonization of applicant names. We assigned a category to each applicant, the subcategories were aggregated for each company and phase, as seen in Table 4. In the table, we differentiate between internal knowledge, citations to the same firm, and external knowledge (either close or distant) when the citations are to other firms' patents.

For all three companies, we can see a drop in internal knowledge sourcing during the second stage, followed by an increase in the third stage. Notably, the share of internal knowledge sourcing differs significantly, with VW consistently sourcing the least knowledge internally and MB the most. All companies rely heavily on old partners and competitors throughout all stages.

Using the citation data, we create a network graph for each stage.¹ Each node represents an actor cited, with the number in brackets indicating the total amount of citations received. The three major companies investigated in this study receive a distinct color to identify the source of citations. Both nodes and edges scale with the number of citations received. To increase readability, the second and third graphs were pruned only to show nodes that received at least three citations. The resulting graphs for each of the three stages are plotted in Figures 5–7, respectively.

The network grows in both size and diversity in each stage. MB is the node receiving the most citations throughout all three stages. Due to the physical simulation, nodes relevant to all three companies are drawn toward the center of the three companies. This shows that the core of knowledge during stages two and three is dominated by other car companies, as well as Siemens and Bosch. Notably, as the network of knowledge exchanges increases, Bosch becomes the second most significant source of knowledge after MB and exceeds both BMW and VW in patent citations in all stages.

6. Discussion

In our study, we proposed and explored a theoretical framework that connects innovation shocks, uncertainty, and firm-level responses. We expected to capture adjustments in the knowledge search activity of firms undergoing technology and market disruptions in their industry. We had theorized that changes in their knowledge search (internal vs. external) would be explained by a transition in the sources of uncertainty from technology to market. Using data from a group of established firms with geographic proximity and similar cultural factors, we expected to observe firm-level differences in their R&D behavior. Our data shows the slow reaction of incumbents to an innovation shock created by the successful emergence of a niche. We find evidence of the incumbents' response difficulties, first in their attempt to build internal knowledge to catch-up and match the technology, and later to imitate the new entrant's product as the niche gains market presence. We capture how the emergence of a niche promotes an industry evolution situation, where knowledge flows are restructured, giving opportunities to established and new firms to (re-) position themselves. We next discuss the study's

Table 4. Source of knowledge flows: internal or external (close or distant)

Source of knowledge flows				
Company	Scope of knowledge search	Stage 1 (%)	Stage 2 (%)	Stage 3 (%)
VW	Internal	12.12	7.80	10.33
	External (close)	63.64	67.93	62.33
	External (distant)	15.15	16.70	20.65
MB	Internal	31.34	22.74	35.58
	External (close)	40.30	47.56	45.35
	External (distant)	23.88	16.71	12.79
BMW	Internal	20.00	14.53	16.67
	External (close)	68.57	54.27	65.38
	External (distant)	5.71	22.22	11.54

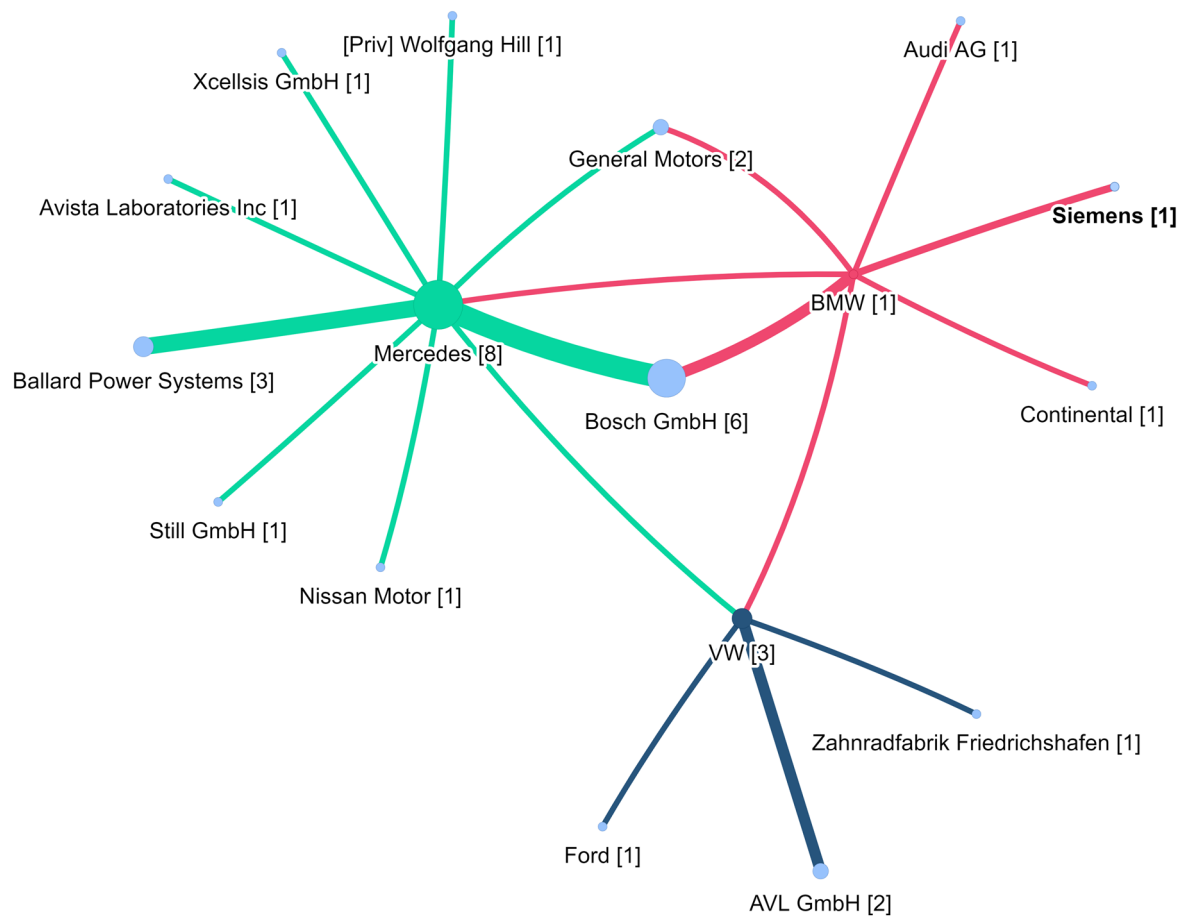


Figure 5. Stage 1, Incubation stage 2000–2009. [Colour figure can be viewed at wileyonlinelibrary.com]

results, explain why our initial theoretical framework did not anticipate the actual response dynamics, and describe the limitations of our findings.

