Revisiting Disruption:

Lessons from Automotive and Mobility Service Innovations

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ABSTRACT

The concept of "disruption" is frequently discussed in today's business landscape, especially with the rise of new technologies and the pervasiveness of digitization. We examine this notion through the transition from Internal Combustion Engine Vehicles (ICEVs) to Battery Electric Vehicles (BEVs), challenging the common belief that this shift disrupts traditional automakers and ushers in a new era of modular production dominated by newcomers, particularly battery manufacturers. Our findings suggest that the expected modularity of BEVs and the resulting industry disruption are overstated. Even with some new entrants striving for modularity, organizational and industry structures remain largely unchanged, with the Industry Architecture showing resilience and adaptability, as new players engage with incumbents. We also see that the dominant digital players (a.k.a "Big Tech") collaborate with incumbents, even while they try to compete for consumer value add. To illustrate this point further, we also briefly explore how the integration of connected, autonomous, and shared (CAS) technologies might affect automakers and their strategies to maintain their value propositions amidst potential shifts in the mobility ecosystem. Generalizing beyond the automotive sector and mobility, we believe these patterns are broadly applicable and introduce the "Mark 3" model, which revises the classic Schumpeterian dichotomy of sectors whereby innovation is the province of entrant-led gales of creative destruction ("Mark 1") vs sectors dominated by incumbents ("Mark 2"). We highlight a pattern of closer collaboration between incumbents and innovators, through acquisitions, alliances, and ecosystem participation. This model is particularly relevant in industries at the intersection of physical and digital goods, where incumbents protected by clockspeed and sectoral regulations and liability increasingly act as complementors rather than competitors. Our analysis provides a nuanced perspective on technological disruption, emphasizing the enduring influence of established firms amid the growing role of Big Tech and intricate ecosystem dynamics.

(294 words)

* The two main authors of this paper are Michael G. Jacobides and John Paul MacDuffie, who have been supported by Jennifer Tae in terms of the evidence and the approach alike. MacDuffie has led the thinking about the persistence of integrality and the role of incumbents and has also led our empirical investigation. Jacobides has advanced the conceptual framing around Mark 3, the need to revisit disruption, and the connection between digital and physical. This author ordering will ensure that this second major research initiative of this authorship team (after the Jacobides et al, 2016 *SMJ*) will reflect the balance of the contributions of the two main authors in what was a truly collaborative effort. The authors thank the many people who have provided input for this paper, including executives and analysts from the mobility sector, and participants in the conferences, workshops, and symposia over the past 8 years at which these ideas have taken shape. For financial support of those activities, we thank the Program on Vehicle and Mobility Innovation (PVMI) at the Mack Institute for Innovation Management at the Wharton School, U. Pennsylvania, London School of Business, and University of Tokyo, as well as Evolution Ltd for funding the much-appreciated editorial work of Tom Albrighton.

1. Introduction

As technologies such as AI advance by leaps and bounds and established industries are turned on their heads, the rhetoric of "disruption" is all around. If we expect technological change to redraw the industrial order, we need robust and balanced theories to appraise and analyze this disruption. How does technological disruption translate into industrial disruption (Christensen, 2006; Christensen et al 2018; McDonald, Altman, & Palmer, 2018)? In particular, how do new technologies affect the division of labor between firms, the rules, roles, and relationships that define their Industry Architecture (IA) (Jacobides, Knudsen, & Augier, 2006), and the subsequent division of profits? Can we still rely on our prevailing understanding of "waves" of creative disruption (Schumpeter, 1911, 1945), or do new developments demand new ideas? And how does disruption that comes from complements, rather than substitutes, change the picture (Adner, 2021; Adner & Lieberman, 2021)?

Drawing on the evolution of the automobile sector, we argue that theory is being systematically misapplied. Pundits and analysts are all too ready to converge on a model of industrial revolution that is both oversimplified and misconceived. This model rests on the idea that new digital technologies are inherently modular (Baldwin & Clark, 2000; Baldwin, 2023) and that narrow, horizontally specialized actors can build on module advantage to disrupt incumbents (Christensen, Verlinden & Westerman, 2002; Truett, 2022), transferring value from the integrated industrial denizens of yesteryear to those who hold the bottlenecks of today (Hannah & Eisenhardt, 2018; Jacobides, MacDuffie, & Tae, 2016; Murmann & Schuler, 2023). This model is consequential, as it also drives stock market valuations, which gives ambitious yet loss-making newcomers the leeway to withstand competitive pressures (Bigelow, 2020; Boigon, 2023a, b) and challenge the status quo (Birkinshaw, 2022). It also creates an "expected baseline" for industrial dynamics in our field, distorting our view of reality (Bessen, Denk, Kim, & Righi, 2020). We find, however, that it is misleading.

In this paper, we provide a sectoral and ecosystem deep dive to complement recent cross-sectoral evidence that challenges this model (Birkinshaw, 2023) and argue for a critical consideration of the nature of technological disruption and how it affects the existing industrial order. We explore the dynamics of automotive production—long a setting that has pushed the boundaries of management research (Drucker, 1946; Womack, Jones, & Roos, 1990). We synthesize findings from papers on the shift from internal combustion engine vehicles (ICEVs) to battery-operated electric vehicles (BEVs) and its impact on the structure and competitive dynamics of automotive production, e.g., Bohnsack, Pinske and Kolk (2014), Murmann and Schuler (2023), and Alochet, MacDuffie, & Midler (2023a), explaining how these extend and qualify earlier work on the automotive sector (Jacobides et al., 2016). We then extend these conclusions with our own research and engagement in the field, considering (a) how much the shift from ICEVs to BEVs changes the underlying technology of production and the Industry Architecture (IA) of the sector, (b) how the expansion of mobility services, offered through connectivity and enhanced by AI to provide autonomous driving, affects the IA and the dynamics of competition, cooperation, and "coopetition" and (c) the consequences for value creation and value capture for incumbents (from automotive and Big Tech) and new entrants.

