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Re-examining path dependence in the digital age: The evolution of connected car business models

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ABSTRACT

Proliferating digitalization affects the evolution of business models across contexts and challenges firms' established innovation trajectories. Prior work on organizational path dependence suggests that firms experience decreasing option spaces over time and ultimately arrive at lock-in situations that prevent them from reacting to changing environmental conditions. Contemporary business practice, however, challenges these assumptions, as firms—even industrial-age incumbents—appear to be able to escape lock-ins and restore choices. One potential explanation for this could be the flexible nature of digital technologies that are increasingly integrated into business models during digitalization. To explore how and why this process affects organizational path dependence, we conducted a longitudinal multiple case study on connected car business models. We derive four business model archetypes adopted by different companies in the automotive industry and by new entrants, and we describe their evolution over time. We find that the growing integration of digital technologies into business models increases the number of possible pathways and can help to break path-dependent behavior. Based on our findings, we challenge and extend established knowledge on organizational path dependence with regard to key tenets, such as initial conditions and lock-ins, and provide a nuanced perspective on path dependence's resource- and cognition-based foundations.

1. Introduction

Digital technologies—such as the Internet of Things (IoT), cloud computing, or connectivity—are creating novel opportunities and threats for organizations (Teece and Linden, 2017). Digital transformation leads to adaptations in products, capabilities, and partner networks, and shapes business model evolution (Hanelt et al., 2020). While this process started to unfold in industries such as photography, telecom or media, this type of business model evolution is now emerging in industrial-age settings with large and complex products, such as the automotive industry. Interestingly, however, in these contexts, we do not observe the outright digital disruption of formerly dominant business models and the associated actors; more multifaceted dynamics are at play. Players from within and from outside the industry have started to explore novel business models arising from the introduction of digital technologies, such as digital marketplaces, application ecosystems, or car-sharing platforms.

According to path-dependence theory (Arthur, 1994, 1989; David, 1985)—a powerful lens through which to make sense of innovation and change—these observations come as a surprise, as incumbents have, to date, been considered unable to adapt to technological changes due to path-dependent behavior (Bohnsack et al., 2014). More specifically, as a result from positive feedback caused by learning, coordination, network externalities or investments, incumbents are said to enter lock-in situations which are irreversible (Garud et al., 2010; Sydow et al., 2009; Vergne and Durand, 2010). However, recent developments in the car industry suggest that this mechanism becomes weakened; that is, incumbents engaging in digital transformation appear to be able to restore choices and escape lock-ins. As path dependence is grounded in the resources involved (Vergne and Durand, 2010), one potential explanation for this shift might be that the idiosyncratic nature of digital technologies restores choices.

So far, restoring choices has been attributed to the agency of actors (Garud et al., 2010; Garud and Karnoe, 2001); the role of digital technologies—more specifically, the distinct characteristics of digital technologies—has not been considered. Studies have shown that digital

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technologies differ from other technologies due to their reprogrammable, homogeneous, and self-referential nature (Yoo et al., 2010). These traits change not only the way innovation processes come about – e.g. they afford agile development or allow updates of products in use – but they also challenge conventional assumptions about path dependent behavior, calling for a re-examination of path dependence and a more nuanced perspective.

One perspective in which processes of path-dependent behavior become visible and are of particular strategic importance (Priem et al., 2013) is the evolution of business models (Bohnsack et al., 2014). Business models reflect how a company sets up its organization to create a value proposition for its customers and how this value is captured (Zott and Amit, 2010). Changing business models has been considered challenging for incumbents due to their existing resources and routines (Bohnsack et al., 2014). Thus, studying the integration of digital technologies in business models promises novel insights into the underlying mechanisms of path dependent behavior. Therefore, in this paper we set out to investigate: *why and how does the incorporation of digital technologies in business models influence organizational path dependence?*

To find answers to this question, we conducted a longitudinal multiple case study on connected car business models involving a dataset of 632 articles that were systematically collected and analyzed (cf. Bohnsack et al., 2014). We derive four business model archetypes adopted by different companies from the automotive industry and from new entrants, and we describe their evolution over time. We find that the growing integration of digital technologies into business models increases the number of possible pathways and can help to break path-dependent behavior. We also unravel how different companies are working together to get the car connected and how this fosters industry convergence.

Although path dependency has earned its way as an important theoretical concept, the mechanisms of its occurrence and non-occurrence are still unclear (Vergne and Durand, 2010). In an attempt to contribute to the literature on path dependence, we challenge established key assumptions and complement existing knowledge by, first, providing new insights into the resource-based foundations of path dependency, their interplay with cognitive foundations and how they shape initial conditions and subsequent path formation. In doing so, we reveal how path dependence is influenced by the blend of physical and digital characteristics, and how they differ; in fact, we show that new entrants investing in physical products (e.g. Apple car) are setting out on a path in which they might become locked into. Second, we shed more light on the concept of lock-ins, one of the key tenets of path-dependency theory. While prior work has suggested that exogenous shocks are required to break free from lock-ins, we provide new ideas about the process of restoring choices and setting new paths. Last, we show how the integration of digital technologies into physical business models allows for new emerging options regarding (digital) business model evolution and how each evolutionary step creates even more options for new paths.

2. Background

2.1. Path dependence: contingent events, self-reinforcing mechanisms, and lock-ins

Studies on organizational path dependence go back to the seminal work of Arthur (1994, 1989) and David (1985), proliferating in recent years (Schreyögg and Sydow, 2011), and have generated much debate (Garud et al., 2010; Liebowitz and Margolis, 1995; Vergne and Durand, 2013, 2010) At its core, path dependence depicts a process in which the scope of available options of a company is gradually reduced over time, which results in persistence in a company's decision-making processes (e.g. Garud et al., 2010; Garud and Karnoe, 2001; Sydow et al., 2009; Vergne and Durand, 2010). For example, a decision to use a particular system to power a plant may have a controlling influence on subsequent decisions for years to come. Central to the concept of path dependence is that positive feedback on past decisions affects actions in the future and encourages similar decisions to be made (Schreyögg et al., 2011). At first, this sequence of decisions has a positive effect through increased efficiency; however, over time, path-dependent behavior leads to a decrease in the scope of action and, ultimately, to lock-ins (Sydow et al., 2009).

Path dependence evolves in three stages: The *pre-formation stage* is characterized by a broad, although not unlimited, scope of options a company may pursue (Sydow et al., 2009). Decisions taken in this initial stage are not entirely predictable. When a so-called critical juncture occurs, it may initiate the *formation stage* by triggering self-reinforcing mechanisms. These mechanisms, in turn, constitute any process of positive feedback driving the selection of a strategic pattern (Arthur, 1989; Schreyögg and Sydow, 2011). For instance, network externalities such as direct (same side) or indirect (cross-side) network effects can not only lead to exponential growth but also strongly reinforce existing innovation trajectories (Katz and Shapiro, 1985; Liebowitz and Margolis, 1995; Shapiro and Varian, 1998). Finally, as soon as the self-reinforcing mechanisms have crowded out all alternatives to a specific path, the company enters the *lock-in stage,* and the perception is that there are very few, if any, alternatives to this course of action (Schreyögg and Sydow, 2011). Importantly, the limited option space does not *per se* negatively affect a company's performance (Koch, 2011; Rothmann and Koch, 2014). Only when environmental changes (e.g. through the emergence of a novel technology or practice) lead to options outside the current path that an organization is locked into, path dependence poses a challenge (Schreyögg and Kliesch-Eberl, 2007).

2.1.1. Initial conditions and contingent events

The origin of path dependence and the resulting lock-ins lie in the initial conditions and contingent decisions in the *pre-formation stage*. The initial conditions refer to the routines and practices, culture and competences, organizational structure, and resources that persist in an organization (Sydow et al., 2009). These are initially shaped by the founders, early employees, and the external conditions at the time of founding (Mathias et al., 2015), and later by the emerging routines and institutions of the organization (Hannan and Freeman, 1984). Yet, there is still disagreement about what exactly triggers path dependence (Vergne and Durand, 2010). Although it is generally accepted that contingent events are important in the emergence of a path-dependence process (e.g. Arthur, 1989; David, 1985; De Rond and Thietart, 2007; Pierson, 2000), there are different perceptions on the influence of initial conditions and their reciprocal relationship to contingent events (Vergne and Durand, 2010, 2011).

2.1.2. Lock-in and path-dependent behavior

After the critical juncture, a path emerges that is nurtured by self-reinforcing mechanisms in the *formation phase* (Pierson, 2004; Sydow et al., 2009)[1]. As a result, organizations become locked in on a path that is said to be *de facto* irreversible. While it has long been assumed that "exogenous shocks are required to shake the system free of its history" (Vergne and Durand, 2010) it has also been speculated that endogenous developments might produce a similar effect. The grounds for lock-ins and the resulting path-dependent behavior can be cognition, resources, or both (Sydow et al., 2009). *Cognitive path dependence* refers to cognitive frames that lie within an organization and influence decision-making. Thrane et al. (2010) show, for instance, that organizations may be locked into an innovation approach, repeatedly favoring one type of innovation over others (e.g. market-driven innovations vs. R&D-driven innovations). *Resource-based path dependence*, on the other hand, refers to lock-ins due to complementary assets that organizations possess (e.g. production plants or distribution networks) (Teece, 2018, 1986), but also the technologies and products in and of themselves, as "repeated R&D investment creates sunk costs, which result in

[1] Next to positive feedback mechanisms, some studies suggest that negative feedback mechanisms can also drive path-dependent processes (Vergne and Durand, 2010, 2011, p.2006).

irreversibilities along the path of technology development" (Vergne and Durand, 2010). As a result, physical products embody a specific product architecture that is hard, if not impossible, to change (Henderson and Clark, 1990; Tushman and Anderson, 1986).

In combination, cognition and resources shape the path-dependent behavior of firms (Thrane et al., 2010; Vergne and Durand, 2010). This becomes particularly visible in the (evolution of) business models. Choices in the business model determine the expansion path of firms and are shaped by three factors: the *dominant logic, complementary assets*, and the abovementioned *contingent events* (cf. Bohnsack et al., 2014). A company's dominant logic is more cognition based and guides the actions of company over time (Chesbrough and Rosenbloom, 2002; David, 1994). The *complementary assets* of a company refer to specialized assets required to commercialize a specific innovation and they are of a resource-based nature (Teece, 1986).

Once a business model is established, firms struggle to change it (Teece, 2010). For example, Bohnsack et al. (2014) found that incumbents in the car industry—faced with electric vehicle technology—tended to follow their existing business models due to their complementary assets and existing dominant logic, building converted multi-purpose vehicles and offering them in the same way as cars with internal combustion engines. This essentially led to the emerging dominance of the new entrant, Tesla, with a novel and superior business model, as reflected in the significantly higher market capitalization of the tech company from Silicon Valley at the time of writing this article. In sum, cognitive and resource-based path dependence lock in firms' business models (Teece, 2010; Thrane et al., 2010; Vergne and Durand, 2010).