6.1. Alternative explanations for local and external search

As we analyzed the response path of each of the firms, we observed an overall tendency to rely excessively on local search that offers access to external, but close, knowledge. In line with Li-Ying et al. (2014), we identified a case where geographic proximity harms the companies' long term innovation output, limiting their search scope (Tripsas, 1997) and over relying on direct observation of competitors' behavior. An important drawback of this R&D behavior is to underestimate the niche emergence. External (local) knowledge might not represent global excellence in the new domain (Brem and Nylund, 2021), and might not provide a good match for the new technology. This problem resonates with the observation of Ozalp and Kretschmer (2019) who argue that information-based imitation by an incumbent

requires understanding how the technology works and is integrated in the products.

We speculate that MB's quicker (compared to VW and BMW) response to the innovation shock can be explained by its internal knowledge (see Table 4). MB was able to decipher the technology and magnitude of the innovation shock and leverage the necessary R&D capabilities. This would support the insight from Giustiziero et al. (2019) on a dual response option to the new entrant, balancing an accelerated internal effort and an imitation approach. A potential explanation of this behavior is the unique inside knowledge MB gained as an active investor in Tesla. This allowed MB to decode better the actual technology and how to potentially match its performance, while the other incumbents were exposed to higher technology uncertainty (Agarwal and Audretsch, 2001).

6.2. Delayed transition to broaden search

Our framework posits that firms facing an innovation shock would shift from internal to external knowledge as they realize they cannot match the

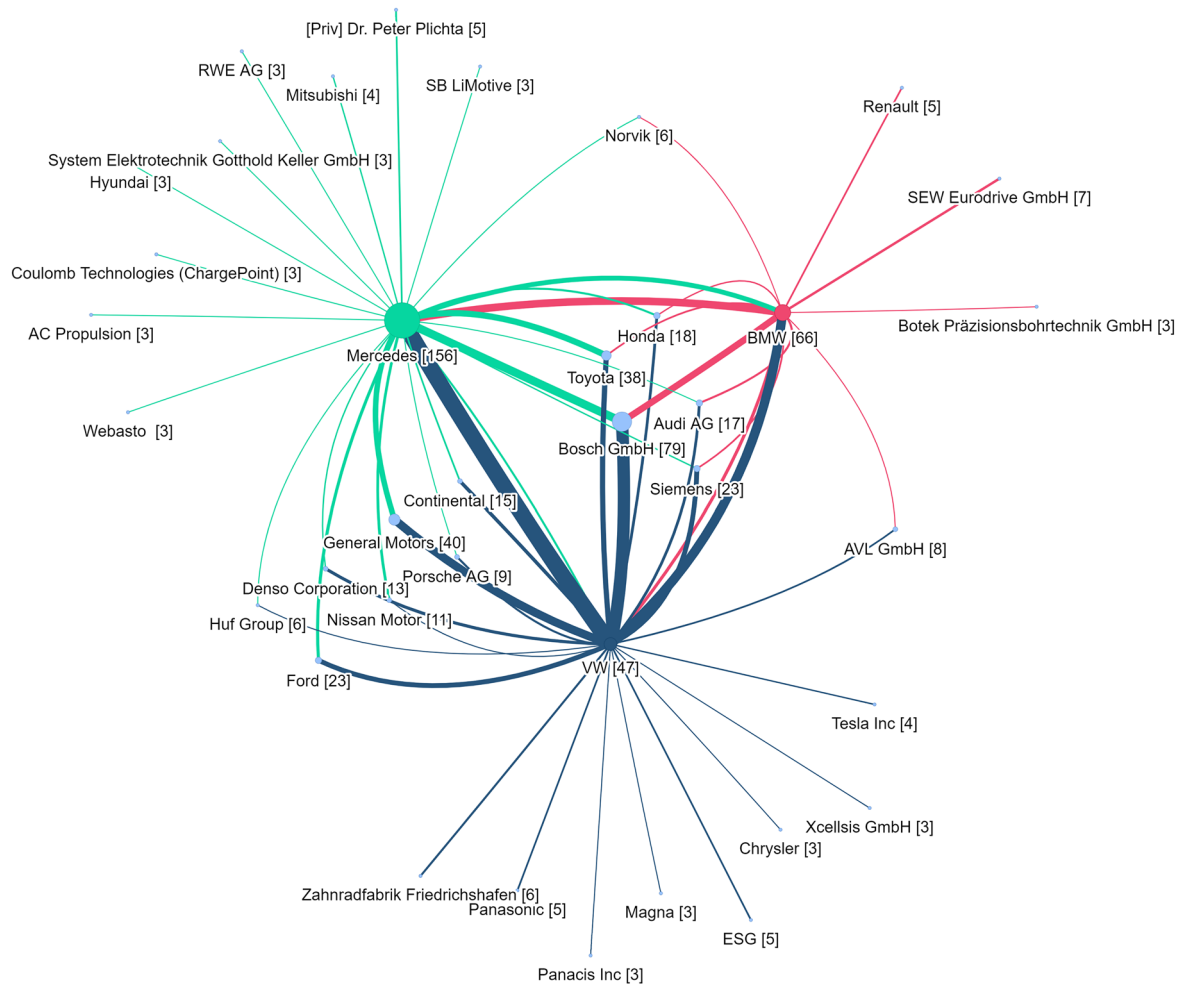


Figure 6. Stage 2, Prefirm takeoff stage 2010–2016. [Colour figure can be viewed at wileyonlinelibrary.com]

technology performance (see Figure 1). However, the response of the incumbents shows little to no activity in the new entrant's technology, staying committed to their existing innovation direction and prior R&D investments (e.g., fuel cells) as shown in Table 2. Their negative prior experiences on alternative technologies to the combustion engine did not help them to decode the actual threat of the electric vehicle technology (Argyres et al., 2015; Ozalp and Kretschmer, 2019). Either assuming that it was not superior to their internal knowledge, or that the new entrant's technology would fail to deliver. Instead of shifting gears or starting to imitate, they doubled down on their R&D efforts on the fuel cells technology. Supporting the idea that the failure-driven inertia of incumbents is hard to overcome (Eggers, 2012).