In doing so, we document the common mistakes made by researchers and analysts alike when applying existing theory (Murmann & Schuler, 2023). We also suggest that a nuanced understanding of automotive-sector dynamics helps us move beyond both Schumpeter's (1911) early view, in which new, innovative entrants disrupt the status quo and displace incumbents (a pattern dubbed "Mark 1" innovation) and his later perspective (Schumpeter, 1945) where leading firms internalize innovation to perpetuate their dominance ("Mark 2"—see Breschi, Malerba, & Orsenigo, 2000). We find that the emergence of innovation – and subsequent competitive dynamics - seen in many contemporary sectors, including automobile production, belong to a new category that we dub "Mark 3." In this development path, which embodies elements of both Mark 1 and 2, incumbents are able to internalize much of the external innovation, both by absorbing it directly (through acquisitions and internal development) and by renewing their supply chains. This more evolutionary and less revolutionary pattern expands the canon of innovation research (Breschi et al., 2000).

While we argue that Mark 3 provides insights into the dynamics for all of the CASE technologies and their impact on the automotive sector and related mobility ecosystems, we also see theoretical nuances which emerge by considering the important differences between the CAS (Connected, Autonomous, Shared) and E (Electric) innovations. The latter are arguably both more fundamental (i.e., potentially the first new dominant design for automobiles since the mid-1920s) and less disruptive (i.e., because incumbents are better positioned in terms of capabilities and as kingpins in the value chain to make the ICE-to-BEV transition, despite facing many challenges) than the former, which foregrounds digital software's significance for mobility innovations.

Furthermore, digital software is modular, changes rapidly and can be updated easily, and relies on a rapid underlying rate of technical change (linked still, albeit less strongly, to Moore's Law) and corresponds to what Baldwin (2023) calls "platform with options", contradistinguishing this from traditional "flow production". Automotive product architecture is more integral than its digital counterparts, operates on a slower product life cycle, and involves multiple technologies such that overall rate of technical advance is determined by interdependencies across older and newer technical features; it is rare for the latest technologies to appear in vehicles until they have been thoroughly validated and concerns about their obsolescence have subsided.

Yet the CASE innovations are not easily separable; they will coexist and function interdependently in a "phygital" product that combines technologies of different types and clockspeed. What organizational model – and industry architecture – will best suit the CASE-filled vehicles of the future? Many observers, especially strategy scholars and consultants well-versed in the digital disruptions that have overturned countless industries, confidently predict that platform-with-options and the associated Big Tech ecosystems will dominate. We find instead that the capacity of "digital native" *de novo* firms and Big Tech incumbents to surge to quick dominance over automotive OEMs is overstated because of the unique nature of products that combine distinctive physical characteristics (for automobiles, being heavy, fast-moving, dangerous objects operating primarily in public space) with digital software that provides both a controlling overlay on physical operations and access to connected and autonomous services. We document the role of regulation and clockspeed in underpinning these dynamics. Finally, contrasting the ICEV/BEV dynamics that are easier to discern to the more fluid and still ongoing CAS innovations, we see that Big Tech already does play a bigger role in organizing the latter by virtue of its role and interest in the user experience / user interface (UX/UI), seen as important for the protection of its franchise (Jacobides et al, 2024).

Our findings go beyond setting limits on speculation over the potential dynamics of the automotive sector/mobility ecosystem as they allow us to uncover what we think is a broadly generalizable pattern of industry evolution. We think that at a time of a rethink of the role of regulation in shaping ecosystems (Jacobides & Lianos, 2021, Caffarra, 2023, US DoJ, 2024) it is important to understand such patterns of sectoral evolution, disruption and incumbent evolution, profit and power to inform not only industry studies, innovation and strategy but also to drive policy and strategy alike. Finally, with concerns that GenAI is about to transform the industrial landscape, it is important to establish a more robust, empirically based and comprehensive understanding of the nature of innovation, industry / ecosystem evolution and value appropriation in shifting contexts. By examining these changes through the lens of Mark 3 dynamics, we hope to show not just contrast but also commonality across E and CAS innovations that is "grounded", quite literally, in the physical (physics-based) realities of "phygital" products.

2. Methods and Industry Context

Methods. This is a layered, multiple-methods study which draws on several sources of data. The foundation is provided by our long-time engagement with the auto industry leading up to our earlier paper (Jacobides, MacDuffie, Tae, 2016) on the (lack of) value migration in the sector following a largely ineffective effort in the early 2000s to shift both product and industry architecture towards modularity (see also MacDuffie, 2013). Following that paper, we organized two workshops with industry participants in 2017 and 2018 to explore how our framework would apply to the CASE innovations as well as testing out these ideas at several academic conferences. Finally, since March 2022, we have organized a focused project which has looked at the key questions of interest.

By way of background, John Paul MacDuffie has been involved in the sector since 1985, and was part of the MIT-based (and, later, Sloan Foundation-sponsored) International Motor Vehicle Program (IMVP). He became its director, and then the director of its successor, the Program on Mobility and

Vehicle Innovation (PVMI), and has participated in joint projects on the sectors' evolution with researchers from the global network for nearly 40 years, including projects with Michael Jacobides for over a decade. Michael Jacobides has looked at organizational and value distribution issues since the late 1990's including work with Carliss Baldwin in the 2000's that informed Jacobides & MacDuffie (2013), and has also looked at mobility services in his work with Teng and others (Teng & Jacobides, 2023) as well as industry events and advisory. Jennifer Tae has undertaken a separate set of interviews with executives in the sector and also drawn together analyses from archival sources, summarizing the main themes and noting key events related to the diffusion of CASE innovations over time and examples of Mark 3 dynamics.

For this paper, we started from the empirical foundation provided by our longitudinal project on the evolution of the product and industry architecture of the sector – and the anticipated changes that *didn't* happen (aka "the dog that didn't bark" (Doyle, 1892) when modularity initiatives swept through the ranks of OEMs and first-tier suppliers in the late 1990s and early 2000s. Following its publication, we organized PVMI conferences around the dynamics of the sector in Philadelphia (2017), London (2017), and Tokyo (2018), with a focus on mobility ecosystems and disruption, and in the process interviewed senior executives from the auto sector, consultants, and industry specialists.