Despite the rich knowledge that has been generated about path dependence, doubts still exist about the theory's explanatory power (Dobusch and Kapeller, 2013). In particular, scholars observe how "it remains unclear why path dependence sometimes occurs and sometimes not" (Vergne and Durand, 2010). Although several further issues in this regard have been identified, e.g., methodological shortcomings (Vergne and Durand, 2013), also contextual variations need to be considered. It is important to note that the vast majority of path dependency research, fundamental to our theoretical understanding of the concept, dates back to pre-digital times (Besson and Rowe, 2012). The profound changes that we witness in the era of society level digitalization (Tilson et al., 2010) and firm level digital transformation (Hanelt et al. 2020), challenge some assumptions about path dependency (Alvesson and Sandberg, 2011). In particular, first, with regard to its resource-based foundations, it is said that digital technologies exhibit unique traits that set them apart from others. In particular, their inherent flexible nature seems to alter our understanding on the role of resources defining and constraining innovation trajectories (Hanelt et al., 2021; Kallinikos et al., 2013). Relatedly, second, the force of digitalization has substantially (re)shaped the business models of firms (Hanelt et al., 2020). New digital players enter established contexts, yet incumbents are now also increasingly introducing digital business models, and in doing so, they seem to be able to escape from established innovation trajectories (Hanelt et al., 2020, 2015). Such observations challenge our thinking related to the idea of lock-ins. Hence, the next section will explore the interplay between business models and digital technologies.

2.2. Business models and digital technologies

Following Zott and Amit (2010, p. 2019), a business model is "designed so as to create value through the exploitation of business opportunities."[2] The core components of a business model constitute the value proposition, the value network, and the revenue–cost model (Bohnsack et al., 2014; Demil and Lecocq, 2010). The value proposition represents the offered value to the customer; for example, a product or service. The value network determines how the value is created and delivered to the customer, and the revenue–cost model defines how value is captured (Chesbrough and Rosenbloom, 2002; Johnson et al., 2008; Morris et al., 2005; Osterwalder et al., 2005). The overall configuration of the business model determines the success potential of the commercialization of a product (Chesbrough, 2010). In that sense, there needs to be a good fit between the business model and the product to bring out the best of the product's features. As such, the same product can yield different economic value depending on the chosen business model. Conversely, if the gestalt—e.g. individual components or the product architectures as a whole—of a product changes, the business model may have to be re-evaluated as well.

With the advent of digital technologies, new opportunities for value creation and capture emerged, and firms began to integrate them into their industrial-age products (Hacklin et al., 2018; Svahn et al., 2017). Such integration involves the *digitization* of physical products, for example, via the installation of an internet connection device to transmit information, and the subsequent *connectivity* between digitized products (Lanzolla et al., 2020). As a result, new opportunities have arisen because digital technologies have characteristics that are very different from physical technologies; most notably, they offer *reprogrammability* and *homogeneity,* and they have a *self-referential nature* (Yoo et al., 2012, 2010). *Reprogrammability* enables the separation of the functional logic of the device from the physical embodiment that executes it, allowing digital devices to perform a wide range of functions and for them to be continuously updated. The *homogenization of data* allows for the separation of the digital content from a medium, resulting from the binary nature of digital signals, and leading to data that can be stored, transmitted, processed, and displayed by different devices. Last, *self-reference* describes the fact that a digital innovation requires the use of digital technology; thus, the diffusion of a digital innovation creates positive network externalities, further accelerating the emergence of new digital technology (Yoo et al., 2012, 2010).[3]

As firms, particularly incumbents, start to integrate digital components into physical products, the architecture of the products changes. In the process of digitalization (Tilson et al., 2010), the traditional *modular architecture* of physical products based on fixed boundaries at the product level (Henderson and Clark, 1990) is extended by the *layered architecture* typical of digital products that do not have fixed boundaries (Yoo et al., 2010). With changes in the product architecture—particularly relating to the idiosyncratic characteristics of digital technologies—also comes the need for changes in the business model, as explained above. That is, physical products that are based on a modular architecture (e.g. cars) require different types of value creation and capture than digital products with a layered architecture (e.g. apps). As a result, business model configurations differ. Thus, we can distinguish between physically oriented business models and digitally oriented business models (cf. Weill and Woerner, 2013), which form a continuum (see Fig. 1). Business models that fall in between are a hybrid between the two extremes (Yoo et al., 2010), i.e.

The question is whether the integration of digital technologies into physically oriented business models influences the path-dependent behavior of firms as they move from the left side of Fig. 1 toward the right side of the continuum. In fact, it is equally interesting to explore how the path-dependent behavior of firms with digitally oriented business models changes as they move more toward physically oriented business models (e.g. Apple developing a car).

[2] It must be noted that the business model concept has recently been extended beyond the pure managerial perspective that we adopt here for the purpose of this study; most notably, those streams focusing on non-financial values and business models for sustainability (e.g. Bolton and Hannon, 2016; Boons and Bocken, 2018; Freudenreich et al. 2020).

[3] It should be noted that digital technologies can also have negative externalities such as legacy codes or incompatibility across systems (e.g. Android vs iOS).

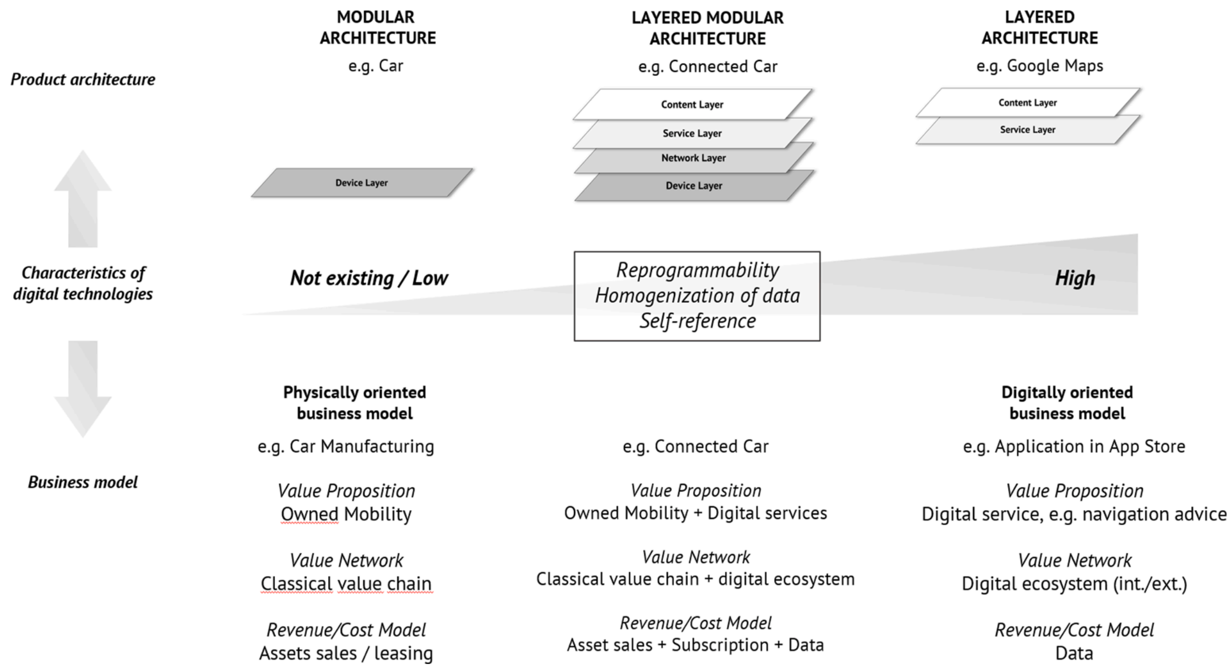

Fig. 1. Product architectures and business models.

3. Methodology, data sample, and analysis

To find out why and how the integration of digital technologies into business models affects the path-dependent behavior of organizations, investigating the evolution of business models around connected cars is a valuable context, as incumbents in the car industry are increasingly digitalizing their products and are offering new digital business models. What is more, new entrants also enter the industry with novel business models around connected cars. This allows us to understand changes in path-dependent behavior over time. In addition, we choose the car industry as it exhibits very specific path dependent characteristics, idiosyncratic to complex industrial products. These characteristics include incumbents in the industry seeking to leverage their capital-intensive investments in plants, patents, or tools, focusing on efficiencies and exploiting accumulated manufacturing knowledge (Bohnsack et al., 2020), but also a strong culture around the car, resistant to change (Calkins, 2009) and embedded in a complex socio-technical configuration constituting regulation, infrastructure or supply chains (Geels, 2002; Steinhilber et al., 2013).

We applied a case-based research strategy that is appropriate to answer "how" or "why" research questions (Yin, 1994). We used the case "industry" as unit of analysis in order to explain the dominant logic, complementary assets and contingent events as well as specific cases of "firms" in order to explore how business models evolved. The cases were selected following a diverse technique (Gerring, 2007). Accordingly, following the approach of Bohnsack et al. (2014), we present a longitudinal multiple case study.

For the data collection, established sources for case research in the automotive industry were used. Following the example of previous studies (e.g. Bohnsack et al., 2014; Hanelt et al., 2015), *Automotive News* and *Ward's Auto World*, two industry trade magazines, as well as a car magazine called *Autoweek*, were selected. Furthermore, because of its focus on business strategy as well as on political and economic topics, the *Financial Times* newspaper was chosen. No scientific journals were selected, as this ensured a purely narrative—and not an analytical—description of the business models.

To generate the data sample, a keyword search was performed for the period from 2007 to 2017. The year 2007 was selected because the first iPhone was launched, a cornerstone in the industry, leading people toward increasingly being connected to the internet and facilitating entirely novel business models (Nischak and Hanelt, 2019; Svahn et al., 2017). The final year, 2017, was selected not only because connected car business models were fully established but also because the retrospective study commenced in 2018. Using the search terms "connected car" and "car connectivity," a dataset of 1036 articles over a period of 11 years was generated. These search terms were selected since they resulted in the largest sample with the least irrelevant articles. Nevertheless, while reviewing the initial set of 1036 articles, not all articles turned out to be relevant, as some of them only marginally or inadequately addressed the topic. Therefore, the dataset was filtered and the analyzed relevant dataset consisted of 632 articles. As shown in Figure 2, the number of articles per year and newspaper increased over time (the left bar of a respective year indicates the initial set of articles, and the right bar shows the remaining number of articles after filtering).

To analyze the articles, in the first step, the filtered dataset was imported into the qualitative data-analysis software NVivo for coding. We analyzed the data using a semi-structured coding scheme. The business models in the connected car business were examined by allocating all relevant statements to categories representing the business models' key components; that is, the value proposition, value network, and revenue–cost model. We chose this level of granularity to allow for the comparability of business models. During the coding process, we paid particular attention to any statements about the resource foundations of the business models, such as digital or other kinds of technologies. Statements were coded when exhibiting a causal relationship to the characteristics of value creation and value capture (Chesbrough, 2010). Facts, such as company names, corresponding with the information, were coded as well. This meant that information could contain

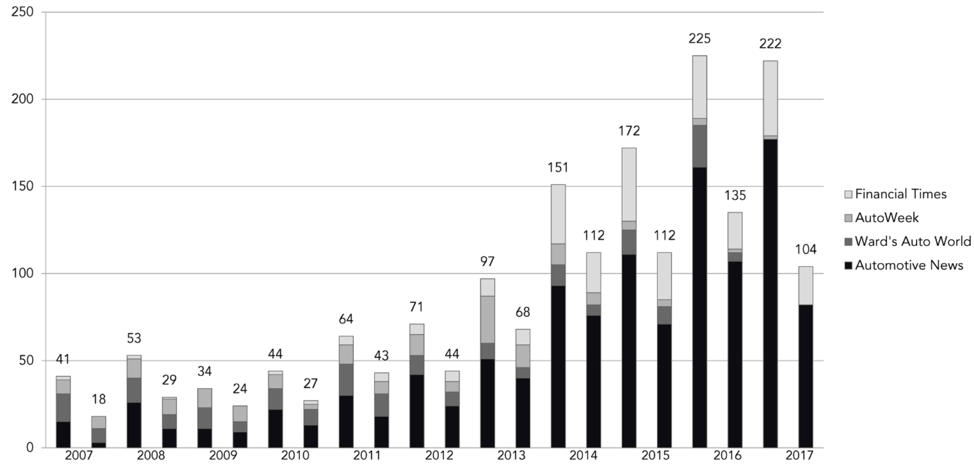

Fig. 2. Relationship between the initial and final datasets per year and newspaper.

several facts, such as "value proposition," "company name," and "value creation." In addition, categories regarding path dependence, e.g. dominant logic, complementary assets and contingent events, were coded. See Table 1 for an overview of all coded excerpts over time.

