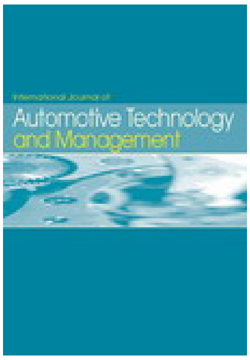


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# In-house software development for software-defined vehicles: major changes ahead in automotive value chains?

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# In-house software development for software-defined vehicles: major changes ahead in automotive value chains?

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**Abstract:** In response to the emergence of software-defined vehicles, incumbent OEMs announced software-focused strategies. Seeking to move software development in-house, they invested in building the requisite capabilities. This paper develops propositions about whether and how OEMs' software-focused strategies might reshape the division of labour and value in automotive value chains. We propose that the evolution of industry architecture is shaped not only by incumbents' shifting transactional choices regarding how they access the new technology inputs. There are several – occasionally counteracting – forces at play, generated by the efforts, interactions, and strategic pivots of heterogeneous actors. We argue that against predictions of disruptive change, the relative stability of industry architecture is also a conceivable scenario. Although incumbent OEMs' software-related strategic initiatives were only partially successful in terms of financial performance, their investments in the internalisation of various software-defined functions will prevent excessive value migration and the commoditisation of their core offerings.

**Keywords:** software-defined vehicle; SDV; industry architecture; incumbent OEMs; autotech startups; value migration; adaptation to technological change; make-buy-ally; software strategy.

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## 1 Introduction

The long period of value chain consolidation in the automotive industry seemed to be over in the 2010s (Ferràs-Hernández et al., 2017). For decades, the average number of participants in automotive value chains kept declining as a result of takeovers, mergers, and consolidation in the number of suppliers (MacDuffie, 2013; Sturgeon et al., 2009). From the second half of the 2010s, however, a flock of new entrants arrived from outside the previously defined boundaries of the automotive industry (Szalavetz, 2022a). The new entrants are technology companies that induced and enabled the transformation of automotive products, production and business processes, and business models.

Against this background, observers discussed whether the new entrants could bring about major shifts in the division of labour and the distribution of value in automotive value chains (Murmann and Vogt, 2023; Perkins and Murmann, 2018; Teece, 2018). Scholars proposed that incumbents' prior dominant position may be challenged in the wake of fundamental changes in the drivers of value (Ferràs-Hernández et al., 2017; Perkins and Murmann, 2018). Specifically, their core offerings may be commodified and as value migrates toward the offerings of technology complementors their profitability will shrink (Adner and Lieberman, 2021). Others argued that automotive incumbents will spearhead the fundamental transformation of their industry (Svahn et al., 2017) and thus their value chain position will not be shaken by the new entrants. By accumulating the requisite capabilities, OEMs can preserve a relative stability in the industry architecture (Alvarez León and Aoyama, 2022; Jacobides et al., 2016; Murmann and Vogt, 2023).

Given the fundamental and ongoing nature of technology-driven transformation, the debate over the degree to which it will reshape the division of labour in automotive value chains and engender value migration to beyond-industry-boundary newcomers has neither been exhausted nor concluded. In particular, the changes that the transition to software-defined vehicles (SDVs) may entail in the architecture of the automotive industry have not received sufficient scientific attention.

We address this research gap by developing propositions about the implications of the transition to SDVs for the architecture of the automotive industry. Industry architecture refers to the division of labour ('who does what') and the distribution of profit ('who takes what') – [Jacobides et al., (2016), p.1942]. More specifically, we explore automotive OEMs' recently announced software-focused strategies, initiated in response to the obsolescence of the industry's traditional hardware-defined innovation trajectory, and advance propositions regarding the size and direction of change in the architecture of their value chains.

We propose that transition to SDVs impacts OEMs' value capture capabilities and requires the accumulation of technological and related complementary resources. To reinforce their value chain position and increase/sustain value capture, incumbent OEMs need to reconsider and possibly modify their prior transactional choices regarding how they access the requisite technology inputs and what they decide to internalise. While several OEMs have made extensive investments to internalise the development of the previously outsourced technology inputs and thus reduce the risk of value migration toward autotech companies, we argue that the sporadic evidence of OEMs' initiatives to internalise software development is insufficient for definitive conclusions regarding the future direction of change in the industry architecture.

We argue and show that besides the fact that the evolution of industry architecture depends not only on OEMs' transactional choices, there are several other, occasionally counteracting forces at play, which precludes hasty inferences. In sum, in line with Jacobides et al. (2016), we posit that the division of labour and profit changes slowly in the automotive industry. Against predictions of disruptive change wrought both by technological progress and OEMs' efforts to adapt to it and avoid excessive value migration, the complexity of developments (Eden and Nielsen, 2020) makes the relative stability of industry architecture also a conceivable scenario. Accordingly, OEMs' software-focused strategies will effectively prevent value migration from reaching a level that could relegate their core offerings to a simple commodity status but will not drastically alter the industry architecture.