We also organized or participated in academic workshops around this topic in Venice (2015), Anaheim (2016), Berlin (2016), Sao Paolo (2017), Chicago (2018), Toronto (2018), Boston (2019), and Paris (2020), often with the participation of leading industry analysts and advisors. During the pandemic, engagement with various audiences on these topics occurred primarily via webinars and other remote/virtual formats, particularly on the CASE technologies and global competitive dynamics in the sector amid changing geopolitics. These opportunities have continued, most notably when the first and second authors addressed nearly 1000 alumni of CEIBS in Shanghai in November 2023, drawing on the arguments and evidence in this paper. All told, over the past 8 years, we have interacted with hundreds of executives, industry analysts, and consultants and debated these topics with dozens of researchers from the PVMI global network, shaping our ideas and building our evidence base. The events at which these interactions occurred, with topics, dates, and locations, are listed in Appendix A.

In addition, from March 2022 we have engaged in a detailed project of gathering sectoral evidence, with an aim to provide a faithful and empirically triangulated account of industry dynamics, which has included a persistent focus on general and industry news. Our triangulation came from discussions with various practitioners and complemented with archival, secondary sources from business news outlets, analyst reports, and academic work. More specifically yet, the research design relies on putting the prevalent expectations of pundits and analysts to scrutiny against what has happened in the sector thus far, at product-, firm-, and sector-levels, to critically examine the impact of technological innovations manifest in transition from ICEVs to BEVs and the rise of connected and autonomous mobility services on industry disruption. The analysis of how things have (not) changed and the actions taken by various sector participants, our primary focus, is based on multi-method evidence from discussion with practitioners and the published sources, in keeping with the combination of historical analysis and qualitative involvement in in our 2016 paper.

Specifically, the authors conducted semi-structured interviews to capture perspectives of what has happened and how things may change in the future. We started with open-ended questions about their observations of the transition from ICEVs to BEVs and the rise of connected and autonomous mobility services in the global automotive industry, and then asked follow-up questions to understand their view of the underlying dynamics as well as their expectations for future industry structure and competitive dynamics. Although the scope of our analysis is the global automotive industry and the broader mobility ecosystem, our informants are thus far overwhelmingly from the U.S. and Europe, leaving perspectives from participants from Asia, and especially China, less well represented, if not absent. The names and affiliations of interviewees can be found in Appendix B.

We also drew on media coverage and secondary sources that cover the sector to capture the interpretations of these phenomena as they have occurred. Data were collected on publicly available sources such as Nexis Lexis and Google News between 2012, when Tesla's first mass-market sedan, Model S, launched in the U.S. market, and January 2024. We provide a list of the keywords we used to conduct these analyses in Appendix C. These secondary data complement our data from interviews and add valuable nuance to our analysis. Moreover, secondary sources helped us fill the gap arising from the lack of interview participants representing the Chinese BEV value chain participants. While we do not cover specific OEMs or other firms in the sector in the style of inductive case studies, we make use of specific examples involving major OEMs and battery manufacturers in the evidence section. Finally, we rely on recent academic work on the transition from ICEVs to BEVs (e.g., Bohnsack et al., 2014, Murmann & Schuler, 2023, Alochet et al., 2023a), as well as academic efforts to anticipate and examine the competitive dynamics around CAS (e.g., Adner and Lieberman, 2021; Reischauer et al, 2023) to establish a pre-CASE innovations baseline.

The level of analysis is the entire automotive sector with examples from a few key participants, namely OEMs, old and new, (e.g., GM, Hyundai, Toyota, VW, Tesla, BYD), battery manufacturers (e.g., CATL, LG Energy Solution), new mobility service providers (e.g., Uber/Lyft/Didi/Grab) and adjacent Big Tech firms newly interested in mobility (e.g., Google/Waymo, Apple, Foxconn). Furthermore, the scope of the research is global to match our research questions, although we cannot provide comprehensive data on these topics across all actors and settings.

Setting. The automobile sector has long served as a distinguished laboratory for management research and practice (see Baldwin, 2023, Chapter 6, for a recent summary). Auto production has been hugely influential in many subfields, from the mass production and standardization of Ford's Model T in the 1920s (Hounshell, 1984) and the subsequent differentiation, brand management, and proliferation driven by Alfred Sloan in the 1930s (Drucker, 1946; Chandler, 1962) to early evidence (still contested) on the drivers of vertical integration and internalization exemplified by GM's acquisition of Fisher Body (Klein, Crawford, & Alchian, 1978; Coase, 2000; Freeland, 2000) and studies of industry life cycles and populations (Utterback and Suarez, 1993; Suarez, 1995; Klepper, 2002).

In *The Machine that Changed the World*, Womack et al. (1990) draw on research from the MIT-based International Motor Vehicle Program to introduce "lean production" (a term it coined, albeit based on close examination of Toyota Production System), disentangling the idiosyncrasies of Japanese management from a new way to organize production that was diffusing globally. Fujimoto (1999) developed a rich depiction of multi-level firm and inter-organizational learning through deep exploration of Toyota's routines and meta-routines. More recently, analysis of the automobile sector has been crucial in understanding modularity (Campagnolo & Camuffo, 2010; Cabigiosu, Zirpoli, & Camuffo, 2013; MacDuffie, 2013) and its potential impact on the dynamics of value migration (MacDuffie & Fujimoto, 2010; Jacobides & MacDuffie, 2013; Jacobides, MacDuffie, and Tae, 2016).

After over a century under a single dominant design (ICEV), the automotive sector is being challenged by the emergence of a new technology—the battery electric vehicle (BEV). The success of battery electric vehicles (BEVs) is hailed as a key milestone in the "disruption" of the automotive industry and a threat to the performance of incumbent ICEV OEMs. This has provoked speculation about the radical nature of the change and driven a wholesale change in market valuations (Perkins & Murmann, 2018; MacDuffie, 2018; Teece, 2018) that suggest a strong belief in BEV entrants to outperform incumbents and in battery makers to prevail in terms of value creation.