In a second step, we began to iterate between the three business model dimensions (i.e. value proposition, value network, and revenue–cost model) and the literature to extract criteria for the identification of business model archetypes[4] for connected cars (see Table 2 in the next section). The codes were assigned to the different archetypes, which made it possible to distill four different archetypes and to compare them with each other. In a third step, individual companies' business models, their evolution over time, and the interplay between them were analyzed. To do so, the business models of the studied companies were allocated to the four business model archetypes. What is more, we specifically analyzed the value positions of the respective business models and assigned them to the corresponding layer on the layered modular architecture (i.e. to the device, network, service, or content layer). We discovered that certain business models within an archetype occupied several layers, while others were only present on one layer. Next, all archetypes and their interactions were summarized in a matrix and illustrated visually. Finally, the evolution of the individual business models was illustrated on timelines, and narrative descriptions were constructed (Bourgeoise and Eisenhardt, 1988). Figs. 4 and 5 contain the key elements, which will be explained in the next section. Further material is provided in Appendix B and the vignette in Section A of the supplementary material (available online).

4. Findings

Connected cars—referring to cars being connected to the internet and the associated applications, such as emergency assistance systems or remote parking—originate from telematics, a field at the intersection of vehicle technologies with telecommunications, computer science, and electrical engineering. Improvements in information technology, especially the internet, and the emergence of smartphones were key impulses leading to the rise in connected cars. Over time, incumbent players and new entrants with different backgrounds entered the connected car industry via different business models. In our analysis, we identified four business model archetypes within the connected car industry, which we illustrate and explain in the next section. We subsequently turn to the evolution of the connected car business models over time and the dynamics of business models on the firm level, focusing on path-dependent behavior. Finally, we show how value propositions within individual business model archetypes have changed over the course of time and, in some cases, how they have expanded due to competitive moves made by the companies within and across the individual business model archetypes.

4.1. Business model archetypes in the connected car business

The first archetype we distilled from the data is *Product-based Digital Extension,* which only original equipment manufacturers (OEMs) occupy. The other three archetypes—namely, *Digital Stand-alone Offerings, Connectivity Provision,* and *Digital Mirroring*—are primarily adopted by companies from the digital economy. The archetypes contrast with each other in terms of the configuration of their value propositions, value networks, and revenue–cost models, as well as their physical and digital orientation (see Fig. 3), determined by their location on the layered modular architecture. In the following we introduce each archetype (see Table 2 for an overview).

4.1.1. Business model archetype I—product-based digital extension

The first connected car business model, *Product-based Digital Extension*, is located on the device layer in the layered modular architecture of connected cars (see Figs. 1 and 4) and is primarily physically oriented as it enriches the physical architecture of the already existing product with digital layers by gradually adding new digital services to them. Digital services include, for instance, advanced vehicle diagnostics, remote door locking, or long-term evolution (LTE) wireless internet connections. An example is General Motor's (GM's) *OnStar* service. The value proposition is characterized by its wide array of diverse services. These services can be add-ons, such as Bluetooth connectivity, or self-developed independent services with potential new revenue streams. They are either vehicle-related or vehicle-unrelated. Therefore, diversified pricing models such as "Free/Freemium/Premium" subscriptions, or modular pricing are used. Moreover, the data are seen as a non-monetary revenue stream, though they initially played a less important role. The value network is characterized by a balance between in-house development and outsourced production. This outsourcing requires extensive partnerships between OEMs and tech companies.

4.1.2. Business model archetype II—digital stand-alone offerings

The next business model, *Digital Stand-alone Offerings*, is purely digital in nature and refers to services on the digital service layer and content layer of the layered modular architecture. Prominent examples within this archetype are FIXD, Spotify, or Google Maps. FIXD offers

[4] Business model archetypes can be defined as general business model logics that represent typical models of value creation and value capture; nonetheless, within that logic, firms still make choices to create unique positions (Casadesus-Masanell and Ricart, 2010; Morris et al., 2005; Teece, 2010).

Table 1
Excerpt counts per company and year.

Companies	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	Share
OEMs													
General Motors	6	5	5	26	9	8	18	22	11	12	6	128	17%
Ford	6	2	7	18	14	14	10	18	9	5	9	112	15%
Volkswagen	3	0	0	4	3	16	10	19	11	11	10	87	12%
Hyundai	0	6	2	3	1	4	6	8	4	4	5	43	6%
Toyota	0	0	0	2	10	7	3	2	2	11	5	42	6%
BMW	1	3	1	2	4	1	11	3	3	6	2	37	5%
Daimler	4	0	0	2	2	3	6	8	6	4	2	37	5%
Fiat Chrysler	2	3	0	2	0	0	2	4	0	4	0	17	2%
Nissan	0	1	1	1	1	1	0	4	1	5	2	17	2%
Tesla	0	0	0	0	0	0	0	4	8	2	3	17	2%
Honda	0	1	0	0	0	2	1	3	3	2	1	13	2%
Volvo	0	0	0	0	0	0	1	8	0	3	0	12	2%
Mazda	0	1	1	0	0	1	1	3	0	0	0	7	1%
Tata Motors	0	0	0	0	0	0	1	1	1	2	0	5	1%
PSA Peugeot	0	0	0	0	0	0	1	1	0	1	0	3	0%
Subaru	0	0	0	0	1	0	1	1	0	0	0	3	0%
Mitsubishi	0	0	0	0	0	1	0	1	0	0	0	2	0%
Suzuki	0	0	0	0	0	0	0	1	0	0	0	1	0%
Tech Companies													
Google	0	0	0	6	0	2	1	20	10	7	2	48	6%
Apple	0	0	0	0	0	2	2	15	16	5	3	43	6%
Microsoft	2	6	1	1	0	4	0	3	2	1	2	22	3%
AT&T	1	0	0	0	0	0	4	2	0	2	0	9	1%
Verizon	1	0	0	0	0	0	0	5	0	2	0	8	1%
Amazon	0	0	0	0	0	0	0	0	0	0	5	5	1%
Nokia	0	0	0	2	2	0	0	0	0	0	0	4	1%
Spotify	0	0	0	0	0	0	2	1	1	0	1	5	1%
Others[1]	0	2	1	0	1	0	0	6	0	3	0	13	2%
Total	26	30	19	69	48	66	81	163	88	92	58	740	100%

[1]Others include companies such as: Inrix, Zubie, Dash Labs, FIXD, Mojio, Urgent.ly, etc.

Table 2
Connected car business model archetypes.

Archetype	Value proposition	Value network	Revenue-cost model	Examples
Product-based Digital Extension	• Service portfolio as comprehensive as possible • Vehicle context-related and in-dependent services	• Production mostly in-house • Dependent on external knowledge and technology provider	• Diversified revenue model (free, freemium, premium, subscription, pay per use) • Data are seen as a non-monetary revenue stream yet with a lesser role	• *GM OnStar* • *Ford Sync*
Digital Stand-alone Offerings	• Specialized service portfolio • Niche products • Retrofitting solutions	• Production mostly in-house • Dependent on external distribution networks	• Diversified revenue model (single purchase, subscription, pay per use)	• *FIXD* • *Spotify* • *Google Maps*
Connectivity Provision	• LTE connectivity	• In-house production • Dependent on external distribution networks	• Licenses for software and data plans • Data as a non-monetary revenue stream	• *Verizon* • *AT&T*
Digital Mirroring	• Service portfolio as comprehensive as possible • Mirroring of already existing services	• Production mostly outsourced to external ecosystem • Platform approach, functions as a gatekeeper • Dependent on agreements with OEMs	• Licenses for software, brokerage fee for services offered on platform • Data as a non-monetary revenue stream	• *Android Auto* • *Apple CarPlay*

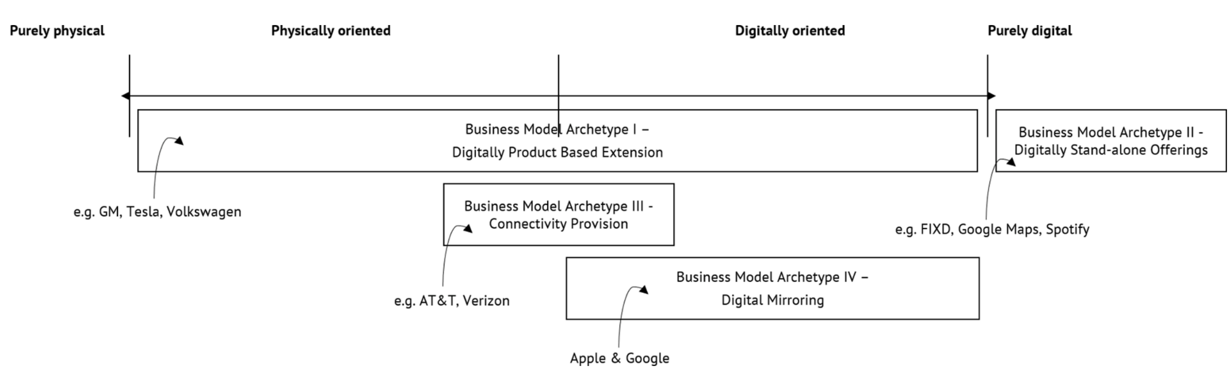

Fig. 3. Business model archetypes in the connected car business and their product orientations.

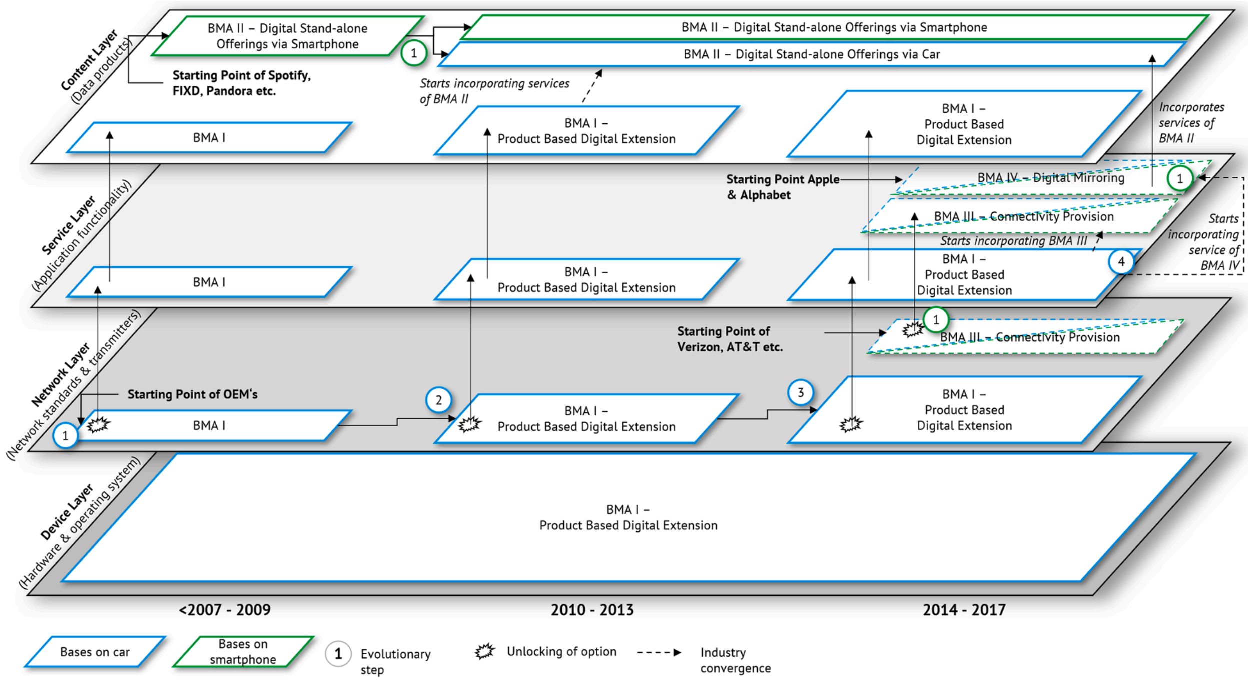

Fig. 4. Evolution of connected car business models on the layered modular architecture of a connected car.

vehicle diagnostics as a solution for the secondary market and is positioned on the service layer. In many cases, offerings such as Spotify or Google Maps were already used by drivers in their cars via their smartphones and were thus associated with connected cars. The value propositions of these offerings are often customer-centric and are focused on one service or product. Common revenue–cost models are subscription or pay-per-use. In addition, in this archetype, data are also seen as a non-monetary revenue stream. An important characteristic of the value network is the strong dependency on external distribution networks, such as platforms for services and apps (e.g. the App Store).