Their strong reliance on few sources of knowledge (mostly local) and their focus on efficiency, led to an ingrained reduction of resources dedicated to supporting search breadth, internally or externally. Contrary to the findings of Chiang and Hung (2010),

this situation did not facilitate the development of radical innovations by the industry incumbents.

Interestingly, prior research on responses to innovation shocks (see Argyres et al., 2015) disregarded the option of persevering with no changes (Wenzel et al., 2021). An innovation shock is not “only” a temporal shock to the industry, it is a non-formative disruption. It is plausible, that the leading firms in the German car manufacturing industry could have miscalculated the impact of the electric vehicle innovation shock, underestimating both the technological complexity and its market acceptance. This could explain the misaligned R&D reaction (holding on to alternative technologies for too long) and the delayed imitation response to rival the new entrant—they failed to learn fast enough (Giustiziero et al., 2019) in a context where “innovating may be increasingly valuable, if not unavoidable to sustain firm survival” (Wenzel et al., 2021).

By maintaining a strong focus on the competing technology of fuel cells, all three companies failed to

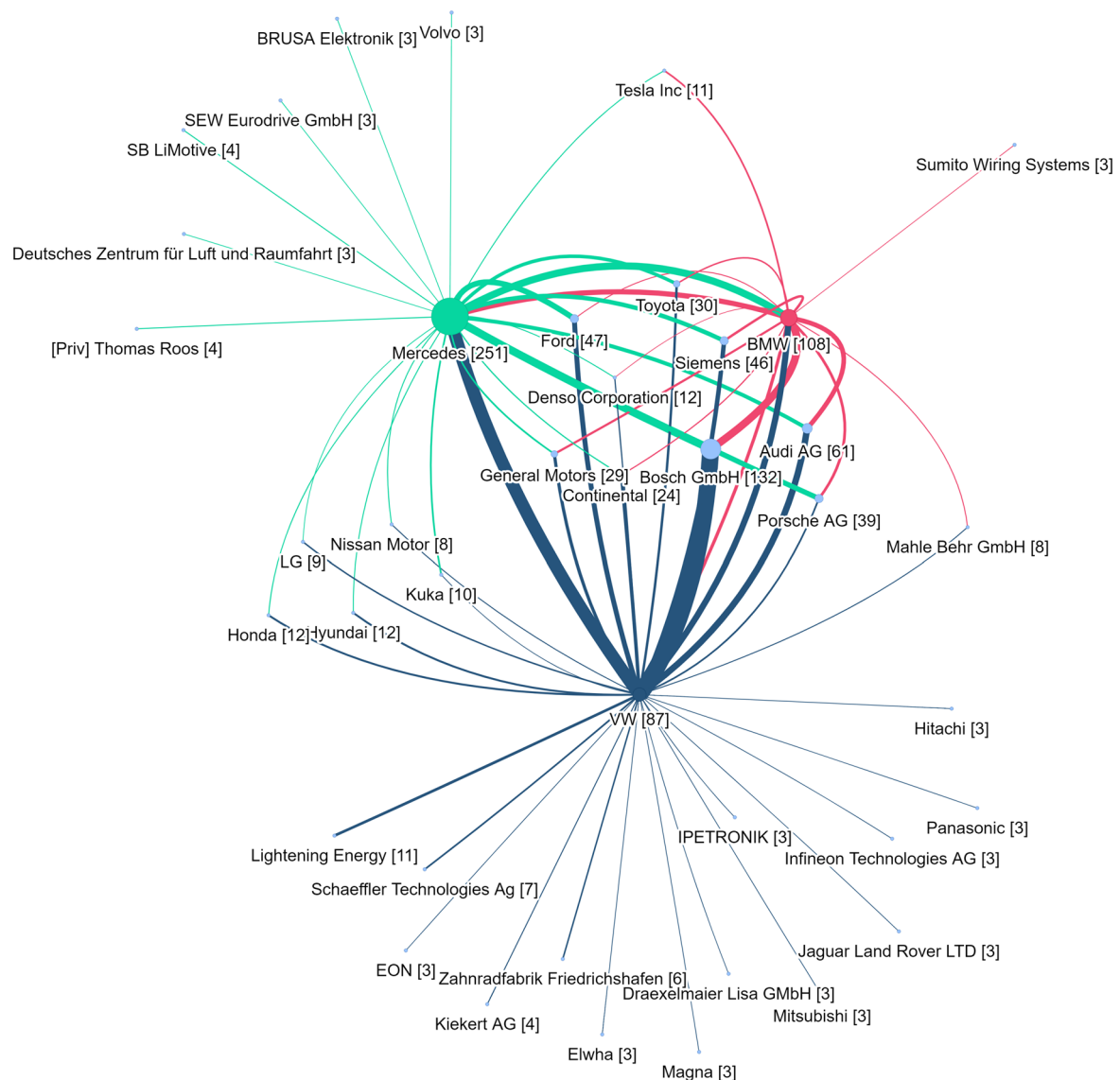


Figure 7. Stage 3: Presales takeoff stage 2017–2020. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

integrate crucial knowledge of the new technology. Likely their prolonged focus on static efficiency, i.e. cost optimization did not only slow down their initial response, but also retarded their later actions, as they assumed they were already too far behind (Ghemawat and Costa, 1993). This in turn resulted in their reliance—and dependency—on actors who possessed this knowledge during the later stages. We elaborate on this in the following section.

6.3. Enabling the industry evolution by filling the gaps in the innovation system

A surprising finding in our analysis is that a secondary actor in the automotive industry, Bosch, stepped in as what is described as a hub firm (Dhanaraj and

Parkhe, 2006; Remneland Wikhamn and Styhre, 2022). It filled the growing knowledge gap between the evolving electric vehicle niche and the prior technical knowledge of the leading car manufacturers.