We begin with presenting the theoretical concepts that guide our analysis and proceed to our propositions. In the subsequent sections, we evaluate these propositions considering incumbent OEMs' adaptation and repositioning choices and other factors that exert an impact on industry architecture. We show that the observed patterns in the evolution of industry architecture do not allow for a straightforward prediction of the direction of change. We conclude with managerial implications, limitations, and future research directions.

## 2 Theoretical background

The most recent stage in the advanced vehicle technologies-induced transformation of the automotive industry is the emergence of SDVs. SDVs mark the culmination of a long process in which the traditional, hardware-defined innovation trajectory of the industry has been replaced by a new evolutionary course. The functional features of and user experience in SDVs are to a large extent defined by software (Liu et al., 2022). Consequently, and due to the capability to update software over the air (OTA), SDVs can evolve throughout their entire lifecycle: their functions can be optimised, and new functions added. Since the architectural design of SDVs is determined by software[1], and software gradually becomes decoupled from hardware, the relationship between OEMs and suppliers may undergo radical restructuring (Zhao et al., 2022). Note that while the decoupling of the hardware from the software can be fully implemented only with the standardisation of design interfaces, only the first steps have been taken in this direction (cf. Cariad, 2023). It is still a long way to go for the key actors in the automotive industry to align their product development approaches with the requirements of SDVs.

Notwithstanding, the new evolutionary trajectory of the automotive industry did not leave the industry architecture intact. New (technology) companies entered the automotive value chains and exerted a strong impact on the evolution, structure, and boundaries of the industry (Alvarez León and Aoyama, 2022; Kim et al., 2022; Szalavetz, 2022a). The rapidly evolving business environment, specifically, the anticipated changes in the drivers of value and the distribution of profits called for incumbents' adjustment and strategic repositioning to be able to capture the software-related new revenue streams.

Incumbents' adjustment warrants the accumulation of technological and complementary resources (Eggers and Park, 2018), which can occur through building the requisite resources internally, purchasing them externally, and/or allying (collaborating) with external partners (Coase, 1937; Williamson, 1975). In a context of internal capability constraints, serious time constraints, and uncertainties regarding the direction of technological progress, incumbents would choose to rely on external knowledge inflows based on market and/or collaborative mechanisms (purchase from specialist technology vendors and/or alliances with external partners, e.g., startups).

A potential adverse side-effect of these transactional choices is disruption through commoditisation (Adner and Lieberman, 2021), whereby the solutions of technology complementors become the key drivers of value. With the proliferation of software-defined new functionalities in the car, autotech companies may gradually account for an increasing share of total value created and captured. This phenomenon is referred to as value migration, a concept coined by Slywotzky (1996).

Another factor to consider is that even if incumbents choose to purchase the requisite technologies from or collaborate with external providers, they need to invest in complementary assets and capabilities: develop absorptive capacity to identify, integrate, transform, and exploit external knowledge (Zahra and George, 2002) and enhance their system integration capability (Brusoni et al., 2001; Cohen and Levinthal, 1990). The incessant increase in the quantity and complexity of automotive software has made system integration capabilities particularly paramount.

OEMs may in principle opt for building the requisite capabilities internally and create the needed technologies themselves. This would enable them to capture the related profit and maintain their central position in the value chain. In this case, however, they not only incur the upfront costs of investing in the necessary assets and capabilities but also face the risks related to the uncertainties regarding the evolutionary directions of the industry (they may invest in technologies and capabilities that prove to be irrelevant).

From a dynamic perspective, make-buy-ally choices are present not only once, at the moment when incumbents identify the relevant direction of technological progress. At a later stage, after having accumulated internal capabilities and complementary assets in the process of collaborating with external technology providers, incumbents may also decide to internalise specific activities (Jacobides and Winter, 2005). The best-known example is Tesla Motors' comprehensive shift from outsourcing to vertical integration (Chen et al., 2019). Another and a more common way to internalise the activities that were previously performed in collaboration with external providers is when a joint development partnership between an established incumbent and a technology startup entails the acquisition of the startup.

In this context, the key question, with significant repercussions for both the architecture of the automotive industry and OEMs' value chain position, is which technologies OEMs should internalise. The theory guiding these choices emphasises the role of bottleneck assets (Jacobides and Tae, 2015; Teece, 1986). Since technological change in general, and in particular the transformation of cars into SDVs is expected to bring about new bottlenecks in the value adding process (Iansiti and Lakhani, 2017), a related question is whether OEMs should try to internalise and control *specific* technologies, that are deemed to become the future bottleneck segments, or focus on developing *generic bottleneck capabilities*.

Examples of generic capabilities are ecosystem management capability (Hannah and Eisenhardt, 2018) and the capability to engage in business model innovation (Teece and Linden, 2017). Another notable generic capability is system integration capability that helped automotive incumbents maintain their leadership position and avoid a major erosion of value capture in the 2000s – the era marked by modularisation and outsourcing (Jacobides et al., 2016). Relatedly, Murmann and Vogt (2023) point out that some generic ordinary capabilities, such as manufacturing and assembly, strategic sourcing, capability to validate compliance with quality and safety requirements are also hard-to-imitate assets, enabling a relative stability of OEMs' position amidst technological turbulence.