Furthermore, the shift from automobile ownership to mobility services offers yet another set of issues that affect industry organization and value distribution (and potential migration). It provides a textbook opportunity to examine disruption by complements (Adner & Lieberman, 2021) and underlines the importance of ecosystem dynamics through the emergence of powerful new actors such as ride-hailing giant Uber. The emergence of innovations driven by tech giants (e.g., Google/Waymo, Apple) and entrepreneurs have pushed vehicles and mobility experiences to become more connected, autonomous, or shared, prompting debates over whether Big Tech will become the epicenter of the new mobility ecosystem instead of the incumbent carmakers – or a "coopetitive" combination (Keith and MacDuffie, 2018). Recent research is casting doubt on analysts' early certainties, once again turning the automobile sector into a fresh and fascinating theoretical testbed where we need research to shed light on practice so we can push the boundaries of our understanding.

Overall, the automotive world can help us revisit the nature of sectoral change and understand the nature of "disruption" (Christensen, 1996)—a term that is frequently (and, we argue, uncritically) applied to the sector. As Birkinshaw (2022, 2023) rightly points out, the fashionable thesis that disruption is upending established firms is at odds with the empirical evidence, which convincingly demonstrates incumbents' persistence and ability to adapt. By exploring why this is so, we can contextualize existing theory and rethink our understanding of sectoral dynamics.

3. Theoretical Background on Sector Evolution and Disruptive Change

The notion of disruption is as old as studies of technological and entrepreneurial change. Schumpeter (1911) famously described the "waves of creative destruction" that allowed entrepreneurs to come up with new ideas, build companies around them, and displace dominant firms. In his later years (Schumpeter, 1945), he rethought his views, arguing that innovation had become institutionalized within large enterprises, which should therefore be expected to last. Later scholarship reconciled Schumpeter's two apparently contradictory perspectives. Scholars dubbed his early view the "Mark 1" model and his later revision "Mark 2," arguing that they each represented a fundamentally different "technological regime"—a different set of conditions of knowledge generation and, crucially, appropriability—with sectors falling under one model or the other (Malerba and Orsenigo, 1995, 1996; Breschi et al., 2000). Drawing on innovation/pattern data and industrial demographics, more recent research has validated the empirical assertions of this literature and the relationship between conditions of knowledge accumulation/appropriability and the resulting industrial patterns, with some sectors aligning with "Mark 1" and others with "Mark 2" (Fontana, Martinelli, & Nuvolari, 2021).

The literature on industry evolution considers how firms draw on process or product innovation (Klepper, 1996; Aggarwal, Audretsch, & Sarkar, 2007), leading to an industry lifecycle comprising early growth, variety, shakeout, and finally consolidation (Fine, 1998; Fine & Whitney, 2002; Mooen & Agarwal, 2017; Moeen, Agarwal, & Shah, 2020).[1] The implication is that industrial change "resets"

[1] For electric vehicles (E) and connected autonomous shared (CAS) vehicles, the period we analyze when viewed through the lens of Moeen et al's (2020) work is clearly after technology incubation and firm takeoff stages. Assessing sales takeoff is more difficult. For EVs, sales have reached 14-16% globally and nearly 8% in the U.S. as of the end of 2023, yet most

the life-cycle clock, setting off a new wave of entry that is followed by consolidation, presumably by new actors.[2] Research considers the nature of the newcomers, with a distinction between “de novo” entrants (i.e., those that are “truly new”) and “de alio” entrants from other fields (e.g., Sosa, 2013). Other studies consider “spin-offs” (Klepper & Sleeper, 2005), which emerge as new and strong competitors within their own sectors.

The existence of spin-offs was also what partly motivated research in “disruptive innovation” (Christensen, 1996). Drawing on Joe Bower’s work on resource allocation, Christensen pointed out that existing firms often neglect some of their most demanding customers, who would otherwise push them into unprofitable but highly promising trajectories. Thus, they endogenously leave the field open to entrants and inadvertently motivate their own employees to quit and form a spin-off to commercialize the new opportunity. Although this thesis may have been exaggerated (King & Baatartogtokh, 2015), it has clearly transformed many practitioners’ view of innovation dynamics, since the fear of disruption can be a powerful motivator for corporate action (Gilbert, 2005; Christensen et al, 2018).[3]

Gans (2016) argues that “disruption” is an overly broad and potentially confusing term, showcasing how demand- and supply-based disruption differ and how incumbents can tackle both more successfully than prevailing wisdom suggests. Birkinshaw (2022) provides evidence to confirm that in recent years the dominance of incumbents has, if anything, been reinforced. Reviewing potentially disruptive change in multiple sectors including automotive, Birkinshaw (2023) shows that incumbents

analysts would say they still face major barriers to diffusion and sales have not risen as much as expected. For CAS, while connected technologies are now ubiquitous and ride-hailing (Shared) is widely available worldwide, purely autonomous vehicles (AV) are not yet sold to individual consumers, though firms like Waymo, Cruise, Aurora, and Zoox continue to push towards offering robotaxi services. Also, since these technologies are being integrated into the existing automotive and trucking industries), this is not a situation of a nascent or new industry per se. That said, the stages covered in Moeen et al (2020) and the mechanisms of knowledge generation and aggregation that underlie the temporal transition across these stages are very much related to the Mark 3 dynamics of innovation that we discuss.

[2] A surprisingly limited amount of work considers the implications of “clockspeed” (Fine, 1998), which looks at the velocity of the operation and product development cycles in a sector. As Fine notes, sectors tend to have different rates at which new products, processes, and organizational structures are introduced, and these rates play a critical role in shaping the structure and profitability patterns in the sector.

[3] As Christensen et al (2018) note, “popular literature, in conjunction with the trends in management research noted above, suggests overly broad application of the terms disruption/disruptive innovation to signify threat or change of any kind, and underuse of disruptive innovation as a coherent theoretical concept” (1046-47)

can integrate new technologies and find ways to leverage their strengths. Bessen, Den, Kim, and Ringhi (2020) show on the basis of broad econometric evidence that since 2000, leaders have become markedly harder to dislodge, not easier, challenging the prevailing narrative on disruption.