In only a few years, Bosch emerges as a central source of knowledge for the incumbents. When discussed in the context of innovation systems research, this is a situation where a network of loosely coupled actors interdependently create value (Ritala et al., 2013; Adner and Kapoor, 2016; Dattee et al., 2018; Jacobides et al., 2018). The new central position for Bosch, in the latter stage of evolution, makes it a knowledge bottleneck. It has contributed to the final response of the incumbents, but it has created a knowledge dependency that could “limit the growth or the performance of the ecosystem” (Shipilov and Gawer, 2020). The industry structure has evolved,

redefining the inter-ecosystem cooperation and competition dynamics (Hannah and Eisenhardt, 2018).

6.4. Limitations of the study

Our work is not absent from limitations; some are related to the data we used, others to our research design choices. First, as we built out a study using patents, we miss some nascent non-patented R&D activity that might have happened inside the different organizations. Second, although we combined patent and news articles, we could not capture innovation strategy discussions that might have been occurring inside the car manufacturing firms. Similarly, we could have extended our study to all car manufacturing firms, capturing potential cultural or additional technological differences in their response to the innovation shock. Most of our limitations could hopefully set the ground for other researchers to continue exploring how technology and market disruptions trigger uncertainty among industry players, opening opportunities for new entrants and accelerating industry evolution.

7. Implications

Our study addresses the relationship between innovation shocks, firm-level response, and industry evolution. We contribute to the discussion on technology disruptions and industry emergence by identifying the potential mechanisms that explain industry renewal (Gustafsson et al., 2016). We theorize and explore a framework where incumbents can adjust their knowledge search behavior as an innovation shock unfolds. Tracing knowledge flows in the R&D activities of the incumbents, we illustrate how knowledge search—internal and external—reflects differences in perceived uncertainty (from technology to market) and biases in the observation of technology and expected market dynamics.

Our results support research appeals for micro-level perspectives to explain differences in firm-level technology trajectories, understanding how the complementors role can influence the industry's future (B. Wu et al., 2014)—exemplified in our case with the new central role of Bosch in the ecosystem. We also show that new entrants ability to overcome technological challenges and gain market traction can displace incumbents, in particular when the new technology competes with existent alternative technologies and knowledge domains (S. L. Cohen and Tripsas, 2018; Eggers and Park, 2018).

7.1. R&D managerial implications

We have used a notorious case to study how incumbents might struggle to respond to a new entrant that transforms a niche into an industry-wide innovation shock. Our results provide valuable lessons for R&D and technology innovation managers.

We observed that sustaining a high level of R&D activity is insufficient to respond to an innovation shock. Established players should combine a diversity of internal R&D activities that allow them to keep their options open, increasing their ability to decode emerging technologies. Instead of fighting the unavoidable organizational inertia, we suggest “relaxing” the requirements to engage in external distant knowledge search, keeping organizational resources engaged with weak signals and anomalies (Reeves et al., 2021). In our study, the early investments in EVs done by MB might not have been financially sound, but they gave them a relative advantage in responding to the innovation shock.

8. Conclusions

The evolution and transformation of an industry is inherently related to periodic disruptions that create uncertainty. These disruptions can trigger innovation shocks forcing established firms to search for knowledge within and beyond their R&D activities. This can result in a substantial renewal at an industry level, with new niches emerging and a rebalancing of the relationships between focal firms and complementors. We propose a theoretical framework to explain how the response of incumbents reflects distinct uncertainty sources during an innovation shock. We use data from leading car manufacturing firms' responses to the electric vehicle emergence to explain this complex problem. We posit that the geographic and knowledge proximity creates not only a shared inertia among incumbents but also additional challenges to decipher the technology and market magnitude of the innovation shock. The accelerated evolution of the industry offers opportunities to specialized firms to fill the knowledge gap and increase their importance in the ecosystem and overall industry.

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement no. 956745. Results reflect the author's view only. The European Commission is not responsible

for any use that may be made of the information it contains. Open Access funding enabled and organized by Projekt DEAL.

Conflict of interest

The authors declare that there are no conflicts of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