In contrast, some observers suggest (e.g., Felser and Wynn, 2023; Fletcher et al., 2020) that OEMs' should rather try to internalise the *specific bottleneck segments of the future*. They should bring a variety of specific technological assets in-house, e.g., develop a proprietary operating system, an app store, and an OTA-upgrade solution. There is no consensus opinion, however, on which part of the – increasingly complex – software stack is it critical to control internally.

From a bird's-eye perspective, a major pitfall of analysing the dynamics of OEMs' transactional choices is that this approach cannot yield a reliable prediction of change in the industry architecture. In the era of SDVs, the division of labour and profits in the automotive industry is shaped not only by the incessant emergence of new technologies and functionalities but also by multiple unforeseen developments driven by the strategic efforts, pivots, and interactions of heterogeneous actors.

Accordingly, it must be acknowledged already at the outset that by focusing on OEMs and the technology startups in their ecosystems and omitting among others the discussion of tier 1 suppliers' software strategies, this paper offers a limited purview (see also the section on limitations). Even within this narrow perspective, when analysing the dynamics of the industry architecture, we need to bear Eden and Nielsen's (2020) assertions in mind. These authors called attention to the inherent complexity of international business research. Complexity arises from the multiplicity and variety of actors and the multiplexity of interactions among them. Consistently with these conjectures, we need to avoid drawing hasty conclusions that infer a trend through extrapolating from emerging developments (cf. Tversky and Kahneman, 1974). Eden and Nielsen (2020) also analysed a third source of complexity, generated by dynamism, e.g., dynamic changes in actors' value chains and strategies. This feature of international business – that gives rise to uncertainty, volatility and ambiguity – is consistent with the observation that continuously ongoing organisational reconfiguration trends may intensify in certain periods (Sass and Szalavetz, 2014; Szalavetz, 2016) and slow down or be reversed in others.

This theoretical discussion leads us to propose that:

P1 Transition to SDVs impacts OEMs' value capture capabilities and requires strategic adjustment, specifically the accumulation of technological and related complementary resources.

P2 Over and beyond incumbents' evolving transactional choices regarding how they access the new technology inputs and what they decide to internalise, the division of labour and value in automotive value chains is shaped by the strategy and performance of multiple heterogeneous actors. There are several and occasionally counteracting forces at play, such as (further) technological progress, emergence of new value chain participants, collaborations, mergers and acquisitions.

P3 Incumbents' transactional choices need to be analysed from an evolutionary perspective. For example, a successful accumulation of internal capabilities related to the initial 'buy' or 'ally' decisions reduces the costs of modifying these choices.

P4 To reinforce their value chain position, avoid disruption through commoditisation, and increase/sustain value capture, from time to time incumbent OEMs need to reconsider and occasionally modify their prior transactional choices.

In the next sections, we empirically investigate these propositions by reviewing how in the process of adjusting to the transformation of their end-products into SDVs incumbent OEMs designed and redesigned the scope of their activities and what other factors shaping the division of labour have been at play. Before embarking on the analysis, we briefly outline the applied research method.

## 3 Research design, data collection and analysis

To obtain an up-to-date coverage of recent developments in OEMs' adaptation to the transition to SDVs, we undertook six mini case studies, involving the collection of a variety of secondary data about the software strategy of a purposefully selected sample (Volkswagen, Toyota, Stellantis, GM, Mercedes-Benz and Volvo Cars). In accordance with the literature on purposeful sampling (Patton, 2002) which allows analysts to select the units of investigation based on their relevance to the study, the unique criterion of including an OEM was the illuminative character of its strategic efforts.

Mini case studies allow for identifying typical patterns in areas that are relatively new for academic research. They are particularly suitable for pointing out phenomena that should be subject to further research, rather than for developing new theories (McBride, 2009).

Our data collection focused exclusively on the software strategies of these OEMs. We reviewed their press announcements (between 2019 and 2023) and annual reports, business press information, analyses by industry experts, and blogposts of automotive consultancy firms. This data was triangulated with data obtained from YouTube presentations by the representatives of the OEMs in the sample[2] and from the author's prior research and interviews (Szalavetz and Sass, 2023; Szalavetz, 2022b; Szalavetz and Sauvage, 2024).

As for the issues addressed by OEMs, we investigated their stated strategic stance regarding the industry's shift to SDVs and the actions implemented to execute the stated strategy. Specifically, we collected data on OEMs' evolving make/ally choices: investments in in-house software capability development versus strategic actions indicating collaboration with external technology providers, including both technology giants and emerging startups. An illustrative mini-case study is provided in Appendix.