One structural aspect that has been connected to disruption and sectoral dynamics of innovation and competitive advantage is the degree of modularity (Baldwin & Clark, 2000; Baldwin, 2023). Inasmuch as a sectoral technology is or becomes modular, its product development or production process can become disaggregated (Jacobides, 2005) and innovation can be unleashed, as it can focus on one or more of the "modules" (the connected but quasi-independent parts of the product or production process).[4] This accelerates experimentation without any necessary coordination from a central organization, leading to significant entrepreneurial entry (Funk & Luo, 2015).[5] Modularization is thus expected to transform dynamics at the level of the sector.[6]

The ability of modularity to reshape industry landscapes brings us to the question of agency and endogeneity in driving this change, which has been explored in the literature on industry architecture (IA) (Jacobides, Knudsen & Augier, 2006). Work in this tradition considers how the structure of an industry (in terms of not only technology, but also institutions, rules, and conventions) shapes the division of labor, which in turn shapes the division of profit—as well as how firms try to manipulate it. Sometimes, firms with a dominant position, like Shimano in bicycles, may push the sector towards a more integral structure rather than a modular one, since this increases their ability to benefit from their existing asset base and cement their leadership (Fixson & Park, 2008).

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[4] Intriguingly, despite this identified consequence of modularity (Langlois, 2002; Jacobides, 2005; Shibata, Yano, & Kodama, 2005), other research argues that architectural innovation may require *re-integration* (Jacobides & Winter, 2005; Cacciatori & Jacobides, 2005; MacDuffie, 2013; Helfat & Campo Rembado, 2016).

[5] An area which has received considerable attention, focusing on automotive evidence, among others, is the relationship between product architecture and production process (MacDuffie, 2013; Alochet et al., 2023a) using the "mirroring hypothesis" (Colfer & Baldwin, 2016). This proposes that a product architecture will be reflected in how the organization is designed to implement the tasks with varying degrees of interdependence, and, in turn, be reflected in how an industry is organized (Colfer & Baldwin, 2016; Murmann & Schuler, 2023).

[6] In contrast, Christensen, Verlinden and Westerman (2002) argue that modularity is efficient for the less demanding parts of the market but that over time, modular and disintegrated structures will become gradually more efficient and will spread, changing the sector.

Recent work has also suggested that as sectors become more modular, ecosystems form (Jacobides et al, 2018; Adner, 2021; Baldwin, 2023) and that even though complementors might initiate much of the innovation in an ecosystem, powerful orchestrators may be those that disproportionately benefit from it, appropriating the lion's share, potentially raising issues of regulatory intervention (Jacobides & Lianos, 2021; Caffarra, 2023; Jacobides et al, 2024). Also, as Jacobides et al (2024) note, some orchestrators (like Big Tech) may be interested to engage in new ecosystems (like the metaverse) in order to protect their dominant position in their core markets.

Such dynamics take us to the discussion of disruption through complements, put forth by Adner & Lieberman (2021) and Adner (2021), who note that most of the existing work on disruption has been about a focal sector (e.g., automobiles) and not the adjacent, related sectors (e.g., mobility) where the entry of a new type of complementor can shift from being an advantage to being a threat. Adner & Lieberman (2021) posit that such complementor disruption can lead to commoditization, where the entry of new complementors can shift the locus of differentiability (as in Jacobides & MacDuffie, 2013); adjacent entry, where the complementor expands to disrupt the incumbent (as in platform envelopment, per Eisenmann et al 2011); or value inversion (Adner, 2021) where the complement starts by being supportive and ultimately undermines the core offer, e.g., ride-hailing and privately-owned cars.

In all, there are several wide-ranging and partly intersecting literatures that may help to answer the question of what drives potentially discontinuous and disruptive change. However, the literature does not clearly differentiate between the underlying *technological* disruption, the *organizational* implications, and *incumbents' ability to respond*. It is generally accepted that discontinuities do not favor incumbents, and a broadly shared expectation that modular technologies will drive competition to mimic the PC sector (Baldwin & Clark, 2000), where profound structural disruption heralded huge value redistribution and the emergence of new bottlenecks (Ethiraj, 2007) and kingpins (Jacobides & Tae, 2015). Yet we see that existing firms, far from being monolithic incumbents, bring important knowledge and capabilities to bear on the challenge of incorporating new technologies – and also form their ecosystems with an ever increasing number of partners that are important to expand that knowledge and keep them relevant. These dynamics, which include incursions from large incumbents in adjacent sectors, aka Big Tech, as well as startups collaborating with incumbents and hoping to be acquired by them, constitute the Mark 3 pattern of innovation that we will describe more fully below.

We conclude our theoretical framing with related work in the automotive industry, where in the late 1990s and early 2000s, executives and analysts alike communicated great excitement over the expectation that the sector would become completely modular, leading to a massive value reconfiguration and the upending of the traditional industry structure, based on the example of digital technology sectors (e.g. Bain, 1999). Jacobides, MacDuffie, and Tae (2016) examine that struggle to establish modularity in the automotive sector using an IA lens. Here, despite suppliers' best efforts to improve their plight and take advantage of their own innovations, it was the OEMs who managed to maintain both the sector's integral structure and their own role as the key beneficiaries of the value distribution process. The question the authors left open, and which will be a key part of our study, is how the shift from ICEVs to BEVs can be understood through the lens of modularity vis-à-vis changing the automotive sector and value distribution within it (Murmann & Schuler, 2023). Also, Adner & Lieberman (2021) speculate about CAS innovations, speculating on how disruptive or supportive they will be to the incumbents of the core industry and the mobility ecosystem.