4.1.3. *Business model archetype III—connectivity provision*

Another set of firms adopted the business model *Connectivity Provision*, which exhibits both physical and digital aspects and, therefore, can be considered equally physically and digitally oriented. Business models within this archetype are located on the network layer and the service layer of the layered modular architecture. Companies adopting this archetype, on the one hand, provide the basic infrastructure for digital initiatives in connected cars. On the other hand, companies such as Verizon or AT&T offer data plans that are offered to the OEMs, who in turn pass them on to the customer. The revenue–cost model is not much different from the companies' traditional business models, as they offer white label development services that are remunerated accordingly, or they issue licenses for LTE connectivity. Another revenue stream is the monetization of customer data generated by the connected car. The value network relies on a combination of in-house development and outsourcing to strategic partners.

4.1.4. *Business model archetype IV—digital mirroring*

The last business model archetype, *Digital Mirroring*, is primarily digitally oriented. Business models are located on the service layer of the layered modular architecture but become part of the device layer. The only companies adopting this archetype are Apple and Google, both of which digitally mirrored their operating systems in the vehicle's infotainment system. The value proposition can be distinguished by providing complementary goods and thereby expanding already existing ecosystems by adding new devices to them. The revenue–cost model includes licensing or selling software solutions to OEMs, thus providing a technological multi-sided platform for various app developers. In addition, the data are an important non-monetary revenue stream, particularly in the form of customer insights into cars. Regarding the value network, the companies in this archetype have strong leverage in terms of determining the offered portfolio of products and services on the platform, but they are also dependent on the OEMs and their willingness to grant them access to their product architectures in the form of application programming interfaces (APIs).

Overall, our findings show that archetypes are associated with different layers on the layered modular architecture. Physically oriented business models were mainly located on the device layer, whereas digitally oriented business models were located predominantly on the content and service layers. Nevertheless, business models within each archetype also underwent changes over time, particularly with respect to novel value propositions on the different layers of the layered modular architecture. The process of this evolution will be examined next.

4.2. *The evolution of connected car business models*

During the studied period, three distinct phases were detected in the evolution of connected car business models. A detailed description of the business model evolution, including accounts of individual companies, is provided in Appendix B and in Section B of the Supplementary Material (available online).

4.2.1. *Era of experimentation*

The first phase lasted from 2007 to 2009 and was primarily characterized by OEMs experimenting with archetype *I—Product-based Digital Extension* (see step 1 in Fig. 4) and by small startups entering the industry, leading to a fragmentation of offerings and approaches. Only archetypes I and II existed during this phase. Archetype II was only present on the customers' smartphones (see Fig. 4). A notable contingent event in this phase was the world financial crisis. The crisis affected almost every OEM, which is why many projects outside of the core business were often canceled or significantly reduced. GM, with its near-bankruptcy, was particularly affected, which almost led to *OnStar* being sold. Another important contingent event was the discussion about distracted driving and the resulting legislative changes and guidelines for automobile manufacturers. After increasing uncertainty about which services could be offered, OEMs increasingly positioned themselves as part of the solution to protect drivers from distracted driving, and they developed the corresponding guidelines.

4.2.2. Era of alignment

The second phase, from 2010 to 2013, was characterized by an alignment of offerings and approaches. The reason for this was, on the one hand, that OEMs tried to imitate the service portfolio of other OEMs by copying their services. On the other hand, OEMs had to offer certain services, such as Spotify, to which customers had a strong loyalty, and therefore required them to be integrated into the car. Accordingly, OEMs started to cooperate with companies that provided *Digital Stand-alone Offerings* (see step 2 in Fig. 4). An important contingent event in this period was the heated public discussion on data security and data protection, which increasingly affected the connected car business and the data generated during a drive. For all participants within the ecosystem, this raised the question of who owned the data generated in the car. It further led to a dispute between OEMs, which provided the infotainment systems as well as the automobiles, and new entrants which acted as contributors and deliverers of external services that actually generated the data. This resulted in OEMs gaining a much better understanding of the value of data and gradually adjusting their revenue streams. As a result, OEMs started to be keener about protecting the data their own services generated, but at the same time, they allowed other companies to commercialize the data generated by their services.

4.2.3. Era of convergence

The phase from 2014 to 2017 was characterized by the emergence of two business model archetypes; namely *Connectivity Provision* and *Digital Mirroring*. Simultaneously, the *Product-based Digital Extension* archetype changed and evolved again as OEMs tried to differentiate themselves more strongly from offerings of companies with *Digital Stand-alone Offerings*. In doing so, they let companies adopting *Digital Mirroring* incorporate the services of companies adopting *Digital Stand-alone Offerings,* and, concurrently, they developed their own services, initiating convergence. To do so, OEMs adopting started to cooperate with *Connectivity Provision* companies (see steps 3 and 4 of *business model archetype I* as well as step 1 of *business model archetype III* and *business model archetype IV* in Fig. 4). With regard to contingent events, above all, Volkswagen's (VW's) emission scandal influenced this era. The company had to pay high fines in the following years, restricting investments in new technologies. Still, the company continued its efforts in the connected car business by further improving existing solutions and rolling them out across the entire product range. Other car manufacturers were also affected by this event, as, in the following years, there was much stronger monitoring by the authorities, and the automotive industry had to remain on guard for a long time. In addition, there were fierce discussions about the safety of connected cars with regard to hacking attacks. This forced automobile manufacturers to invest more in the safety of their onboard systems and also led to increased monitoring of third-party products.

4.3. Unlocking the layered modular architecture and the migration of the individual business model archetypes' value propositions

Over time, automobile manufacturers adopting the archetype *Product-based Digital Extension* expanded their value proposition to all layers of the layered modular architecture compared to the value propositions of the companies adopting the other business model archetypes, which remained on their initial layers. The OEMs were gradually adding more and more services. This expansion of the value proposition was enabled by changes and technological enhancements on the network layer (e.g. 3G connection), service layer (e.g. technological platform) but also on the device layer (e.g. touchscreen), which, as a consequence, unlocked the layered modular architecture of the connected car. Interestingly, due to the further developed network layer, OEMs were able to grant external players access to the emerging digital product platform the automobile had become. As a result, they had to build up fewer resources themselves and were able to benefit from the resources and skills of external contributors (see Section A in the supplementary material available online for a vignette study on how this process evolved for VW). Companies adopting the other business model archetypes, in contrast, did not have to change their business models as much. Being mostly located on the service and content layer of the digital product platform they could continue offering digital services.

When comparing the value propositions of the four business model archetypes toward the end of the studied period, it is clear that the car manufacturers' value propositions expanded over time as more internally developed digital services were offered (see Fig. 5), but doors were

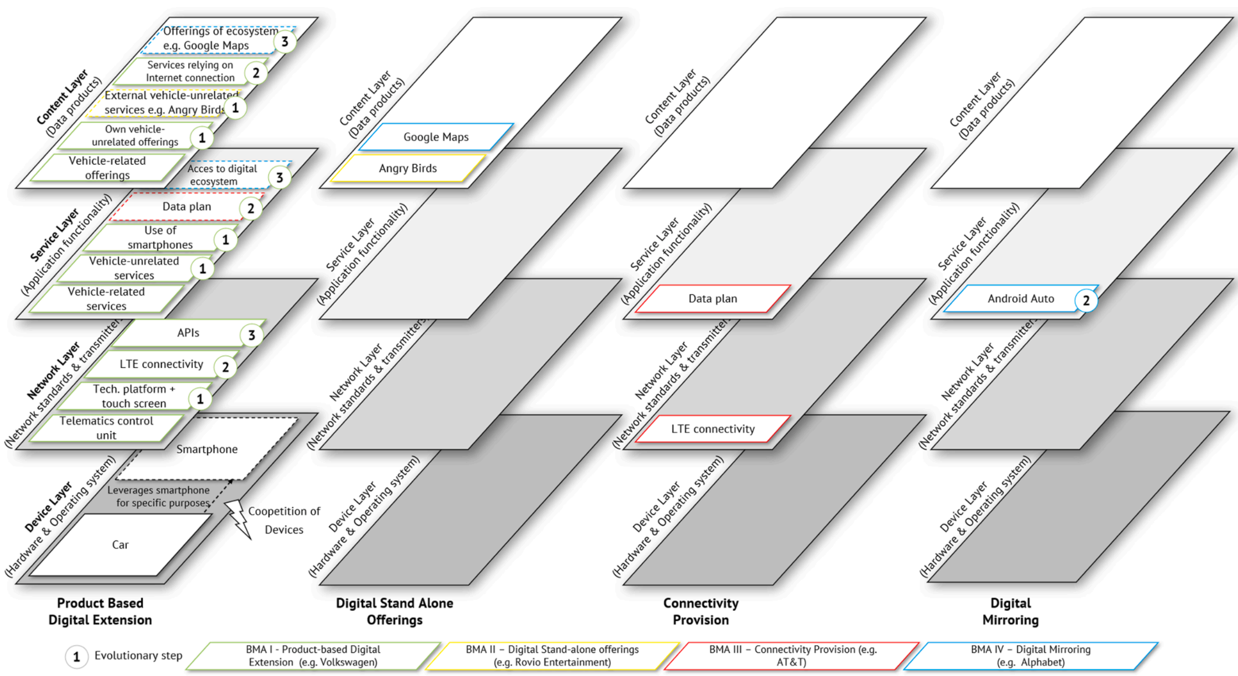

Fig. 5. Value propositions of the respective business model archetypes in the last period under study.

also opened for external companies. Put differently, car manufacturers had considerably more options for generating value, either in the form of additional digital services or by incorporating the value propositions of external firms adopting the other business model archetypes, providing access to their cars. In stark contrast, companies adopting the other business model archetypes did not benefit as much from the migration of their value propositions as the OEMs did. One reason for this was that they had already been present and available to the customer on smartphones prior to the migration.

4.4. Path dependence and digital technologies in business model evolution

Our results indicate that, for companies that shifted from physically to digitally oriented business models, the integration of digital technologies reduced organizational path dependence, resulting in new options for the further innovation of companies' business models, a process that evolved over time.