For data analysis, we used the approach suggested by Miles and Huberman (1994) and focused on identifying the typical patterns in and essential elements of the surveyed OEMs' software strategies. To guide our analysis, we classified the data into two groups in terms of whether they suggest a quest to develop internal software capabilities and/or internalise previously outsourced technology inputs or indicate collaboration with external actors, including alliances, joint development partnerships, and corporate venture capital investments. Analysis of the identified patterns enabled us to make tentative predictions about whether and how OEMs' responses to the transition to SDV might reshape the industry architecture. Note that the purpose of this paper is to offer a general discussion of the factors that shape the architecture of the automotive industry in the context of the transition to SDVs, rather than to analyse the strategies of specific OEMs.

Before presenting the core part of our analysis of the factors that shape the architecture of the automotive industry in the context of the transition to SDVs, we briefly review the historical antecedents of OEMs' current software and internalisation-focused strategies.

## 4 Automotive incumbents' journey to the SDV – a reversal of the initial transactional choices?

Automotive firms traditionally pursued a quasi-closed innovation strategy based on in-house development and control of knowledge (Ili et al., 2010). Although over time, the structure of automotive OEMs' value chains – that was initially a textbook example of producer-driven chains (Gereffi, 1994) – became more complex with the modularisation and outsourcing of module-specific R&D tasks to tier 1 suppliers (Frigant, 2011; MacDuffie, 2013), it was probably only with the advent of digital technologies that OEMs fully acknowledged that the era of operating as 'drivers' of value chains that they mostly control is over. The ongoing digital race, marked by the entry of countless potential complementors, called for multi-industry collaboration (Teece and Linden, 2017), especially in light of incumbents' increasingly obvious capability gaps.

OEMs pivoted to source technology from external providers and boosted inbound knowledge inflows also through other tools. For example, they setup corporate venture capital funds[3], created internal startup collaboration units, established accelerators and incubators, and initiated strategic partnerships with complementors and/or competitors (e.g., CB Insights, 2021; Corvello et al., 2023; Kohler, 2016; Weiblen and Chesbrough, 2015). Since incumbents were highly effective in identifying and attracting complementors and integrating external knowledge, the number of their autotech suppliers and collaboration partners multiplied, as demonstrated by Kim et al. (2022), using Volkswagen's and Toyota's cases, and Alvarez León and Aoyama (2022), who analysed the alliance networks of Toyota, Daimler, Ford, GM and BMW.

Considered from the perspective of the evolution of industry architecture, however, it is questionable to claim that a linear development is taking place and transforming the structural characteristics of OEMs' supply networks. Rather, incumbent OEMs have apparently been swinging back and forth from a system of internal control of production and development – moderated by modularisation and outsourcing of module-specific R&D tasks – to managing a dispersed network of technology suppliers in the 2010s, and then backwards: in the sense of trying to gain increased control over the development of software-based automotive systems.

## 5 Incumbent OEMs' quest to bring software development in-house

Capitalising on their improved absorptive capacity and R&D capabilities, developed over the course of collaborating with and managing a dispersed network of technology suppliers (Alvarez León and Aoyama, 2022; Kim et al., 2022)[4] incumbent OEMs changed strategy in the early 2020s, seeking to gain greater control over their value chains (*The Economist*, 2022).

**Table 1** Illustrative examples of OEMs' software strategy

| *OEM* | *Components of software strategy* | *Expected annual additional software-enabled revenue (by 2030)* |
|---|---|---|
| GM | Development of proprietary vehicle intelligence platform able to manage over-the-air updates, process and analyse data flows from sensors (and real-time driving data and environment data), and support fee-based cloud services (vehicle apps) also for third parties. Proprietary solution for managing subscription-based communication, safety and security services. | \$20–25 billion |
| Stellantis | Development of a common software platform and artificial intelligence-powered technology platforms for the automotive product portfolio. Roll out of new subscription-based services and OTA-update services. Establishment of a data-as-a-service business unit, monetisation of connected vehicle data. | \$22.5 billion |
| Mercedes-Benz | Development of a proprietary operating system that together with proprietary cloud will ensure the integration of all car functions. Provision of digital services, e.g., in-car payment through the Mercedes ePayment platform, OTA upgrades, automotive cloud.[∆] | \$ high single-digit billion |
| Volkswagen | Development of a unified software platform along with a wide range of software-based services: a proprietary operating system, infotainment, driver assistance, and connected services (partly subscription-based to monetise vehicle data), OTA-update capability and proprietary mobility solutions, automotive cloud.[□] | 2×–2.5× of today's software-enabled revenue pools |
| Toyota | Internalisation of software and connected technologies. Establishment of Woven Planet Holding, a fully owned subsidiary responsible among others for the development of a proprietary software platform, Arene (operating system, cloud-based services, fleet management services). Establishment of Toyota Big Data Center and Toyota Connected (technology companies specialised in vehicle big data processing, mobility services and other automotive related services). | n.a. |
| Volvo Cars | Development of proprietary operating system together with OTA-update capabilities and a variety of application programming interfaces that enable integration of third party software solutions. | Software and digital solutions will account for 50% of total revenues |