4. The Transition from ICEVs to BEVs: How It Changes the IA

To deepen our understanding of sectoral dynamics, we now focus on an iconic disruption: the transition from ICEVs to BEVs, hailed as one of the biggest discontinuities the automotive sector has ever seen (LaMonica, 2012; Murphy, 2020), with a widespread expectation that the product architecture of BEVs will be much more modular than that of ICEVs. At the center of this architecture sits the battery, the central module and source of value—and thus, potentially, the technical bottleneck too (Murmann & Frenken, 2006; Perkins & Murmann, 2018). In this view, batteries would be the primary factor bringing about a new dominant design, accompanied by changes in both process and industry architecture (Tushman & Murmann, 1998) that allow battery makers to challenge the longstanding dominance of OEMs (Truett, 2022).

Relatedly, the shift from ICEVs to BEVs could mark a change from vertically integrated OEMs to a horizontal structure of dominant module suppliers (Grove, 1996). With the push for a modular product architecture in BEVs, plans for contract manufacturing by firms such as Foxconn and the successful forward integration into BEV manufacturing by BYD, a former battery manufacturing specialist, all the elements for disruptive transformation in the industry architecture appear to be in place (Reeves, Bergman, Gourevitch, & Ortiz, 2016). In this view, the impact of new and more modular technologies on industry evolution and strategy will ultimately depend on whether incumbent OEMs can manage to cope with the challenges of this dominant design transformation. In this section, we first consider the rising evidence and then move to the theoretical implications of the (limited) structural transformation we observe.

4.1. ICEV to BEV Changes in the IA: Evidence

The transition to BEVs is broadly expected to feature two elements, assumed to operate in tandem: 1) as a shift in dominant design away from ICEVs after a century of stability and 2) as a shift from a primarily integral architecture to a modular one. Early evidence suggests that the first claim about dominant design is on the mark, but that the second claim about product and industry architecture is not. Instead, initial moves towards electrification are more often characterized by increased integration in both product and production architecture than by modularity. As these architectures are in transition, our analysis below focuses on the trajectory of change, in addition to current facts.

While the idea of modular design for BEVs may be motivating many new entrants, it is not the one implemented by current BEV producers. Based on Design Structure Matrix (DSM) analyses (Murmann & Schuler, 2023), BEVs have, at present, *more* interdependencies in product design than ICEVs. DSM analysis shows where interdependencies across functions or components are high or low; modular designs have low interdependencies in contrast with the high interdependencies of integrated designs. The simpler drive train of a BEV in comparison with an ICEV shows up in DSM as being more modular. But total interdependencies for BEVs are higher, largely because the functional subsystems that draw on energy in some way, i.e., nearly the entire vehicle, now need to interact with the energy source (the battery) in new ways. This is based not only on how electric drive trains differ from internal combustion engines but also on how batteries are charged and how their stored energy is utilized in order to maximize range between recharging cycles.

Put differently, while ICEVs and BEVs differ in their drivetrain and energy source subsystems, the overall design of an automobile (a multi-technology, multi-function, complex product) remains preponderately integral. Recall that product architecture ranges between modularity and integrality along a continuum (MacDuffie, 2013). Hence, as shown in Figures 1a and 1b, while some subsystems in the automobile are moving towards more modularity (e.g., the electric drive train, software for infotainment and autonomy), overall product architecture still remains relatively close to the integral endpoint. High interdependence among subsystems, as with certain high-specification long-range BEVs, can tilt the product architecture even further towards integrality while low-spec BEVs are more modular. Furthermore, some mobility business models center on a shift towards greater modularity.

-- Figures 1a and 1b about here --

The misguided presumptions about BEVs driving modularity, which overestimate new entrants' capacity to compete, may be due to the fact that analysis seizes on the wrong tools to consider the nature of modularity (Baldwin & Clark, 2000; Baldwin, 2023). Technical analysis of BEVs often draws on metrics that provide maximal contrast with ICEVs, such as parts counts focusing on powertrains; a representative estimate claims that "an ICEV powertrain may have more than 1,000 components while a BEV powertrain has only a few hundred (not counting each individual battery cell separately)" (Kupper, Kuhlmann, Tominaga, Arora & Schlageter, 2020). Electric powertrains also have fewer interfaces, requiring only that the battery be connected to one or more e-motors, in contrast to the ICEV's combination of engine, transmission, battery, and alternator.

Another expectation of how BEVs would take the automotive industry towards modularity was that the (thought-to-be) simpler manufacturing process would lend itself to contract manufacturing, i.e. horizontal specialization in manufacturing by firms separate from the OEM doing the design. At the extreme, those predicting that battery suppliers would be the new kingpins of the BEV value chain could anticipate that they would be doing vehicle design and subcontracting out manufacturing to legacy OEMs. Yet, as we will discuss further below, battery-pack sourcing (beyond cell manufacturing) has been moving towards more vertical integration or quasi-vertical alliances – and BEV manufacturing is so far being handled within existing production facilities with only modest process adjustments (Alochet et al., 2023a). No contract manufacturer of BEVs has yet emerged (Boigon, 2023b).

Therefore, according to the trajectory of change so far, the product architecture of the BEV is *less*, not more, modular than that of the ICEV; the process architecture for BEV production is not significantly different; and the industry architecture, rather than moving to decentralized outsourcing and horizontal structure, is boosting vertical integration. This stands in contrast to the OEMs most active in producing BEVs to date, who are following a far more integrated path. When we evaluate the strategies of entrants like Tesla (top in BEV sales for several years), BEV- and plug-in hybrid electric vehicle (PHEV)- firms such as BYD (a battery maker that got into automotive manufacturing via acquisitions and is now world's #1 in combined BEV and PHEV sales), and ICEV-legacy firms such as Ford, General Motors, VW, and Hyundai/Kia, certain shared attributes are evident.

First, BEV designs are vertically integrated, with key decisions about physical battery design and chemistry made internally but more commonly in close consultation with a battery supplier in an alliance or JV-type arrangement (e.g., Tesla with Panasonic or CATL; GM, Hyundai, and Kia with LG Energy Solutions and Samsung SDI; Ford with SK On; VW with 24M and on its own). Tesla, as the first pure-BEV startup to become a global-scale automotive manufacturer, has moved steadily towards greater vertical integration with each new decision on products, production, and supply chains. BYD, Tesla's unlikely challenger at the economy end of the market, is at least as vertically integrated as its rival—partly due to becoming a full OEM via its acquisition of Qinchuan Automobile Company.