- Adner, R. (2012) *The Wide Lens: A New Strategy for Innovation*. London: Portfolio Penguin.
- Adner, R. and Kapoor, R. (2016) Innovation ecosystems and the pace of substitution: re-examining technology S-curves. *Strategic Management Journal*, **37**, 4, 625–648. <https://doi.org/10.1002/smj.2363>.
- Agarwal, R. and Audretsch, D.B. (2001) Does entry size matter? The impact of the life cycle and technology on firm survival. *Journal of Industrial Economics*, **49**, 1, 21–43. <https://doi.org/10.1111/1467-6451.00136>.
- Agarwal, R. and Bayus, B.L. (2002) The market evolution and sales takeoff of product innovations. *Management Science*, **48**, 8, 1024–1041. <https://doi.org/10.1287/mnsc.48.8.1024.167>.
- Agarwal, R., Ganco, M., and Ziedonis, R.H. (2009) Reputations for toughness in patent enforcement: implications for knowledge spillovers via inventor mobility. *Strategic Management Journal*, **30**, 13, 1349–1374. <https://doi.org/10.1002/smj.792>.
- Agarwal, R., Buenstorf, G., Cohen, W.M., and Malerba, F. (2015) The legacy of Steven Klepper: industry evolution, entrepreneurship, and geography. *Industrial and Corporate Change*, **24**, 4, 739–753. <https://doi.org/10.1093/icc/dtv030>.
- Agarwal, R., Moeen, M., and Shah, S.K. (2017) Athena's birth: triggers, actors, and actions preceding industry inception. *Strategic Entrepreneurship Journal*, **11**, 3, 287–305. <https://doi.org/10.1002/sej.1259>.
- Alcácer, J. and Gittelman, M. (2006) Patent citations as a measure of knowledge flows: the influence of examiner citations. *The Review of Economics and Statistics*, **88**, 4, 774–779.
- Appel, H. (2011) BMW i3 und i8: Bayerische Elektromotoren Werke. *Frankfurter Allgemeine*. <https://www.faz.net/aktuell/technik-motor/motor/bmw-i3-und-i8-bayerische-elektromotoren-werke-11108307.html>.
- Appel, H. and Schmidt, B. (2016a) Pariser Autosalon: Ohmmächtig an der Seine. *Frankfurter Allgemeine*. <https://www.faz.net/aktuell/technik-motor/motor/pariser-autosalon-ohmmaechtig-an-der-seine-14462632.html>.
- Appel, H. and Schmidt, B. (2016b) Pariser Autosalon: Ohmmächtig an der Seine. *Frankfurter Allgemeine*.
- Argyres, N., Bigelow, L., and Nickerson, J.A. (2015) Dominant designs, innovation shocks, and the follower's dilemma. *Strategic Management Journal*, **36**, 2, 216–234. <https://doi.org/10.1002/smj.2207>.
- Bakker, S. (2010) The car industry and the blow-out of the hydrogen hype. *Energy Policy*, **38**, 11, 6540–6544. <https://doi.org/10.1016/j.enpol.2010.07.019>.
- Bhaskarabhatla, A. and Klepper, S. (2014) Latent submarket dynamics and industry evolution: lessons from the US laser industry. *Industrial and Corporate Change*, **23**, 6, 1381–1415. <https://doi.org/10.1093/icc/dtt060>.
- Bhatt, S. (2016) *Paris motor show: Mercedes-Benz announces all-electric EQ division*.
- Bi, J., Sarpong, D., Botchie, D., and Rao-Nicholson, R. (2017) From imitation to innovation: the discursive processes of knowledge creation in the Chinese space industry. *Technological Forecasting and Social Change*, **120**, 261–270. <https://doi.org/10.1016/j.techfore.2017.01.008>.
- Bigelow, L., Nickerson, J.A., and Park, W.Y. (2019) When and how to shift gears: dynamic trade-offs among adjustment, opportunity, and transaction costs in response to an innovation shock. *Strategic Management Journal*, **40**, 3, 377–407. <https://doi.org/10.1002/smj.2996>.
- BMW (2018) *Feierliche Auslieferung von 18 der ersten BMW i8 Roadster in der BMW Welt. Streng limitierte First Edition mit exklusiver Nummerierung „1 of 18“ geht an den internationalen BMW i8 Club e.V.* <https://www.press.bmwgroup.com/deutschland/article/detail/T0281407DE/feierliche-auslieferung-von-18-der-ersten-bmw-i8-roadster-in-der-bmw-welt-streng-limitierte-first-edition-mit-exklusiver-nummerierung-„1-of-18“-geht-an-den-internationalen-bmw-i8-club-e->
- Brem, A. and Nylund, P.A. (2021) Maneuvering the bumps in the new silk road: open innovation, technological complexity, dominant design, and the international impact of Chinese innovation. *R and D Management*, **51**, 3, 293–308. <https://doi.org/10.1111/rdm.12451>.
- Cassiman, B. and Veugelers, R. (2006) In search of complementarity in innovation strategy: internal R & D and external knowledge acquisition. *Management Science*, **52**, 1, 68–82. <https://doi.org/10.1287/mnsc.1050.0470>.
- Chandler, D. and Hwang, H. (2015) Learning from learning theory. *Journal of Management*, **41**, 5, 1446–1476. <https://doi.org/10.1177/0149206315572698>.
- Chiang, Y.H. and Hung, K.P. (2010) Exploring open search strategies and perceived innovation performance from the perspective of inter-organizational knowledge flows. *R and D Management*, **40**, 3, 292–299. <https://doi.org/10.1111/j.1467-9310.2010.00588.x>.
- Cohen, W.M. and Levinthal, D.A. (1990) Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, **35**, 1, 128–152.
- Cohen, S.L. and Tripsas, M. (2018) Managing technological transitions by building bridges. *Academy of*