Notes: [∆]Together with partners, e.g., Microsoft and Google (Mercedes-Benz News, 2022, 2023).
[□]Together with partners, e.g., Amazon Web Services and Siemens (Felser and Wynn, 2023)

*Source:* Author's compilation from press announcements by the corporations and business press news

Acknowledging that software is a key differentiator for their brands and that software-enabled, recurring revenues represent an increasing share of total automotive revenues and profit[5], one by one OEMs announced software-focused transformative strategies and reported that they seek to move an increasing share of software development in-house to capture software-enabled new revenue pools (Table 1) (see also: Blankesteijn et al., 2019; Juliussen, 2021; Yamamoto, 2021).

For example, Volkswagen Group announced that by 2025, it will boost the share of in-house developed software from below 10% to at least 60% (Volkswagen AG, 2019). Other OEMs envisage an in-house share of 20% to 30% in the field of vehicle software (*The Economist*, 2023).

This represents a radical departure from past strategic stance. For a long time, software was considered as non-core service input to be sourced externally. Consequently, OEMs failed to build up the requisite degree of competences (Felser and Wynn, 2023). When it came to accomplish a shift to SDVs, coupled with the implementation of smart factories and digital business models, incumbents had to resort to external technology providers. At the end of the 2010s, a large portion of incumbents' vehicle software was delivered by external suppliers (*The Economist*, 2023).

Over and beyond the above-promulgated specific initiatives, the creation of new business units dedicated to software development, the expansion of the headcount of these units[6], the sizeable software R&D budgets[7], and the acquisition of autotech providers (Table 2) also indicate that OEMs consider internal software capabilities and the internal control of specific building blocks of the SDV strategically important.

**Table 2** Illustrative examples of OEMs' acquisitions of software and technology companies

| *Acquirer* | *Acquired technology company (year of announcement)* |
|---|---|
| Volkswagen (acquisitions made by the software unit CARIAD) | The automotive division of Intenta GmbH, specialised in sensor data fusion (2022) |
| | Semvox specialised in voice control and artificial intelligence powered human-machine interaction technology (2022) |
| | The mobility services platform business unit of Hexad, specialised in cloud-based services (2023) |
| Stellantis | AiMotive, an artificial intelligence and autonomous driving software provider (2022) |
| GM | ALGOLiON, a battery software company (2023) |
| | Cruise Automation, an autonomous driving technology company (announced in 2016, increased equity stake in 2022) |
| Toyota (acquisitions made by the software subsidiary, Woven Planet Holding) | Renovo Motors, an operating system developer company (2021) |
| | Carmera, a developer of autonomous high-definition maps for autonomous vehicle customers (2021) |
| | Acquisition of Lyft's autonomous vehicle developing unit (2021) |
| Volvo Cars | Acquisition of Zenseact, the developer of OnePilot, an AI-powered software platform for autonomous driving and ADAS applications (2022) |

*Source:* Author's compilation from corporate websites and press announcements

Note that OEMs' rush to internalise SDV-specific technologies should not be interpreted solely as a defensive move. OEMs are rather moving forward along a journey from a piecemeal (when they simply try to increase the portion of the software value chain that they own) to a comprehensive approach, whereby they turn the car into an end-to-end, service-oriented system. This strategy can also be interpreted as *turning the product into a platform*, whereby vehicles become innovation platforms, enabling both the incumbent OEM and third parties to develop smart services on it (Zhu and Furr, 2016).

Do incumbents' afore-discussed strategic moves allow us to predict major changes in the industry architecture, specifically the reversal of the growing fragmentation of vehicle technology creation? However compelling this interpretation might seem, other real-world developments cast a different light on this prediction. Describing three sets of real-world developments suggesting that automotive incumbents are far from reversing their reliance on external technology suppliers, the next section will allow us to return to the assertions by Eden and Nielsen (2020) about the inherent complexity of international business.

## 6 The three sources of complexity in action … shaping the architecture of the automotive industry

The first set of real-world developments that cautions against drawing hasty conclusions from the data described in Tables 1 and 2 concerns the multiplication of OEMs' autotech suppliers and collaboration partners.

Incumbent OEMs' investments in developing software in-house did not bring their efforts to access emerging technologies developed by autotech companies to standstill (Buck and Watkowski, 2023; Nguyen et al., 2023). Just the contrary happened. Over the past decade, practically all large, traditional OEMs have established corporate venture capital funds[8], i.e., investment vehicles that make minority equity investments in startups that develop pioneering technologies (Gompers and Lerner, 2000). In addition to making strategic equity investments in potential technology complementors[9], most OEMs have created and manage a distributed ecosystem of corporate accelerators, incubators, and other startup-scouting units (Andonov, 2023; Kohler, 2016; Weiblen and Chesbrough, 2015). Together, these units help OEMs obtain a broad purview of the relevant ecosystem of technology complementors and manage hundreds of innovation collaboration projects.