At the beginning of the studied period, OEMs' business models were purely physically oriented; they were following their existing dominant logic, and they sought to exploit their complementary assets (see columns II and III in Appendix B). This was evidenced by the OEMs retaining their existing revenue–cost models, making use of previously developed technologies, and their susceptibility to contingent events. For instance, GM, a pioneer of the telematics business, had previously accumulated vast amounts of resources and capabilities for connected cars. While this enabled GM to develop many services and offerings in-house, it also led the company to focus on legacy safety and security features. Consequently, GM was losing ground to competitors in terms of incorporating the car-independent services that customers were looking for, as they were trying to make use of internal complementary assets.

> Don't look for an all-in one telematics and audio system box from *OnStar. OnStar* will stick to safety and security technology. (Geist, 2007)

Other OEMs partnered with companies outside the automotive industry from the beginning. They integrated connectivity into the car mainly via the driver's smartphone, which provided more flexibility in terms of adapting to technological leaps and resulted in companies such as Ford, Hyundai, and Toyota being able to integrate several external services in a short period of time (e.g. Spotify or Angry Birds). Vehicle context-related services were developed by the OEMs themselves. Overall, OEMs often somewhat randomly developed services without knowing whether they were even valued by customers.

> To compound automakers' challenges, portable store-bought devices are becoming more popular. Vehicle engineers work on traffic-alert technologies and introduce them into onboard navigation systems, which can add $2,000 to a car's sticker price. However, an ordinary smart phone already can zoom in on local traffic conditions via the Internet at no extra charge. (Chappell, 2011)

The path-dependent behavior of OEMs was also visible in the way that the companies engaged with external partners. For instance, although Ford further developed its vehicle into a digital product platform and allowed external providers to develop services for it and create complementarities with external providers, Ford initially treated these new digital firms like traditional suppliers and adopted a slow and cumbersome "belt-and-suspender" approach in the onboarding process, which resulted in significantly fewer services being offered than would have been possible.

> Ford Motor Co. […] has approved just 10 outside applications, or software designed for certain tasks, among thousands it has received for use on the first generation of its Sync communications system. (Vellequette, 2012)

Over time, the integration of digital technologies changed the business model of OEMs (see column IV in Appendix B). However, the approach mattered: For instance, Ford decided to bring connectivity and the resulting digital services into the car via the driver's smartphone—in contrast to Tesla, which also used a built-in WiFi solution from the very beginning next to the driver's smartphone—and this initially resulted in increased flexibility with regard to technological leaps and the scalability of its service portfolio. However, later, this approach led to complexity and difficulties for Ford in developing its own car-related services, eventually requiring Ford to develop an entirely new in-built connectivity system in order to make services reasonably accessible to its customers.

> Ford, looking to be a pioneer in the infotainment space, was slammed for years after introducing the glitch MyFord Touch system in 2010. (Bond Jr., 2015)

In stark contrast, the embedded solutions of GM and VW enabled a different approach. On the one hand, in the beginning, GM's approach of an embedded system resulted in difficulties in incorporating external offerings, and they were not updateable to new network standards. On the other hand, this approach resulted in the easier development of car-related services, which in turn promised to be considerably more profitable than car-unrelated services did. In addition, the embedded solutions of both companies enabled them to offer LTE connectivity faster because the systems themselves were equipped for this new standard and were not dependent on the connection to an external smartphone that the driver had to bring in. This, accompanied by the accumulated resources and capabilities, allowed these companies to offer new, sophisticated, and complex services, such as over-the-air updates of the vehicle onboard system, just as Tesla had provided since 2012.

At the beginning of integrating digital technologies, all the OEMs used their familiar revenue–cost models by offering their new digital services as expensive feature packages (e.g. for navigation systems), just as they used to do in their physically oriented business models. In doing so, they overestimated the customers' willingness to pay twice for services that they already had on their smartphones. With increasing experience in digital business models, however, OEMs changed their approach and offered new value propositions with novel revenue–cost models, for example, based on subscriptions (see examples in column IV in Appendix B).

Thus, at the end of the last studied period, OEMs that moved from physically oriented business models more toward digitally oriented business models turned their vehicles into digital product platforms and also experimented with associated novel value propositions based on previously uncommon revenue–cost models in the industry. Nonetheless, path-dependent behavior, of course, did not disappear completely. For instance, the cultivated perception of OEMs was that if something goes wrong, they would be held responsible as being the system integrators, hampered efforts to develop smart solutions against distracted driving or car hacking in cooperation with external complementors.

> Automakers are clearly more fearful than Apple or Google of lawsuits over privacy breaches and distracted driving […] because car companies are historically the ones that get slapped with a lawsuit when something goes wrong with a vehicle. (Nelson, 2014)

New entrants in the connected car industry that offered digitally oriented business models from the beginning and increasingly integrated more into the car, experienced different effects with regards to path-dependent behavior. For instance, companies that adopted the business model *Digital Stand-alone Offerings* or *Connectivity Provision* partially changed their business models over time, and moved into other business model archetypes, or even added new ones over time (see Appendix B column IV). Companies that adopted *Digital Stand-alone Offerings* noticed that deeper integration into the automobile was more beneficial than just being present via a smartphone. The reasons for this were, for example, the possibility of being able to mine data that could be further processed and the opportunity to connect an entirely new device (i.e. the car) into their digital ecosystems. As a result, they had to adapt their value networks, since they were now also suppliers to car manufacturers and had to get used to new product development processes and hierarchical supplier structures. Companies such as AT&T, for instance, adopted in addition to their initial business model *Connectivity Provision, Digital Stand-alone Offerings*. Initially, these companies perceived the automobile as just another device that they were able to connect to the internet:

> We see the car as another wireless device, like a [big] smartphone. (McCarthy and Taylor, 2013)

This was because mobile operators like AT&T learned much about their customers through the data plans they offered, and they were able to leverage their data-processing capabilities by developing fleet management tools that they could sell to customers as aftermarket solutions. Google, due to its services, such as *Google Maps,* was present in the archetype *Digital Stand-alone Offerings* from the very beginning, and it adopted the business model *Digital Mirroring* as soon as OEMs granted it the opportunity to do so. Companies learned about the shortcomings of solely being present via a smartphone and wanted, above all, to learn more about the customers of automobile manufacturers, such as their driving habits, and subsequently, to commercialize these data.

> Google, Apple, Uber, and others are diving into the auto industry because of what they can learn about auto customers—and how they can monetize that information. (Martinez, 2017)

Interestingly, none of the companies from the three archetypes, apart from some exceptions such as Google and Apple, moved the device layer “downwards” to integrate physical components. Although various experimental projects were launched, generally it is clear that firms with digitally oriented business models would rather not move into the physical device layer. This was not only due to monetary reasons—that is, digital services have, in general, much higher margins compared to physical products—but was also due to different developmental mindsets (i.e. moving from agile to more long-term-oriented development cycles). Thus, our results suggest that the expansion into the car by firms offering digitally oriented business models increased path dependency. [5]

5. Discussion of findings

Our study set out to explore how the integration of digital technologies in business models influences organizational path dependence. Drawing on the example of the evolution of business models of connected car firms, we derive a more nuanced perspective on path-dependent behavior in the digital age, involving a differentiation into multiple facets of the construct, their influences, and interplay. We particularly unraveled, the difference of path dependent behavior between firms with physically and digitally oriented business models, the difference in business model evolution, and the path breaking nature of digital technologies.

5.1. Path dependent behavior in physically and digitally oriented business models

Sydow et al. (2009) explain the decrease in a company’s option space, among others, as a result of an interaction between contingent events and resources. We observed that the nature of the business model—physically or digitally oriented—determined by the underlying technology and product architecture also has an influence on path dependent behavior. Firms with physically oriented business models, i.e. the OEMs in this study, rely on a dominant logic of waterfall development necessary due to rigid product boundaries of the modular product architectures of cars, resulting in a higher degree of rigidity and, in turn, fewer available choices in changing business models. The firms have complementary assets required to commercialize physical cars, focusing on the bundling of internal assets (Svahn and Henfridsson, 2012) and are rather susceptible to contingent events. In contrast, companies pursuing digitally oriented business models, such as Google or Spotify, have a dominant logic of developing rapidly contextualizable digital products – due to the reprogrammable, homogeneous, and self-referential nature of digital technologies (Yoo et al., 2010). They rely on internal *and* external complementary assets that are necessary to commercialize digital products, resulting in flexibility and more available choices (Huang et al., 2017; Nambisan et al., 2019), but also dependency on external ecosystems. Digitally oriented firms are less susceptible to contingent events, as evidenced by the fact that their services did not even have to be integrated into the car, as customers could use them via smartphones. See Table 3 for a comparison of the path dependence of physically oriented business models versus digitally oriented business models.

5.2. The influence of technological expansion on business model evolution

Although generally companies tend to remain close to their existing business model (Bohnsack et al., 2014; Teece, 2010), we observed consecutive changes in business models and even migrations between archetypes. Notably, this played out differently for companies with physically-oriented business models than for companies with digitally-oriented business models. OEMs started with an emphasis on the device layer and step-by-step integrated digital technologies to improve the user experience and gain user data, which in turn led to adaptations of the business model. As a result of the expansion, they increasingly benefited from the growing and previously unknown flexibility of being able to offer novel service-based value propositions, as well as from the ability to continuously adapt and enlarge this portfolio later on. At the same time, these changes were accompanied by adjustments to the value network—particularly opening up to the ecosystem of external partners—and to changes in the revenue–cost model—including more usage- and data-driven patterns—to successfully commercialize these novel value propositions.

Companies with digitally-oriented business models, in contrast, started with an emphasis on the service layers. They were able to leverage their existing offerings in a variety of ways (e.g. Spotify, first on smartphones and later also in the entertainment system of connected cars), and only, if at all, had to change their business model slightly. However, some firms were also confronted with shortcomings of their business models. Companies such as Apple and Google, or Spotify, recognized that they needed more integration into the vehicle in order to control the end-user experience or to get access to relevant data; they responded by offering *Apple CarPlay* and *Android Auto*, i.e. they expanded and established the new business model archetype *Digital Mirroring*. Spotify, in turn, either resided directly on the OEM’s platform or was used via the driver’s smartphone. This illustrates that the often-heralded flexibility of companies pursuing digitally oriented business models also exhibits some cognitive path dependence and resistance to enter the physical path.

[5] To corroborate our findings, we conducted the same analysis in the Mobility as a Service industry and found similar results, see the vignette in the supplementary material Section C (available online).

Table 3
Path dependencies in physically and digitally oriented business models.

Path dependencies	Physically oriented business models	Digitally oriented business models
Dominant logic	**Limits option space** in business model design owing to fixed product boundaries (value proposition), up-front plans, and rigid product development (value network) (Henderson and Clark, 1990; Henfridsson et al., 2014; Svahn and Henfridsson, 2012). Promotes **efficiency and complementarities** as sources of value creation (Svahn et al., 2017).	**Increases option space** in business model design owing to fluid product boundaries (value proposition), as well as agile and flexible product development (value network), providing ample opportunities for business model design (Nambisan, 2016; Nambisan et al., 2017; Yoo et al., 2012). Promotes **novelty, efficiency, complementarities, and lock-in** as sources of value creation (Huang et al., 2017).
Complementary assets	Promotes **creating complementarities by bundling internal assets** owing to the modular product architecture (Svahn and Henfridsson, 2012). Promotes a more introverted orientation and **reduces dependency** on external ecosystems, infrastructures, and players (Christensen, 2006; Henfridsson et al., 2014).	Promotes **creating complementarities by bundling internal and external assets** (Yoo et al., 2012, 2010). Promotes a more extroverted orientation and **increases dependency** on external ecosystems, infrastructures, and players (Christensen, 2006; Nambisan, 2016; Nambisan et al., 2017).
Contingent events	**Increased susceptibility to contingent events** since the stable, predefined architecture, the linear product development process, and early binding prevent effortless contextualization (Henfridsson et al., 2014; Hylving et al., 2012; Tumbas et al., 2015).	**Decreased susceptibility to contingent events** as there is an effortless contextualization of already existing offerings (Huang et al., 2017).