- Management Journal*, **61**, 6, 2319–2342. <https://doi.org/10.5465/amj.2015.0690>.
- Companies Market Cap (2022) *Largest automakers by market capitalization* <https://companiesmarketcap.com/automakers/largest-automakers-by-market-cap/>.
- Corsino, M., Mariani, M., and Torrisi, S. (2019) Firm strategic behavior and the measurement of knowledge flows with patent citations. *Strategic Management Journal*, **40**, 7, 1040–1069. <https://doi.org/10.1002/smj.3016>.
- Criscuolo, P. and Verspagen, B. (2008) Does it matter where patent citations come from? Inventor vs. examiner citations in European patents. *Research Policy*, **37**, 10, 1892–1908. <https://doi.org/10.1016/j.respol.2008.07.011>.
- Dattee, B., Alexy, O., and Autio, E. (2018) Maneuvering in poor visibility: how firms play the ecosystem game when uncertainty is high. *Academy of Management Journal*, **61**, 2, 466–498. <https://doi.org/10.5465/amj.2015.0869>.
- De Massis, A. and Kammerlander, N. (2020) *Handbook of qualitative research methods for family business*. Cheltenham: Edward Elgar Publishing.
- Dhanaraj, C. and Parkhe, A. (2006) Orchestrating innovation networks. *Academy of Management Review*, **31**, 3, 659–669. <https://doi.org/10.5465/amr.2006.21318923>.
- Du, X., Li, M., and Wu, B. (2019) Incumbent repositioning with decision biases. *Strategic Management Journal*, **40**, 12, 1984–2010. <https://doi.org/10.1002/smj.3047>.
- Eggers, J.P. (2012) Falling flat: failed technologies and investment under uncertainty. *Administrative Science Quarterly*, **57**, 1, 47–80. <https://doi.org/10.1177/0001839212447181>.
- Eggers, J.P. and Park, K.F. (2018) Incumbent adaptation to technological change: the past, present, and future of research on heterogeneous incumbent response. *Academy of Management Annals*, **12**, 1, 357–389. <https://doi.org/10.5465/annals.2016.0051>.
- Eisenhardt, K.M. (1989) Building theories from case study research. *Academy of Management Review*, **14**, 4, 532–550. <https://doi.org/10.5465/AMR.1989.4308385>.
- Enkel, E. and Gassmann, O. (2010) Creative imitation: exploring the case of cross-industry innovation. *R and D Management*, **40**, 3, 256–270. <https://doi.org/10.1111/j.1467-9310.2010.00591.x>.
- EPO (2022) *Open patent services (OPS)*. https://www.epo.org/searching-for-patents/data/web-services/ops_de.html.
- Financial Times (2009a) Daimler buys near 10% stake in pioneer Tesla.
- Financial Times (2009b) *Tesla unveils second electric car*.
- Financial Times (2011) *Tesla charged up after unveiling mass-market electric car*.
- Financial Times (2016) *VW unveils “new era” long-distance electric car; Automobiles*.
- Fleming, L. (2001) Recombinant uncertainty in technological search. *Management Science*, **47**, 1, 117–132. <https://doi.org/10.1287/mnsc.47.1.117.10671>.
- Frankfurter Allgemeine (2009) *Mit zehn Prozent: Daimler steigt bei Elektroautobauer Tesla ein*. 3–5. <https://www.faz.net/aktuell/wirtschaft/unternehmen/mit-zehn-prozent-daimler-steigt-bei-elektroautobauer-tesla-ein-1799679.html>.
- Furr, N.R. and Eisenhardt, K.M. (2021) Strategy and uncertainty: resource-based view, strategy-creation view, and the hybrid between them. *Journal of Management*, **47**, 7, 1915–1935. <https://doi.org/10.1177/01492063211011760>.
- Furr, N. and Kapoor, R. (2018) Capabilities, technologies, and firm exit during industry shakeout: evidence from the global solar photovoltaic industry. *Strategic Management Journal*, **39**, 1, 33–61. <https://doi.org/10.1002/smj.2709>.
- Ghemawat, P. and Costa, J.E.R. (1993) The organizational tension between static and dynamic efficiency. *Strategic Management Journal*, **14**, 59–73.
- Giustiziero, G., Kaul, A., and Wu, B. (2019) The dynamics of learning and competition in schumpeterian environments. *Organization Science*, **30**, 4, 668–693. <https://doi.org/10.1287/orsc.2018.1264>.
- Golder, P.N. and Tellis, G.J. (1997) Will it ever Fly? Modeling the takeoff of really new consumer durables. *Marketing Science*, **16**, 3, 256–270. <https://doi.org/10.1287/mksc.16.3.256>.
- Gort, M. and Klepper, S. (1982) Time paths in the diffusion of product innovations. *The Economic Journal*, **92**, 367, 630. <https://doi.org/10.2307/2232554>.
- Gustafsson, R., Jääskeläinen, M., Maula, M., and Uotila, J. (2016) Emergence of industries: a review and future directions. *International Journal of Management Reviews*, **18**, 1, 28–50. <https://doi.org/10.1111/ijmr.12057>.
- Hannah, D.P. and Eisenhardt, K.M. (2018) How firms navigate cooperation and competition in nascent ecosystems. *Strategic Management Journal*, **2017**, 3163–3192. <https://doi.org/10.1002/smj.2750>.
- Helfat, C.E. and Raubitschek, R.S. (2000) Product sequencing: co-evolution of knowledge, capabilities and products. *Strategic Management Journal*, **21**, 10–11, 961–979. [https://doi.org/10.1002/1097-0266\(200010/11\)21:10/11<961::AID-SMJ132>3.0.CO;2-E](https://doi.org/10.1002/1097-0266(200010/11)21:10/11<961::AID-SMJ132>3.0.CO;2-E).
- Jacobides, M.G., Cennamo, C., and Gawer, A. (2018) Towards a theory of ecosystems. *Strategic Management Journal*, **39**, 8, 2255–2276. <https://doi.org/10.1002/smj.2904>.
- Jaffe, A.B., Trajtenberg, M., and Henderson, R. (1993) Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, **108**, 3, 577–598. <https://doi.org/10.2307/2118401>.
- Jin, B. and Kirsch, D.A. (2022) The search for alternatives to internal combustion: instantiation mechanisms of institutional logics among scientists and engineers. *Industry and Innovation*, **29**, 10, 1231–1262. <https://doi.org/10.1080/13662716.2022.2114318>.
- Khanagha, S., Ramezan Zadeh, M.T., Mihalache, O.R., and Volberda, H.W. (2018) Embracing bewilderment: responding to technological disruption in heterogeneous