Second, in addition to the extensive investments aimed at moving technology development in-house, OEMs have forged multiple 'ally' and 'buy' relationships with technology giants in a number of technology domains that require strategic partnerships (Covarrubias, 2018). Examples include operating system providers (e.g., Continental, BlackBerry, Red Hat), middleware providers (e.g., ZF, Harman, Continental), hypervisor providers (e.g., Green Hills, NXP Semiconductor, IBM, Siemens), driver assistance/autonomous driving technology providers (e.g., aiMotive, Cruise, Aptiv, Mobileye) automotive cloud solutions providers (e.g., Amazon Web Services, Microsoft, Google, IBM, Alibaba Cloud), and AI chip companies. As for these latter actors in automotive value chains, global technology companies (e.g., Qualcomm, Intel, Nvidia) supply OEMs a range of system on chips that power infotainment, connectivity, driver assistance, autonomous driving, safety, and many other solutions.

Third, despite their best efforts to move technology development in-house, in some instances, incumbent OEMs failed to take control over specific technology domains. A particularly interesting area where OEMs' 'make' ambitions clashed with those of powerful technology companies was user interface provision (car dashboards). While customers wanted to have their smartphone functionalities (e.g., infotainment, navigation, voice assistance) integrated in vehicles to have the same user experience, several OEMs recognised that it is paramount to prevent big tech companies from becoming the gatekeepers of digital services provision.[10] Although both Apple and Google developed solutions that enable car dashboards to mirror smartphone functionalities and provided these solutions free of charge to OEMs, some incumbents invested rather in proprietary infotainment and navigation software and vehicle-specific app stores [examples include Ford, Toyota and Volkswagen – (Hammerschmidt, 2023; Kawai, 2020)], or decided to develop alternative technologies (a notable example is HERE Technologies, a precision mapping data and navigation services provider that was jointly acquired by Daimler, BMW and Audi in 2015).

However, OEMs' efforts to control the user interface through proprietary platforms and effectively monetise the proprietary digital features that account for the distinctive brand experience proved to be inadequate and insufficient. Sooner or later most of them pivoted to partner with Apple, Google, and some of them also with Amazon. OEMs equipped their vehicles with Google's Android automotive operating system and made the cars compatible also with Apple's CarPlay, simply because customers insisted on these familiar user interfaces.

Each of these developments suggests that there are numerous and occasionally counteracting forces shaping the division of labour and value in the automotive industry and making the outcome difficult to predict.

There is a multiplicity of heterogeneous actors and a long list of technology domains to consider. Besides the degree of novelty of a given technology, its impact on industry architecture hinges also upon a multiplexity of interactions among actors in the automotive ecosystem. For example, corporate venture capital investments, takeovers, spinouts, and strategic alliances may drive the division of labour in different directions. The dynamics of change also adds to uncertainty stemming from the complexity of developments. New actors emerge, others pivot, and again others see their longstanding technology development efforts bear fruit. In response to the imperative to revisit from time to time the prior make-buy-ally decisions, actors' transactional choices are often subject to change. For example, OEMs need to consider that managing a widely distributed network of electronics parts, software, and other digital suppliers involves prohibitive coordination costs, which makes them pivot and opt for an integrated solution provider.

Furthermore, OEMs' ambition and initiatives to internalise SDV-specific technologies may not be aligned with their capabilities. The business press is awash with posts reporting software issues delaying the launch of OEMs' new models (e.g., Hawkins, 2023) and recalls because of software errors.[11] The escalating costs of in-house software development, and OEMs' multiplying problems in terms of above-budget, behind-schedule, and error-prone implementation of this ambition suggest that internalisation is easier said than done. In addition to technical problems, failure to meet the ambitious software-enabled revenue goals (e.g., *The Economist*, 2023) and obtain an adequate return on investment through monetising OEMs' newly accumulated digital capabilities (SBD Automotive, 2021) also questions whether or to what extent the changes in industry architecture envisaged by OEMs are feasible.

Automakers' struggles with in-house software development also question one of the propositions advanced earlier in this paper (P3), namely that a successful accumulation of internal capabilities related to firms' 'buy' and 'ally' decisions reduces the costs of modifying these choices. Our results indicate that even a partial reversal of OEMs' initial software-specific transaction choices is a complex undertaking involving large investments.

The multifaceted nature of the surveyed real-world developments evokes Tversky and Kahneman's (1974) discussion of the biases in judgements under uncertainty, leading to a frequent misconception of probability. In the context of this paper, if observers are insensitive to the fact that there is an array of factors influencing OEMs' transactional choices, and these factors pull strategic decisions in different directions, OEMs' well-publicised 'strategic shift to proprietary software' may easily make them overestimate the degree of consolidation in automotive value chains. Consistently with Eden and Nielsen's (2020) description of the factors driving complexity, we posit that if observers are insensitive to:

1 the multiplicity and variety of value chain actors in the case of SDVs

2 the multiplexity of interactions among them

3 the dynamic evolution of OEMs' transactional choices

then they may overestimate the extent to which the promulgated intentions will materialise and underestimate the strength of counter-forces.