This criss-cross of industrial age firms becoming more digital and digital ventures becoming (partially) more physical, challenges established views on the role of initial conditions for path dependency (Vergne and Durand, 2010). In our case, the going-in positions of actors as well as the decision to shift towards more digitally or more physically oriented business models, shaped by the respective history of the companies, had an important influence. The business models, varying in their degree of building upon and expanding into physical or digital technologies, afforded firms more or less flexibility in leveraging their offerings *per se* and therefore resulted in varying degrees of the need to change. Thus, the influence of differences in resource foundations at the beginning of an innovation trajectory, in the digital age, path dependency's sensitivity to initial conditions might increase (Garud et al., 2010).

5.3. The path breaking nature of digital technologies

Overall, our findings suggest that the integration of digital technologies can unlock the path-dependent behavior of companies with physically-oriented business models. Prior research has assumed exogenous shocks are required to break free from the past. Our study indicates that the integration of digital technologies, which start with the digital juncture (see Fig. 6), can break lock-ins. From a resource-based perspective, digital technologies afford firms to develop, offer, and adapt new value propositions, increasing flexibility, of course with the caveat that adding external resources, such as apps, may also create new dependencies. From a cognitive perspective, digital technologies bring with them new agile ways of developing products and the mindset of never-ending product development.

As a result, we witness a bifurcation of paths. While the physical materiality is what it is and, once developed, it follows a very tight path, the incorporation of digital technologies triggers new path formations (Vergne and Durand, 2010). Accordingly, while prior research has clearly contrasted path dependency and path creation (Garud et al., 2010), we find a co-existence (see Fig. 6). Although options remain narrow along the physical path, overall organizational path dependency decreases due to the new options emerging along the digital path. Future research may also find positive spill-over effects, for instance a trickle-down effect of agile thinking from the digital path into the physical path.

Our findings indicate that, in increasingly digital businesses, the idea of a lock-in is challenged (Garud et al., 2010). The flexible nature of digital technologies allows for constant adaptation and (re)contextualization (Kallinikos, 2013). In this vein, organizations following the digital path seem to stay in continuous phases of path pre-formation and formation (Vergne and Durand, 2010) and never arrive in strict lock-in situations. A company pursuing a physically oriented business model will always be more rigid in its behavior, as the modular architecture dictates the way the company can innovate in a much stronger manner. Consequently, companies pursuing physically oriented business models have to adapt their routines much more than companies pursuing a digitally oriented business model to cope successfully with digital business model evolution. However, this also means that when digital players enter the physical path via a physical juncture (see Fig. 6), for example, by producing cars or car parts, they experience decreasing options and potential lock-ins. Thus, digital innovation building upon both, digital and physical, components (Yoo et al. 2010) therefore implies that participating actors have to deal with considerable variance in path dependencies at the same time. This explains why we find substantial competing concerns and associated tensions in companies that "cross-the-border" either from physical to digital (Svahn et al., 2017) or vice versa, as can be witnessed by the case of Tesla's challenges in scaling physical mass-market production. In summary, path dependent behavior is influenced by the initial business model orientation on the one hand, and the expansion direction which changes the product architecture, on the other. When these two aspects are combined, the typology in Fig. 7 emerges which contrasts the path dependent behavior

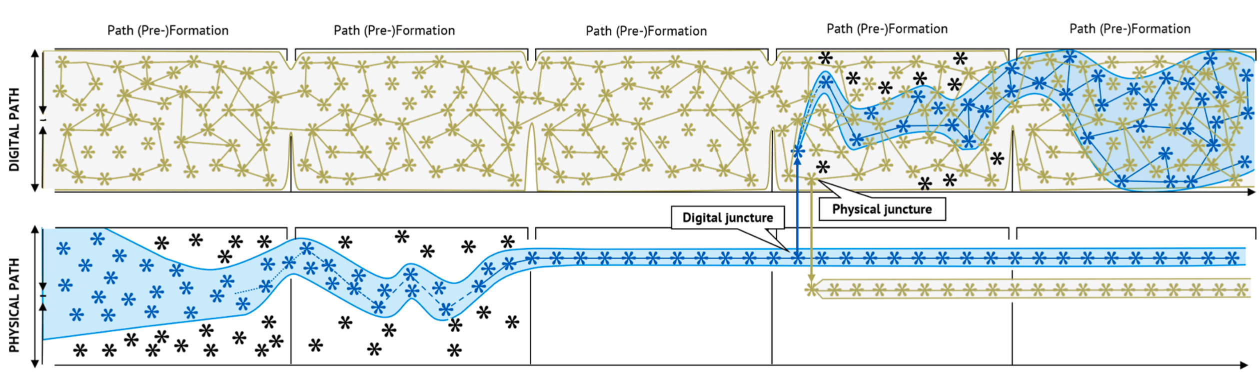

Fig. 6. The influence of digital technologies on organizational paths.

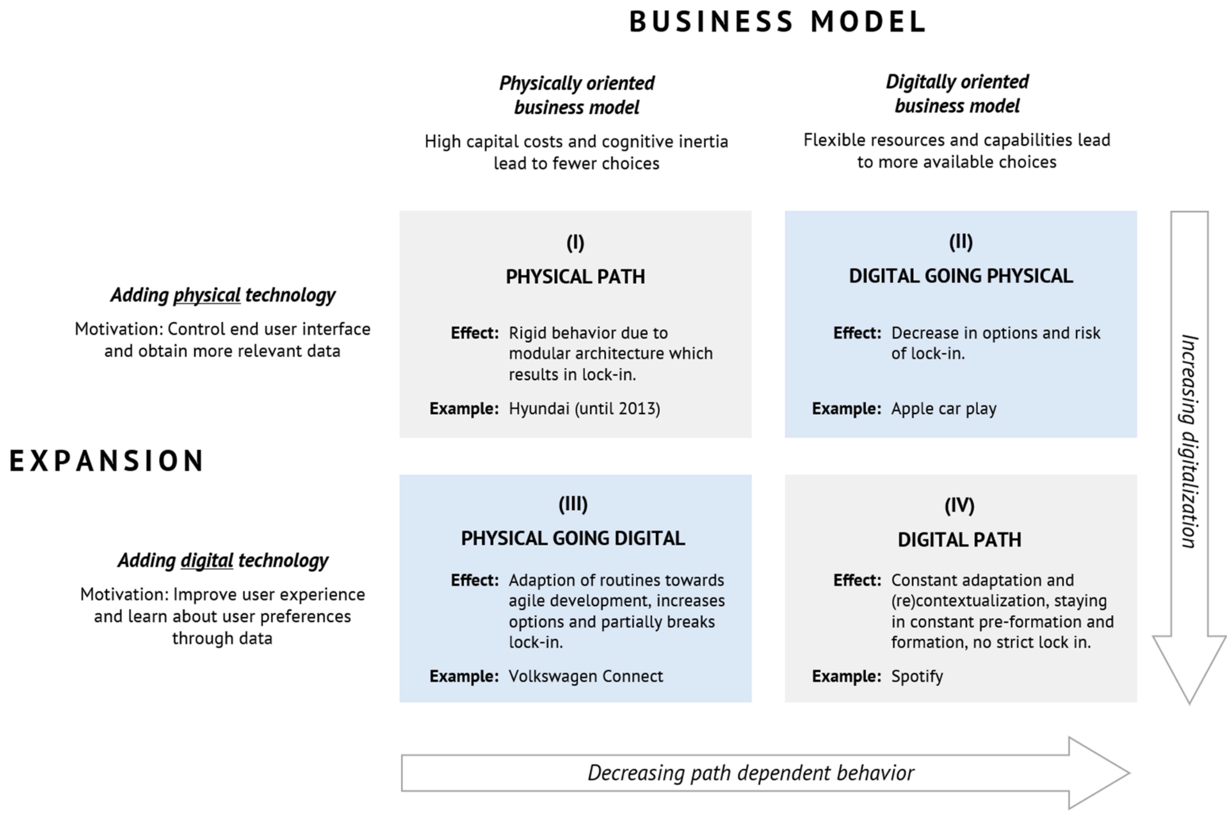

Fig. 7. The influence of the business model and changes in product architecture on path dependent behavior.

on the physical path (cell I) with the digital path (cell II), but also physical going digital (cell III) and digital going physical (cell IV).

Overall, we see that the integration of digital technologies in physical products changes the dynamics of an industry. Digital transformation is said to be associated with the emergence of digital business ecosystems, yet their emergence and effects, especially in non-digital contexts of large, complex industrial products, has been unclear (Hanelt et al., 2020). Our findings show that companies adopting different business model archetypes and expanding into digital or physical, enabled the gradual evolution of a layered modular architecture (Yoo et al., 2010) and convergence of the industry, which is an effect that is likely to occur in other industries also.[6]

6. Contributions and future research

With this study, we sought to contribute to the literature on path dependence more generally (Vergne and Durand, 2010) and its influence on business model evolution more specifically (Bohnsack et al., 2014). Prior research has explained path-dependent behavior as reflected in the limited ability of firms to adapt previously established offerings, structures, and processes in later phases (Sydow et al., 2009). Our findings suggests more nuances to our understanding of path dependence in the digital age by, unearthing how the integration of digital technology into business models can unlock path dependence and restore choices. Thereby, we challenge and extend established knowledge on organizational path dependence with regard to key tenets, such as initial conditions and lock-ins, and provide an updated perspective on path dependence's resource- and cognition-based foundations.

An important area that requires further research in this context is to deepen our knowledge on the interaction between resource-based and cognitive path dependency. For instance, we would expect that within a company pursuing a physical and digital path, the mindset of the digital path could trickle down, also spilling over into the overall dominant logic of the company and increasing flexibility, thus reducing path dependency and influencing organizational change. Going beyond our focus on resource-based and cognitive path dependency, future studies may particularly investigate relational path dependency in the digital age. This is all the more important, as the increasing digitalization of physical products may influence the path dependency of several companies in an ecosystem at once, requiring them to work together and to find a suitable overarching business model in order to successfully commercialize novel digitalized products. Vice versa, constellations of partners within ecosystems may also create forms of path dependence and in fact lead to competition. What is more, we would expect that within a company pursuing a physical and digital path, this mindset of the digital path will trickle down, also spilling over into the overall dominant logic of the company and increasing flexibility, thus reducing path dependency and influencing organizational change.