Second, batteries are viewed as strategically essential. All the major OEMs stage "Battery Day" presentations to inform and impress investors and consumers and hire extensively to maintain the in-house expertise they need to support informed management decisions. The choice between high-power-density battery chemistries that are heavily dependent on manganese, cobalt, and nickel (MNC) vs. lower-power-density lithium-iron-phosphate (LFP) technology is now a major strategic decision affecting both vehicle design and supply chains; upstream investments in lithium mining and downstream investments in battery recycling are closely related decisions. The prediction that battery manufacturers would exploit their bottleneck control of a key module to become the dominant players, driving a shift towards horizontal industry architecture, has not remotely materialized[7] (cf. Jacobides & Tae, 2015; Hannah & Eisenhardt, 2019; Adner & Lieberman, 2021; Furr & Szerb, 2023). This holds true even though a single Chinese battery maker, CATL, wields outsize control over many parts of the battery supply chain.[8]

Third, production is occurring in wholly owned assembly plants rather than via contract manufacturing.[9] Legacy OEMs are almost entirely integrating ICEV and BEV production in the same assembly plants, partly to leverage existing facilities and maintain employment but also to exploit efficiencies during a transition to BEVs, in which most non-powertrain content will be common across powertrain types (Alochet et al, 2023a). However, this may reflect a transitional state. As the anticipated scale of BEV production grows, more OEMs are announcing plans to build or retrofit existing plants to build BEVs only. Manufacturing processes are also changing. Tesla's manufacturing innovations (such as a three-piece chassis design with massive one-piece giga-castings for the front end and back end, installed as bookends for the battery module in the middle), are being closely

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[7] Our conversation with a director of one of the Top 5 battery suppliers revealed that battery suppliers are, just as Tier 1 suppliers were some two decades ago, both not capable and not interested in 'disrupting' the existing industrial order in the automotive sector and upend the dominance of OEMs. He commented "We already have more than enough issues to deal with: the OEMs demand a lot, competition is fierce, geopolitics complicate things further, supply chains are unstable to say the least, and the list goes on. Why would we bite off more than we can chew right now?" (Personal communication under the condition of anonymity.)

[8] CATL received considerable financial assistance from the Chinese government, either directly or indirectly via subsidies given to the Chinese OEMs purchasing CATL batteries. It was early in deciding to backward integrate into battery raw materials and the processing of those materials into battery components, preparing them for a dominant role in the current surge in BEV battery demand. CATL innovated an older battery chemistry originally used for golf carts, Lithium Ferro Phosphate (LFP), which uses no cobalt or nickel (both in short supply) and is also nearly zero risk for combustibility. LFP batteries are now used by Tesla (Model 3 in China and in the US) and most Chinese OEMs. They occupy a prominent place in the battery strategies of the OEMs such as GM, Ford, and VW that closely overseeing production of their own batteries.

[9] As we will elaborate below, the announced strategies of new entrants to BEVs often depend on contract manufacturing and some examples, such as Fisker's use of Magna Steyr in Austria to produce its new Ocean SUV, do exist. Yet these are very small scale and Fisker is currently on the edge of its second bankruptcy, while announced plans, e.g. Xiaomi's (a smartphone competitor to Huawei in China) plan to contract manufacture its new SUV at one of the largest state-owned automakers (Beijing Automotive Industrial Corporation) are as yet untested. If contract manufacturing is expected to be the underpinning of industry disruption via the CASE technologies, we would expect to see more evidence of its happening by now.

followed (and may be imitated) by incumbent OEMs. Yet these innovations, even when they advance modularity in production, are still vertically integrated and aren't necessarily mirrored in more modular designs.

Despite some pressures from the financial sector to separate legacy ICEV from new BEV activities (via spinoffs or other restructuring), we expect that the legacy OEMs will survive the electrification transition if they can manage both the old and new businesses successfully, i.e., developing ambidexterity, in order to cross-subsidize their BEV investments with profits from their ICEV lineup while also leveraging their existing capital and human assets across a portfolio that includes vehicles of both types. Many of the technological trends beyond electrification will affect both ICEVs and BEVs, from new safety and driver-assist features to new connectivity-based mobility services related to driving, maintenance, and the overall ownership experience. OEMs that stay integrated across vehicle types will be able to deploy their system integration capabilities with greater economies of scale and learning synergies than those that separate their ICEV and BEV production.[10]

Incumbent ICEV OEMs are now clearly committed to electrification from a strategic viewpoint and are moving quickly to close the gap in their technical knowledge of batteries and the new interdependencies arising in BEV vehicle design. The latter requires careful attention to all aspects of vehicle energy usage. Lightweighting a vehicle across the board, from chassis and body to individual components, pays off in potentially reversing the dreaded weight spiral, in which a larger battery is required to propel a heavier vehicle at desired range—but that battery itself weighs more, increasing the energy load. Systems for HVAC (heating, ventilation, and air conditioning) can quickly drain a BEV battery and so must be redesigned to be lighter and use battery capacity more efficiently. Multiply these examples across every vehicle function that requires electricity and the design challenges of reworking components, functions, and interdependencies amongst them are huge. Yet,

[10] This is not to say that these legacy OEMs will do no organizational restructuring. Ford's current move to have two separate product development organizations while maintaining integrated manufacturing, supply chain, and sales/after-sales functions will be closely watched (Boudette, 2022). So far, GM has said it will not follow Ford, given its perception of the greater advantages of integration at present (LaReau, 2022). Renault completed its planned spinoff of EVs into a separate organization, named Ampere, although for now the ownership structure hasn't changed the ownership structure has not changed with 100% of Ampere's shares in the hands of Groupe Renault. The date of a planned IPO for Ampere is not yet announced; Renault is judging the best timing (Westerheide, 2023).

this task is well suited to incumbent OEMs' existing design capabilities; it is exactly what these system integrators have tackled to achieve systemic performance gains in automobiles over a century with a stable dominant product architecture.