## 7 Concluding remarks and managerial implications

This paper analysed the implications of incumbent OEMs' initiatives to internalise software development and capitalise on the monetisation potential of digital services provision for the evolution of industry architecture.

In doing so, we contributed to the ongoing debate over the degree to which technology-driven transformation will reshape the division of labour in automotive value chains and engender value migration to beyond-industry-boundary newcomers. We cautioned against drawing hasty inferences from OEMs' emerging responses to the transition to SDVs. We drew on Eden and Nielsen's (2020) theory about the sources of complexity in the global economy and emphasised the evolutionary character of developments.

The reviewed developments indicate that while the race between OEMs and technology complementors for value capture is far from coming to an end, it is safe to posit that by making bold moves toward accumulating SDV-related in-house capabilities, OEMs could prevent their core products from becoming the 'complementor commodities' of big tech companies. OEMs have progressed along the long and winding trajectory of accumulating software, cloud, artificial intelligence, and other autech capabilities and are well-positioned to combine these newly built capabilities with their strategic sourcing, ecosystem management, and longstanding ordinary capabilities (cf. Murmann and Vogt, 2023). As a flipside of the same coin, in the short to medium run, we anticipate no further radical changes ahead in the architecture of the automotive industry.

Regarding the managerial implications, the technological difficulties, strategic challenges, and financial problems that automakers encountered over the course of internalising SDV-specific technologies highlight how critical it is to appropriately assess the complexity of automotive software, the related development and integration costs, the time requirement of adaptation through internal capability building, and the related risks.

More importantly, they underline the paramount importance of strategic planning regarding the technologies the internalisation of which really makes sense.

## 8 Limitations and directions for future research

To conclude, some limitations of this study need to be acknowledged, that remain to be addressed in future work. The main limitation refers to the fact that little time has elapsed since OEMs' straightforward transition to SDVs started to take momentum. Building internal capabilities in unfamiliar domains that used to lie outside the automotive industry is a long and protracted process. Given the significant complexity of the automotive software architecture, return on the huge upfront investment costs takes long time. Moreover, wait-and-see stakeholders would emulate the pioneers in software in-sourcing only if there is obvious evidence of the related financial gains. This calls for further longitudinal research before well-founded predictions could be developed about the evolution of the division of labour within automotive value chains.

Another limitation is that we focus exclusively on incumbent OEMs. To develop reliable predictions about the evolution of the division of labour and distribution of value in automotive value chains, future research also needs to explore the adjustment strategy of global part suppliers. These companies themselves have developed and are implementing comprehensive software strategies. They have made several big-ticket autotech acquisitions and are forging strategic partnerships with technology providers. Studying the strategic initiatives of these actors and the interactions and division of labour between OEMs and global suppliers regarding automotive software, will clearly enhance the validity of our findings.

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## Notes

1 It is beyond the scope of this article to provide a general review of the evolution that culminated in SDVs. The interested reader is referred to Askaripoor et al. (2022) and Liu et al. (2022) for reviews of how the gradual multiplication of in-vehicle software components, each of which introduced new services and functionalities, gave rise to the present architectural design of the vehicle.

2 Examples include a keynote by Volkswagen's CARIAD at CES in 2023 and presentations of Stellantis Dare Forward 2030 Strategy.

3 Corporate investments in transport-focused technology startups increased steadily in the 2010s, from 24 deals annually in the early 2010s to an annual average of 212 deals between 2017 and 2021 (Author's calculation from GCV Analytics, 2022).

4 Corvello et al. (2023) explored the practices of three Swedish automotive OEMs that setup startup collaboration units and engaged in joint development projects with startups. They found that this kind of organisational innovation can not only facilitate knowledge exchange but also contributes to the creation of new knowledge.

5 According to estimates, by 2030, software-enabled revenues will account for one quarter of the car industry's total revenues. Part of this revenue will, however, replaces revenues lost in other segments of the industry (UBS, 2022).

6 According to employment projections by the Bureau of Labor Statistics, in the USA, the number of jobs for software developers in motor vehicle manufacturing will increase by 26.2% between 2021 and 2031 (https://data.bls.gov/projections/nationalMatrix?queryParams=15-1252&ioType=o).

7 On average, global OEMs spent $1.5–2 billion on software R&D in 2021. Mercedes-Benz, and GM spent about $1.5 billion respectively, Toyota: $3.5–4 billion, and Volkswagen: $3–3.5 billion (SBD Automotive, 2021).

8 Examples of recently established corporate venture capital funds include Volvo Cars Tech Fund (VCTF) and Stellantis Ventures (SV), established in 2018 and 2022, respectively. Examples of investment in technology complementors include CorrAction, a developer of artificial intelligence-powered driver monitoring system (VCTF) and Viaduct, a developer of an artificial intelligence vehicle analytics platform (SV).