- market environments. *Journal of Management Studies*, **55**, 7, 1079–1121. <https://doi.org/10.1111/joms.12348>.
- Klepper, S. (1997) Industry life cycles. *Industrial and Corporate Change*, **6**, 1, 145–182.
- Lam, S.K., Ahearne, M., Hu, Y., and Schillewaert, N. (2010) Resistance to brand switching when a radically new brand is introduced: a social identity theory perspective. *Journal of Marketing*, **74**, 6, 128–146. <https://doi.org/10.1509/jmkg.74.6.128>.
- Lardinois, F. (2020) BMW announces the iX, its next-gen electric flagship.
- Lee, K. and Lim, C. (2001) Technological regimes, catching-up and leapfrogging: findings from the Korean industries. *Research Policy*, **30**, 3, 459–483. [https://doi.org/10.1016/S0048-7333\(00\)00088-3](https://doi.org/10.1016/S0048-7333(00)00088-3).
- Leiponen, A. and Helfat, C.E. (2010) Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic Management Journal*, **31**, 2, 224–236. <https://doi.org/10.1002/smj.807>.
- Lewin, A.Y., Massini, S., and Peeters, C. (2011) Microfoundations of internal and external absorptive capacity routines. *Organization Science*, **22**, 1, 81–98. <https://doi.org/10.1287/orsc.1100.0525>.
- Lin, Y., Chen, J., and Chen, Y. (2011) Backbone of technology evolution in the modern era automobile industry: an analysis by the patents citation network. *Journal of Systems Science and Systems Engineering*, **20**, 4, 416–442. <https://doi.org/10.1007/s11518-011-5181-y>.
- Li-Ying, J., Wang, Y., and Salomo, S. (2014) An inquiry on dimensions of external technology search and their influence on technological innovations: evidence from Chinese firms. *R and D Management*, **44**, 1, 53–74. <https://doi.org/10.1111/radm.12038>.
- Lopez-Vega, H. and Moodysson, J. (2023) Digital transformation of the automotive industry: an integrating framework to analyse technological novelty and breadth. *Industry and Innovation*, **30**, 1, 67–102. <https://doi.org/10.1080/13662716.2022.2151873>.
- Lopez-Vega, H., Tell, F., and Vanhaverbeke, W. (2016) Where and how to search? Search paths in open innovation. *Research Policy*, **45**, 1, 125–136. <https://doi.org/10.1016/j.respol.2015.08.003>.
- Loveday, E. (2014) World's first BMW i8 owners take delivery in Germany.
- Lucas, H.C. and Goh, J.M. (2009) Disruptive technology: how Kodak missed the digital photography revolution. *Journal of Strategic Information Systems*, **18**, 1, 46–55. <https://doi.org/10.1016/j.jsis.2009.01.002>.
- Meck, G. (2010) Staatsgeld gefordert – BMW schafft Arbeitsplätze für Elektroautos. *Frankfurter Allgemeine*, 2.
- Moeen, M. and Agarwal, R. (2017) Incubation of an industry: heterogeneous knowledge bases and modes of value capture. *Strategic Management Journal*, **38**, 3, 566–587. <https://doi.org/10.1002/smj.2511>.
- Moeen, M., Agarwal, R., and Shah, S.K. (2020) Building industries by building knowledge: uncertainty reduction over industry milestones. *Strategy Science*, **5**, 3, 218–244. <https://doi.org/10.1287/stsc.2020.0103>.
- Murmann, J.P. and Schuler, B.A. (2022) Exploring the structure of internal combustion engine and battery electric vehicles: implications for the architecture of the automotive industry. *Industrial and Corporate Change*, **2022**, 1, 129–154. <https://doi.org/10.1093/icc/dtac049>.
- Natalicchio, A., Ardito, L., Messeni Petruzzelli, A., and Del Giudice, M. (2019) The origins of external knowledge inflows and the impact of university technologies. *R&D Management*, **4**, radm.12354–radm.12651. <https://doi.org/10.1111/radm.12354>.
- Nelson, R.R. and Winter, S.G. (1982) *An evolutionary theory of economic change*. Cambridge: Harvard University Press.
- Ozalp, H. and Kretschmer, T. (2019) Follow the crowd or follow the trailblazer? The differential role of firm experience in product entry decisions in the US video game industry. *Journal of Management Studies*, **56**, 7, 1452–1481. <https://doi.org/10.1111/joms.12389>.
- Ozalp, H., Eggers, J.P., and Malerba, F. (2023) Hitting reset: industry evolution, generational technology cycles, and the dynamic value of firm experience. *Strategic Management Journal*, **44**, 5, 1292–1327. <https://doi.org/10.1002/smj.3468>.
- Peeters, T. and Martin, X. (2017) Strategies for knowledge use in R&D and their implications for innovative performance. *R and D Management*, **47**, 1, 47–60. <https://doi.org/10.1111/radm.12144>.
- Peitsmeier, H. (2020) Intelligentes E-Auzto von BMW: Gucken muss der Fahrer noch selbst. *Frankfurter Allgemeine*. <https://www.faz.net/aktuell/wirtschaft/auto-verkehr/elektroauto-von-bmw-autonom-und-elekt-risch-mit-dem-ix-fahren-17047953.html>.
- Reeves, M., Goodson, B., and Whitaker, K. (2021) The power of anomaly. *Harvard Business Review*.
- Remneland Wikhamn, B. and Styhre, A. (2022) Open innovation ecosystem organizing from a process view: a longitudinal study in the making of an innovation hub. *R&D Management*, **53**, 24–42. <https://doi.org/10.1111/radm.12537>.
- Ritala, P., Agouridas, V., Assimakopoulos, D., and Gies, O. (2013) Value creation and capture mechanisms in innovation ecosystems: a comparative case study. *International Journal of Technology Management*, **63**, 3–4, 244–267. <https://doi.org/10.1504/IJTM.2013.056900>.
- Rivkin, J.W. (2000) Imitation of complex strategies. *Management Science*, **46**, 6, 824–844. <https://doi.org/10.1287/mnsc.46.6.824.11940>.
- Roper, S. and Love, J.H. (2018) Knowledge context, learning and innovation: an integrating framework. *Industry and Innovation*, **25**, 4, 339–364. <https://doi.org/10.1080/13662716.2017.1414744>.
- Rosenkopf, L. and Almeida, P. (2003) Overcoming local search through alliances and mobility. *Management Science*, **49**, 6, 751–766. <https://doi.org/10.1287/mnsc.49.6.751.16026>.
- Rosenkopf, L. and Nerkar, A. (2001) Beyond local search: boundary-spanning, exploration, and impact in the optical disk industry. *Strategic Management Journal*, **22**, 4, 287–306. <https://doi.org/10.1002/smj.160>.
- Sanderson, S.W. and Simons, K.L. (2014) Light emitting diodes and the lighting revolution: the emergence of a