Moreover, our study provides novel insights into the debate on industry convergence (Hacklin et al., 2018; Kim et al., 2015). Our findings show a gradual manifestation of digital business ecosystems based on layered modular architectures (Yoo et al., 2010) resulting in industry convergence (Tilson et al., 2010). While such architectures have been

[6] Our study is set in the connected car context and based on certain assumptions. In particular, on the one hand, we assume that in this context industrial-age incumbents aim to utilize their established competences, yet also want to transform themselves to deliver digital components to their customers. Furthermore, in this context, security and safety regulations, stemming from the risks of the core product (vehicle) for human lives, clearly hamper the adaptability of the physical components. On the other hand, we assume digital players to enter this context that draw on digital capabilities with great ease, yet might experience difficulties when they face the need to integrate with physical components at scale. The boundary conditions of our theorizing are set by these assumptions. Thus, our insights might apply to other industries where physical components, which create vulnerabilities to human lives, continue to exist, yet are aspired to be complemented with digital components by both industrial-age incumbents and digital players.

conceptually illustrated, the process of their emergence over time has not been well described in the debate and is an important area of inquiry for future innovation research. The 'collision' of physical and digital paths has been taking place in other industries (e.g. media or telecom), yet the observed phenomenon in the connected car industry is rather unique and temporal. The developments offer new insights on the convergence in industries with industrial age products, but the outcomes are still unclear and may depend on upcoming technological advances, e.g. battery or autonomous driving technologies. Future research should further explore the convergence in other industries with industrial age products, e.g. in the energy industry or agriculture, and study the outcomes; particularly how firms continue to innovate on the digital path, whether the position on a layer matters for path dependent behavior, and how players in the layered modular architecture create bargaining power (Pagani, 2013).

Our findings also have important implications for practice and policy. First, automotive managers should be aware that they first need to ensure that their vehicles can serve as a complementary, seamlessly integrated part of emerging layered modular architectures. In fact, we believe that this is relevant for any company that builds physical devices. However, it is important to note that this is only a necessary condition. If OEMs only focus on their technological fit, for example, by ensuring connectivity, they risk being considered as mere hardware providers (like smartphone assemblers) by their partners and customers alike. In the long run—especially with the rise of autonomous cars—this might lead to commoditization. Instead, automotive managers should focus on the actual customer experience inside and around the vehicle. To do so, they could leverage their skills and assets—for instance, by utilizing the access to vehicle data and the deep knowledge about mobility regarding customer experience and safety—to also create new digital services and content, while not letting customers solely use the offerings of players in the digital ecosystem (such as Alphabet or Spotify) that they know and like. Second, our findings have implications for policymakers. With this study, we provide insights into how traditional industries, such as the car industry, are transformed through the integration of digital technologies and how historic pathways can be unlocked. A consequence of our findings could be that upcoming stimulus packages should focus more on incentivizing the development of digital business models rather than drivetrain technologies. This will better prepare incumbents in the industry for the future and drive their ability to compete with digital ventures.

CRediT authorship contribution statement

René Bohnsack: Conceptualization, Writing – review & editing. **Hannes Kurtz:** Data curation, Writing – original draft. **André Hanelt:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.respol.2021.104328.

Appendix B. Evolution of business model archetypes of exemplary players

I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IV Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
Product-Based Digital Extension					
General Motors *OEM*	*Value Proposition:* Owned mobility in form of an automobile and related after sales services	*Dominant logic:* Perceived digital offerings as "traditional" feature packages for which they wanted remuneration	*T1 – Era of Experimentation:* (CE) Financial crisis affected GM strongly as its almost bankruptcy nearly resulted in an intended sale of OnStar; Discussion about distracted driving affect the whole industry but GM less due to its focus on safety and security features	*Value Proposition:* Owned mobility in form of an automobile and related after sales services	*Dominant logic:* Perceives digital offerings as additional, independent businesses
	Specialized portfolio consisting of digital safety and security features	Focused on vehicle-related services such as safety and security features	(TA) n/a	Comprehensive portfolio consisting of advanced vehicle-related (e.g. over the air updates) and vehicle-unrelated (e.g. advanced infotainment) services	Focuses on vehicle-related services to differentiate itself and let others offer vehicle-unrelated services
	Value Network:	Used to be the decisive part in value network as known from the automotive industry	(VP) Offered basic vehicle-related services such as vehicle diagnostics	Digital ecosystem consisting of independent external developers and access to Apple's and Google's digital ecosystems	Is only in parts of the value network the decisive player (e.g. traditional automobile manufacturing)
	Classical value chain approach with different suppliers in different tiers	Used traditional revenue streams for digital services	(VN) no changes	*Value Network:*	Uses multiple revenue streams
		Complementary assets:			*Complementary assets:*

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I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IV` Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
	Mainly in-house development of safety and security features		(RCM) Added subscription for specific services such vehicle diagnostics	Classical value chain approach with different suppliers in different tiers	
	Revenue-cost Model:	Used mainly internal resources and capabilities to develop digital offerings	*T2 – Era of Alignment:*	Mainly in-house development of vehicle-related services	Uses internal and external resources and capabilities
	Traditional revenue streams such as sell of automobiles, after sales services and parts as well as financial services	Pursued an incremental innovation practice for further developing OnStar as they were used to from the automotive industry	(CE) Discussion about data privacy affected the whole automotive industry	Mainly outsourcing of vehicle-unrelated services to ecosystem	Shares innovation projects
		Contingent events:	(TA) Opened product architecture by using a platform for external developers with associated blank screen (MirrorLink)	*Revenue-cost Model:*	Access to ecosystem of external developers
		Susceptible to contingent events due to e.g. rigid development process	(VP) Offered external vehicle-unrelated services such as Pandora and Twitter	Traditional revenue streams such as sell of automobile, after sales services and parts as well as financial services	*Contingent events:*
			(VN) Partnered with external developers to offer new services	Diverse pricing models such as subscription Free/ Freemium/Premium for advanced vehicle-related services	Less susceptible on digital layers
			(RCM) Perceived data as non-monetary revenue stream (e.g. sold it to insurance companies)	Data is seen as a non-monetary revenue stream (e.g. driving behavior)	Less susceptible due to allocation of own digital resources and capabilities
			T3 – Era of Convergence:		
			(CE) Discussion about car hacking and VW emission gate affected the whole automotive industry		
			(TA) Harmonized development and product life cycles of automobiles and digital offerings via LTE connectivity and over-the-air updates; Further opened vehicles architecture by letting Apple and Google offer their stripped down smartphone operating systems		
			(VP) Offered advanced vehicle-related services such as over-the-air updates and access to external digital ecosystems of Apple and Google		
			(VN) Used access to external digital ecosystem of Apple and Google		
			(RCM) no changes		
Ford *OEM*	*Value Proposition:* Owned mobility in form of an automobile and related after sales services	*Dominant logic:* Used to be the decisive part in value network	*T1 – Era of Experimentation* (CE) Financial crisis affected the whole automotive industry; Discussion about distracted driving affect the whole industry and Ford in particular due to its focus on infotainment and concurrently allocation of only less own digital resources and capabilities	*Value Proposition:* Owned mobility in form of an automobile and related after sales services	*Dominant logic:* Perceives digital offerings as additional, independent business
	Value Network:	Used traditional revenue streams for selling their cars (e.g. sell and leasing)	(TA) Opened product architecture via smartphone connection (Sync)	Comprehensive portfolio of vehicle-related (e.g. vehicle diagnostics) and -unrelated (e.g. Spotify) services	Outsources development of most services to external ecosystem
	Classical value chain approach with different suppliers in different tiers	*Complementary assets:*	(VP) Offered vehicle-unrelated services such as Facebook and Twitter	Digital ecosystem consisting of independent external developers and access to Apple's and Google's ecosystems	Is only in parts of the value network the decisive player (e.g. traditional manufacturing)
	Revenue-cost Model:			*Value Network:*	

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I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IV Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
		Used internal resources and capabilities to assemble automobiles	(VN) Partnered with external developers to offer new services		Uses multiple revenue streams
	Traditional revenue streams such as sell of automobiles, after sales services and parts as well as financial services	Outsourced innovation capacity for parts to top tier of supply pyramid	(RCM) no changes	Classical value chain approach with different suppliers in different tiers	*Complementary assets:*
		Pursued an incremental innovation practice for already existing parts	*T2 – Era of Alignment*	Mainly external development of digital offerings	Use mainly external resources and capabilities for digital services
		Contingent events:	(CE) Discussion about data privacy affected the whole industry	*Revenue-cost Model:*	Mainly outsources innovation activities with regard to digital services
		Susceptible to contingent events due to e.g. stable product architecture	(TA) n/a	Traditional revenue streams such as sell of automobiles, after sales services and parts as well as financial services	*Contingent events:*
			(VP) no changes	Used diverse pricing models fsuch as subscription for advanced infotainment	Less susceptible on digital layers
			(VN) no changes	Data (customers' driving behavior)	
			(RCM) Perceived data as a non-monetary revenue stream (e.g. driving behavior)		
			T3 – Era of Convergence		
			(CE) Discussion about car hacking and VW emission gate affected the whole automotive industry		
			(TA) Cancelled separation of MyFord Touch and Sync 2 and harmonized external and internal offerings via a platform (Sync 3); Further opened vehicles architecture by letting Apple and Google offer their stripped down smartphone operating systems		
			(VP) Offered basic vehicle-related services such as vehicle diagnostics and offered access to external digital ecosystems of Apple and Google		
			(VN) Used access to external digital ecosystem of Apple and Google		
			(RCM) no changes		
Volkswagen	*Value Proposition:*	*Dominant logic:*	*T1 – Era of Experimentation*	*Value Proposition:*	*Dominant logic:*
OEM	Owned mobility in form of an automobile and related after sales services	Perceived digital offerings as “traditional” feature packages for which they wanted remuneration	(CE) Financial crisis affected the whole automotive industry; Discussion about distracted driving affect the whole industry	Owned mobility in form of an automobile and related after sales services	Perceives digital offerings as additional, independent businesses
	Value Network:	Used to be the decisive part in value network as known from the automotive industry	(TA) n/a	Comprehensive portfolio consisting of advanced vehicle-related (e.g. over-the-air updates) and vehicle-unrelated (e.g. WeConnect/ AudiConnect) services	Focuses on vehicle-related services to differentiate itself and let others offer vehicle-unrelated services
	Classical value chain approach with different suppliers in different tiers	Used traditional revenue streams for digital services	(VP) Offered connectivity to external devices via USB and Bluetooth connectivity	Digital ecosystem consisting of independent external developers and access to Apple's and Google's digital ecosystems	Is only in parts of the value network the decisive player (e.g. traditional automobile manufacturing)
	Revenue-cost Model:	*Complementary assets:*	(VN) no changes	*Value Network:*	Uses multiple revenue streams
	Traditional revenue streams such as sell of automobiles, after sales services and parts as	Partnered with other OEMs in order to develop a technology platform	(RCM) no changes	Classical value chain approach with different suppliers in different tiers	*Complementary assets:*