9 As relatively new directions of exploration, OEMs' corporate venture capital funds seek investment opportunities in several new areas such as satellite technology for OTA solutions, fintech for in-car payments in connected vehicles, blockchain and quantum computing.

10 Notable exceptions include Renault and Volvo who partnered with Google right from the outset.

11 In 2022, nearly 10 million cars were recalled in the USA due to software-related issues, with nearly half of these requiring the software to be updated by a car dealer (ABI Research, 2023). Note that improvements in OEMs' OTA-update capabilities will significantly reduce the costs of fixing software problems.

# Appendix

## *Mini case study of Stellantis*

| | |
|---|---|
| Software strategy DARE Forward 2030 | 'Building a mobility-tech company'.[3]<br>€30b+ investment (until 2025) in electrification and software.<br>Increasing software-enabled revenues based on features on demand, subscription-based services, data-as-a-service strategy, and fleet services; increased service retention; connected vehicles, 3 tech platforms.[1, 3] |
| New research centres and increased headcount of researchers | Stellantis is growing its software development and engineering network to eight hubs – Brazil, France, Germany, India (2), Italy, the USA – by establishing a new operation in Poland. The Poland software hub will be staffed with up to 300 employees in data analytics and software development and validation.[2] |
| Other actions to implement SW strategy through internal capability development | Moving to a software-defined platform for all brands and models.<br>Establishment of a software and data academy to reskill 1,000+ people.<br>Building a team of 4,500 people focused on Stellantis' proprietary tech platforms (by 2024).[1, 3]<br>Establishment of Mobilisights, a Stellantis business unit, to leverage data from Stellantis' connected vehicles (licensing data to customers).[11]<br>Establishment of Free2Move, a joint venture between Stellantis and NHOA, offering connected fleet management solution and preventive maintenance.[12]<br>Establishment of MobileDrive, a joint venture between Stellantis and Foxconn, developing in collaboration with Siemens advanced driver assistance systems and connected car solutions.[14, 15]<br>Establishment of SiliconAuto, a joint venture between Stellantis and Foxconn, specialised in auto industry-centric semiconductors for computer-controlled features and modules.[16] |
| Acquisitions of technology startups | Acquisition of AiMotive a developer of AI powered solutions for autonomous driving.[13]<br>100% acquisition of ShareNow, a car sharing company.[13] |
| Strategic alliances with technology giants | Collaboration with BMW and Waymo in autonomous driving.[1]<br>Partnership with Foxconn, BMW, and Waymo to execute the capability roadmap[1]; Stellantis, BlackBerry QNX and AWS collaborate to launch the Virtual Cockpit.[9]<br>Collaboration with Qualcomm to utilise Qualcomm's Snapdragon Digital Chassis solutions for STLA SmartCockpit.[6]<br>Collaboration with Amazon (cloud services provision, collaborative innovations, OTA service upgrades).[7]<br>Participation in 164 co-funded projects with public institutions, R&D centers, academies and other stakeholders, e.g., in autonomous driving.[8] |
| Corporate venture capital investment in and partnerships with autotech startups | Establishment of Stellantis Venture Fund with an initial investment of €300 m[3, 4]; investment in Envisics, (dynamic holography platform, i.e., augmented reality head-up displays that help deliver a safer driving experience), Geoflex (satellite positioning augmentation technology), Viaduct (AI platform to improve vehicle analytics), Nauto (AI and computer vision technology).[5]<br>Collaboration with startups: over the period between 2022 and 2023, Stellantis signed more than 110 partnership contracts with startups, including ElectraVehicles (AI-based SW solutions to extend battery lifetime) and Vayyar (4D imaging radar platform for in-cabin monitoring and improved safety).[10] |

*Source:* [1]https://www.stellantis.com/content/dam/stellantis-corporate/investors/events/stellantis-sw-day/Software_Day_2021_Presentation_final.pdf,
[2]https://www.stellantis.com/en/news/press-releases/2023/february/stellantis-grows-software-development-network-with-new-hub-in-poland,
[3]https://www.stellantis.com/content/dam/stellantis-corporate/investors/events/strategic-plan-2030/2022_03_01_Strategic_Plan.pdf,
[4]https://www.stellantis.ventures/en,
[5]https://www.stellantis.com/en/news/press-releases/2023/june/stellantis-ventures-seeds-innovation-with-11-key-investments-into-sustainable-mobility,
[6]https://www.forbes.com/sites/patrickmoorhead/2022/04/14/qualcomm-wins-yet-another-major-automaker-with-its-digital-chassis-stellantis-with-14-brands-more-evidence-that-the-diversification-strategy-is-paying-off/,
[7]https://www.stellantis.com/en/news/press-releases/2022/january/amazon-stellantis-collaborate-on-software-solutions,
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[11]https://www.stellantis.com/en/news/press-releases/2024/january/empowering-customers-a-year-of-major-advances-in-mobilisights-mobility-data,
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