- solid-state lighting industry. *Research Policy*, **43**, 10, 1730–1746. <https://doi.org/10.1016/j.respol.2014.07.011>.
- Schilling, M.A. (2015) Technology Shocks, Technological Collaboration, and Innovation Outcomes. *Organization Science*, **26**, 3, 668–686. <https://doi.org/10.1287/orsc.2015.0970>.
- Schot, J. and Geels, F.W. (2007) Niches in evolutionary theories of technical change: a critical survey of the literature. *Journal of Evolutionary Economics*, **17**, 5, 605–622. <https://doi.org/10.1007/s00191-007-0057-5>.
- Schrader, H. (2002) *Deutsche Autos 1885–1920 (in German)*. Stuttgart: Motorbuch-Verlag.
- Shankar, R.K., Bettenmann, D., and Giones, F. (2023) Building hyper-awareness: how to amplify weak external signals for improved strategic agility. *California Management Review*, **65**, 4, 43–62. <https://doi.org/10.1177/00081256231184912>.
- Shipilov, A. and Gawer, A. (2020) Integrating research on interorganizational networks and ecosystems. *Academy of Management Annals*, **14**, 1, 92–121. <https://doi.org/10.5465/annals.2018.0121>.
- Smith, A. and Raven, R. (2012) What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, **41**, 6, 1025–1036. <https://doi.org/10.1016/j.respol.2011.12.012>.
- Song, J., Almeida, P., and Wu, G. (2003) Learning-by-hiring: when is mobility more likely to facilitate Interfirm knowledge transfer? *Management Science*, **49**, 4, 351–365. <https://doi.org/10.1287/mnsc.49.4.351.14429>.
- Song, Y., Gnyawali, D., and Qian, L. (2024) From early curiosity to space wide web: the emergence of the small satellite innovation ecosystem. *Research Policy*, **53**, 2, 104932. <https://doi.org/10.1016/j.respol.2023.104932>.
- Spithoven, A., Clarysse, B., and Knockaert, M. (2010) Building absorptive capacity to organise inbound open innovation in traditional industries. *Technovation*, **30**, 2, 130–141. <https://doi.org/10.1016/j.technovation.2009.08.004>.
- Statista (2023) *Electric vehicles – Germany*. <https://www.statista.com/outlook/mmo/electric-vehicles/germany>.
- Stringham, E.P., Miller, J.K., and Clark, J.R. (2015) Overcoming barriers to entry in an established industry: Tesla motors. *California Management Review*, **57**, 4, 85–103. <https://doi.org/10.1525/cmr.2015.57.4.85>.
- Stuart, T. (1999) A structural perspective on organizational innovation. *Industrial and Corporate Change*, **8**, 4, 745–775. <https://doi.org/10.1093/icc/8.4.745>.
- Stuart, T.E. and Podolny, J.M. (1996) Local search and the evolution of technological capabilities. *Strategic Management Journal*, **17**, 21–38.
- The New York Times (2009) *Mercedes reveals electric SLS AMG*.
- The New York Times (2010) *BMW inaugurates a factory for electric cars*.
- The New York Times (2011) *Will plug-in BMWs turn enthusiasts on? – Correction appended*.
- The New York Times (2012) *Tesla motors unveils a 3rd model*.
- The New York Times (2014) *Wheelies: the i3 invasion edition*.
- The New York Times (2015) *Tesla adds a family car (an expensive one) to the lineup*.
- The New York Times (2017) *Tesla unveils an electric rival to semi trucks*.
- The New York Times (2019) *Tesla’s electric ‘cybertruck’ is unveiled. It’s pointy*.
- Thompson, P. and Fox-Kean, M. (2005) Patent citations and the geography of knowledge spillovers: a reassessment. *American Economic Review*, **95**, 1, 450–460. <https://doi.org/10.1257/0002828053828509>.
- Tripsas, M. (1997) Surviving radical technological change through dynamic capability: evidence from the type-setter industry. *Industrial and Corporate Change*, **6**, 2, 341–377. <https://doi.org/10.1093/icc/6.2.341>.
- USPTO. (2022) CPC Definition - Subclass B60L. <https://www.uspto.gov/web/patents/classification/cpc/html/cpc-B60L.html>.
- Vega-Jurado, J., Gutiérrez-Gracia, A., and Fernández-De-Lucio, I. (2008) Analyzing the determinants of firm’s absorptive capacity: beyond R&D. *R and D Management*, **38**, 4, 392–405. <https://doi.org/10.1111/j.1467-9310.2008.00525.x>.
- Vith, S., Oberg, A., Höllerer, M.A., and Meyer, R.E. (2019) Envisioning the ‘sharing city’: governance strategies for the sharing economy. *Journal of Business Ethics*, **159**, 4, 1023–1046. <https://doi.org/10.1007/s10551-019-04242-4>.
- Vuori, T.O. and Huy, Q.N. (2016) Distributed attention and shared emotions in the innovation process: how Nokia lost the smartphone battle. *Administrative Science Quarterly*, **61**, 1, 9–51. <https://doi.org/10.1177/0001839215606951>.
- Wald, M.L. (2006) *Zero to 60 in 4 seconds, totally from revving batteries*.
- Wenzel, M., Stanske, S., and Lieberman, M.B. (2021) Strategic responses to crisis. *Strategic Management Journal*, **42**, 2, 7–18. <https://doi.org/10.1002/smj.3161>.
- West, J. and Bogers, M. (2014) Leveraging external sources of innovation: a review of research on open innovation. *Journal of Product Innovation Management*, **31**, 4, 814–831. <https://doi.org/10.1111/jpim.12125>.
- Wu, C.Y. and Mathews, J.A. (2012) Knowledge flows in the solar photovoltaic industry: insights from patenting by Taiwan, Korea, and China. *Research Policy*, **41**, 3, 524–540. <https://doi.org/10.1016/j.respol.2011.10.007>.
- Wu, B., Wan, Z., and Levinthal, D.A. (2014) Complementary assets as pipes and prisms: innovation incentives and trajectory choices. *Strategic Management Journal*, **35**, 9, 1257–1278. <https://doi.org/10.1002/smj.2159>.
- Zöllter, J. (2009) Supersportwagen SLS AMG: Flügeltürer mit der Lizenz zum Stromern. *Frankfurter Allgemeine*. <https://www.faz.net/aktuell/technik-motor/motor/supersportwagen-sls-amg-fluegeltuerer-mit-der-lizenz-zum-stromern-1843982.html>.

Note

- ¹ We used the pyvis library to create the plots. Library available at: <https://github.com/WestHealth/pyvis>.

Finn Jonas Tryggvason is a PhD student at the Institute of Entrepreneurship and Innovation Science (ENI) at the University of Stuttgart, Germany. Before enrolling in the program, he studied Innovation and Business at the University of Southern Denmark. His research and teaching focus is ecosystem emergence, technology entrepreneurship, and industry emergence.

Ferran Giones is the deputy head of the Institute of Entrepreneurship and Innovation Science (ENI) at

the University of Stuttgart, Germany. Before joining academia, he worked in strategy consulting and in international project management. He has been an assistant professor for Technology Entrepreneurship at the University of Southern Denmark. His research and teaching areas are technology entrepreneurship, science commercialization, technology innovation, and industry emergence.