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I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IV Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
	well as financial services	(Terminal Mode) from the very beginning			
		Pursued an incremental innovation practice	*T2 – Era of Alignment*	Mainly in-house development of vehicle-related services	Uses internal and external resources in digital ecosystem
		Contingent events:	(CE) Discussion about data privacy affected whole automotive industry	Mainly outsourcing of vehicle-unrelated services to ecosystem	Shares innovation projects
		Susceptible to contingent events due to e.g. long product life cycles	(TA) Opened product architecture via a platform (Terminal Mode)	Partners with other OEMs to harmonize digital infrastructure (e.g. APIs) to reduce complexity	Engages extensively in partnerships with other OEMs
			(VP) Offered vehicle-related (e.g. vehicle diagnostics) and –unrelated services (e.g. WeConnect/ AudiConnect)	*Revenue-cost Model:*	*Contingent events:*
			(VN) Partnered with external developers mainly for vehicle-unrelated services	Traditional revenue streams such as sell of automobile, after sales services and parts as well as financial services	Less susceptible on digital layers resulting in increased flexibility
			(RCM) Added subscription for services such as WeConnect and perceived data as a non-monetary revenue stream (e.g. customer demands, driving behavior)	Diverse pricing models such as subscription Free/ Freemium/Premium for advanced vehicle-related services and advanced infotainment (WeConnect/ AudiConnect)	Less susceptible due to allocation of own digital resources and capabilities
			T3 – Era of Convergence	Data is seen as a non-monetary revenue stream (e.g. driving behavior, customer demands)	
			(CE) Discussion about car hacking affected the whole industry; VW emission gate affected the company in particular but it decided to still invest in future technology		
			(TA) Synchronized development and product life cycles via LTE and over-the-air updates; Further opened vehicles architecture by letting Apple and Google offer their stripped down smartphone operating systems		
			(VP) Offered advanced vehicle-related services such as over-the-air updates and access to external digital ecosystem of Apple and Google		
			(VN) Used access to external digital ecosystem of Apple and Google		
			(RCM) no changes		
Tesla	*Value Proposition:*	*Dominant logic:*	*T1 – Era of Experimentation*	*Value Proposition:*	*Dominant logic:*
OEM	Owned mobility in form of an automobile	Perceived digital offerings from the very beginning as integral part of an automobile	(CE) Financial crisis affected Tesla in particular as it was a very young company with little cash reserves etc.	Owned mobility in form of an automobile	Perceived digital offerings as additional business
	Connection to external digital devices such as smartphones or Mp3-Players	Perceived digital offerings as purchasing incentives (e.g. Angry Birds to make the waiting time during loading more attractive)	(TA) n/a	Comprehensive portfolio consisting of advanced vehicle-related (e.g. over-the-air updates) and vehicle-unrelated (e.g. Netflix) services	Focused on different services
	Basic infotainment services such as Pandora	*Complementary assets:*	(VP) no changes	Digital ecosystem consisting of independent external developers and access to Apple's and Google's digital ecosystems	Decisive part only in parts of the value network
	Value Network:	Used internal and external resources and capabilities such as those from external	(VN) n/o changes	*Value Network:*	Engaged in value co-creation

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I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IV` Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
		developers in order to develop digital services			
	Classical value chain approach with different suppliers in different tiers	*Contingent events:*	(RCM) no changes	Classical value chain approach with different suppliers in different tiers	Used multiple revenue streams
	In-house development of connectivity solutions	Less susceptible due to better developed digital layers resulting in increased flexibility	*T2 – Era of Alignment*	Mainly in-house development of vehicle-related services	*Complementary assets:*
	Digital ecosystem of external developers for digital services	Less susceptible due to allocation of own digital resources and capabilities	(CE) Discussion about data privacy affected the whole industry	Mainly outsourcing of vehicle-unrelated services to ecosystem	Use of internal and external resources and capabilities
	Revenue-cost Model:	Less susceptible due to ecosystem of external developers	(TA) Synchronized development and product life cycles via over-the-air updates	*Revenue-cost Model:*	Shares innovation projects
	Traditional revenue streams such as sell of automobiles and financial services		(VP) no changes	Traditional revenue streams such as sell of automobile, after sales services and parts as well as financial services	*Contingent events:*
			(VN) no changes	Diverse pricing models such as subscription Free/ Freemium/Premium for advanced vehicle-related services and advanced infotainment	Less susceptible due to better developed digital layers resulting in increased flexibility
			(RCM) no changes	Data is seen as a non-monetary revenue stream (e. g. driving behavior, customer demands)	Less susceptible due to allocation of own digital resources and capabilities
			T3 – Era of Convergence		Less susceptible due to ecosystem of external developers
			(CE) Discussion about car hacking affected the whole industry; VW emission gate didn't affect Tesla		
			(TA) Further opened vehicles architecture by letting Apple and Google offer their stripped down smartphone operating systems		
			(VP) no changes		
			(VN) no changes		
			(RCM) no changes		
Digital Stand-alone Offerings					
Spotify	*Value Proposition:*	*Dominant logic:*	*T1 – Era of Experimentation*	*Value Proposition:*	*Dominant logic:*
Music Streaming Platform	Music streaming	Engaged in the establishment of a multi-sided platform with customers on one and musicians on the other side	(CE) n/a	Music streaming	Engages in steady further development of its multi-sided platform
	Value Network:	Focus was on the steady expansion the own digital ecosystem (e.g. more subscriber, more musicians and music, more devices)	(TA) a/a	*Value Network:*	Focuses on the steady expansion of the own digital ecosystem (e.g. more subscriber, more musician and music, more devices)
	Digital ecosystem of external contributors in the form of musicians publishing their music	Focused on establishing network effects	(VP) no changes	Digital ecosystem of external contributors in the form of musicians publishing their music	Focuses on establishing network effects
	Leveraged external digital devices such as the smartphone to be present at the customer	Focused on generating lock-in effects	(VN) no changes	Leverages external digital devices such as the smartphone to be present at the customer	Focuses on generating lock-in effects
	Revenue-cost Model:	*Complementary assets:*	(RCM) no changes	Leverages also the automobile to be present at the customer	*Complementary assets:*
	Subscription	Used internal and external resources and competencies	*T2 – Era of Alignment*	*Revenue-cost Model:*	Uses internal and external resources and competencies

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I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IV Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
		Extensive network of external contributors	(CE) OEMs' invitation to settle on their architecture	Subscription	Extensive ecosystem of external contributors
		Contingent events:	(TA) Migrated to OEMs' platforms by accommodating their requirements		*Contingent events:*
		Less susceptible to contingent events	(VP) no changes		More susceptible to contingent events on physical layer
			(VN) Started to leverage the automobiles of OEMs		
			(RCM) no changes		
			T3 – Era of Convergence		
			(CE) Apple's and Google's invitation to use their stripped down operating systems		
			(TA) Migrated to Apple's and Google's stripped down smartphone operating systems		
			(VP) no changes		
			(VN) Used access to the vehicles architecture via stripped down smartphone operating systems		
			(RCM) no changes		
FIXD	*Value Proposition:*	*Dominant logic:*	*T1 – Era of Experimentation*	*Value Proposition:*	*Dominant logic:*
App for Vehicle Diagnostics	Vehicle sensor and corresponding smartphone app to read out vehicle data	Impatient with speed of OEMs	(CE) n/a	Vehicle sensor and corresponding smartphone app to read out vehicle data	Impatient with speed of OEMs
	Value Network:	Targeted aftermarket and older vehicles	(TA) n/a	*Value Network:*	Targeted aftermarket and older vehicles
	In-house development of application	Easy contextualization of offering possible	(VP) n/a	In-house development of application	Easy contextualization of offering possible
	Dependent on supplier for hardware	*Complementary assets:*	(VN) n/a	Dependent on supplier for hardware	*Complementary assets:*
	Revenue-cost Model:	Uses internal resources and capabilities	(RCM) n/a	*Revenue-cost Model:*	Uses internal resources and capabilities
	Sell of hardware	Uses Apple's and Google's digital platforms as marketing and sales channels	*T2 – Era of Alignment*	Sell of hardware	Uses Apple's and Google's digital platforms as marketing and sales channels
	Different subscription models (e.g. Free and Premium)	*Contingent events:*	(CE) n/a	Different subscription models (e.g. Free and Premium)	*Contingent events:*
		Susceptible to contingent events as dependence on own developed vehicle sensor (physical integration)	(TA) Developed own vehicle sensor to plug into an automobile's OBD-Port as it was not able to migrate on automobile platforms as OEMs restricted access to vehicle data		Susceptible to contingent events as dependence on own developed vehicle sensor (physical integration)
			(VP) no changes		
			(VN) no changes		
			(RCM) no changes		
			T3 – Era of Convergence		
			(CE)		
			(TA) Was not able to migrate via Apple and Google's stripped down smartphone operating systems as OEMs restricted access to vehicle data and dependence on own developed vehicle sensor		
			(VP)		
			(VN)		
			(RCM)		
Connectivity Provision					
AT&T	*Value Proposition:*	*Dominant logic:*	*T1 – Era of Experimentation*	*Value Proposition:*	*Dominant logic:*
Telecommunication Company	Data plan for internet connectivity	Focused on expanding the ecosystem of connected devices	(CE) n/a	Data plan for internet connectivity	Focuses on expanding the ecosystem of connected devices
	Value Network:	Focused on generating network effects	(TA) n/a	*Value Network:*	Focuses on generating network effects

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I Business Model Archetype // Company	II Business Model before T1	III Path Dependence T1	IVˋ Technological Adjustments & Business Model Evolution T1-T3	V Business Model after T3	VI Path Dependence T3
	In-house development of network standards, protocols etc.	*Complementary assets:*	(VP) no changes	In-house development of network standards, protocols etc.	*Complementary assets:*
	Sold data plans via smartphones	Used internal resources and capabilities	(VN) no changes	Sells data plans via smartphones	Uses internal resources and capabilities
	Revenue-cost Model:	*Contingent events:*	(RCM) no changes	Sells data plans via automobiles	*Contingent events:*
	Subscription	Susceptible to contingent events	*T2 – Era of Alignment*	*Revenue-cost Model:*	Susceptible to contingent events
			(CE) n/a	Subscription	
			(TA) n/a		
			(VP) no changes		
			(VN) no changes		
			(RCM) no changes		
			T3 – Era of Convergence		
			(CE) OEMs' invitation to offer data plans via their automobiles		
			(TA) n/a		
			(VP) no changes		
			(VN) Used automobiles to sell data plans to customers		
			(RCM) no changes		
Digital Mirroring					
Apple	*Value Proposition:*	*Dominant logic:*	*T1 – Era of Experimentation*	*Value Proposition:*	*Dominant logic:*
Consumer Electronics	Smartphone	Focused on establishing a multi-sided platform	(CE) n/a	Smartphone	Focused on establishing a multi-sided platform
	Digital ecosystem of external offerings (e.g. App Store)	Focused on the steady expansion of its own digital ecosystem	(TA) n/a	Digital ecosystem of external offerings (e.g. App Store)	Focused on the steady expansion of its own digital ecosystem
	Value Network:	Focused on generating network effects	(VP) no changes	*Value Network:*	Focused on generating network effects
	In-house development of operating system and "killer applications"	Focused on establishing lock-in effects	(VN) no changes	In-house development of operating system and "killer applications"	Focused on establishing lock-in effects
	Multi-sided platform (Apple's App Store)	*Complementary assets:*	(RCM) no changes	Multi-sided platform (Apple's App Store)	*Complementary assets:*
	Digital ecosystems of external developers offering applications in Apple's App Store	Used internal and external resources and competencies to develop digital services	*T2 – Era of Alignment*	Digital ecosystems (e.g. external developers offering apps on Apple's App Store)	Used internal and external resources and competencies to develop digital services
	Revenue-cost Model:	*Contingent events:*	(CE) n/a	*Revenue-cost Model:*	*Contingent events:*
	Sales of hardware such as smartphones	Less susceptible to contingent events	(TA) n/a	Sales of hardware such as smartphones	More susceptible to contingent events on physical layer
	Fees for intermediation of applications in Apple's App Store		(VP) no changes	Fees for intermediation of applications in Apple's App Store	
			(VN) no changes	Licenses to OEMs for stripped down operating system	
			(RCM) no changes		
			T3 – Era of Convergence		
			(CE) OEMs invitation to use their APIs		
			(TA) Adjustment to APIs provided by OEMs		
			(VP) no changes		
			(VN) no changes		
			(RCM) Licensed stripped down smartphone operating system to OEMs		

Legend: T1 = 2007-2009; T2 = 2010-2013; T3 = 2014-2017; CE = Contingent Events; TA = Technological Adjustments; VP = Value Proposition; VN = Value Network; RCM = Revenue-cost Model; n/a = no technological adjustment found; underlined = emphasis on noteworthy elements

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