Electrification is the technological transition that is currently most affected by regulations and public policy. Most interventions go in the direction of speeding the diffusion of BEVs (vs. hydrogen or biofuels) as the specific path to emissions reduction. Governments worldwide (at national, regional, and city level) are pushing for a speedier transition, whether through phased timelines, production mandates, short-term sales targets, or financial incentives (subsidies, tax credits, lower fees for consumers; tax breaks, onshoring requirements for manufacturing, domestic content rules for vehicles, components, and raw materials). Consumer demand may lag the desired pace of change viewed in terms of these goals – and in the U.S. electrification is becoming yet another issue caught in the dynamics of political polarization, with one party seeking to win voters by advocating for more investment in fossil fuel vehicles. While a slower pace of change will threaten the achievement of climate change goals, it will support a longer period of competition on a wider range of firm strategies ranging from new attempts at fully modular strategies from new entrants to a portfolio approach to drive trains such as Toyota advocates with its emphasis on ICE-BEV hybrids, both covered below.

When the lens widens to consider strategies of individual firms from adjacent sectors attempting to enter the mobility space, we observe significant heterogeneity. A fully modular strategy is apparent in the announcements of Foxconn, which is well known as Apple's primary contract manufacturer but is now moving into the BEV space. Foxconn is pursuing three parallel initiatives: first, it is seeking agreements as a contract manufacturer for BEVs, including talks with luxury maker Fisker; second, it wants to be as a *de novo* BEV OEM in its own right and has announced three models (a sedan, SUV, and city bus) and an alliance with Tech Mahindra of India to enter the Indian, Thailand, and Japanese EV markets; and three, it is the initial orchestrator of the Mobility in Harmony (MIH) ecosystem. (O'Cane, 2021; Mihalasku, 2023; Take, 2023; Wu & Klayman, 2023)

MIH is a consortium for developing autonomous BEVs relying on software from Autoware Foundation, a global open-source network based in Japan. Foxconn will provide the hardware for MIH, built around the inherently modular concept of a "skateboard" chassis that contains the entire powertrain and connects to the wheels; then various body designs can be appended to the chassis. A total of 2,735 consortium partners have signed up for MIH so far, from major automotive suppliers and smaller OEMs to new entrants, suggesting that many players are hedging their bets that the trajectory of future product, production, and industry architecture will bend more intensively towards modularity (MIH Consortium, 2024). When announcing Foxconn's strategy, Chief Technology Officer William Wei said, "most current vehicles are 'hardware-defined' and work in 'closed systems' but Foxconn will compete via 'The Power of Software' and 'The Power of Open'" (Ruffo, 2020).

As we consider the potential for integrated and modular architectures for BEVs to coexist, two temporal dynamics need to be flagged. First, the purely modular approach as pursued by Foxconn and MIH is only just being undertaken—and it reaches beyond BEV architecture to pursue a strategic vision tied as well to the CAS technologies. It is too early to evaluate this vision, and premature to assume that it will fail – or automatically succeed. Second, OEMs' current integrated strategies may reflect a transitional stage of learning about electrification. Since no new dominant design yet exists, we have not yet seen the dynamics of convergence and scale-up that would follow its emergence. As noted above, integration is often chosen, strategically and organizationally, during a period of learning about and mastering new technologies (Jacobides & Winter, 2005; Cacciatori & Jacobides, 2005).

Toyota's strategy is a good case in point. It has occupied a distinctively ambivalent position at this moment in the electrification transition, driven by convictions about both technology and strategy. After innovating in the 1990s with a hybrid drive train (ICE+battery), i.e. Prius, and now extended to its entire product lineup, Toyota has been notably slow to bring BEVs to market, with (now former) CEO Akio Toyoda publicly expressing skepticism about whether this technology can be the one solution for the entire range of mobility needs.

Now under new leadership and signalling its intention to move quickly towards electrification, Toyota is still emphatically evolutionary in approach. Its latest strategy centers on “a carmaker-produced battery EV” (i.e., one that could only be produced by an experienced automaker), innovation in batteries as well as innovation in hydrogen, and a “multi-pathway” approach to powertrains in which traditional hybrids, plug-in hybrids, fuel cell hybrids, and BEVs will all be offered in a portfolio of power trains that will vary over time.[11] Toyota’s stance can be seen as doubling-down on the conviction that the electrification transition will require OEMs to integrate even more of the value chain than in the past, rather than outsourcing and delegating. As noted above, this is exactly the approach taken by BEV market leaders Tesla and BYD.

In contrast, Foxconn seems intent on rivaling the current majority approach to producing BEVs by sponsoring an entire ecosystem that will be able to counter the established status quo. If they gain a foothold, this could mean either that different ways of organizing can coexist even within a single dominant design (as with the different approaches to product variety by Henry Ford and Alfred Sloan at GM in the consolidation phase of ICEVs) or, possibly, that quite different BEV designs could scale and compete in the near future. A committed proponent of modularity’s competitive advantage might argue that, once this initial learning period is over and the competition among alternative product and production architectures is resolved, the anticipated shift to greater modularity would ensue, leading to a change in industry architecture. We remain skeptical and will elaborate in future work.

-- Insert Figure 2 about here --

Finally, beyond the question of modularity (and the apparent persistence of some form of integrality dominated by incumbents), it is important to note how “traditional” OEMs, but also their suppliers have been expanding into an ever-broader set of sectors, partly to be able to “know more than they do”, and better manage the interfaces and connections between automobiles and associated services, ad we will outline below. Looking at the map of the footprint of both incumbents such as Ford and

[11] https://media.toyota.com/toyota-unveils-new-technology-that-will-change-the-future-of-cars/ (Accessed January 16, 2023.)

challengers such as Tesla, or suppliers such as Bosch, we can see in Figure 2 how firms have not only ventured in new realms organically, but how they have used a combination of investment and in particular joint ventures and even more so alliances and ecosystem arrangements to become more current and retain their competitive edge.

4.2. ICEV to BEV Changes in the IA: Implications for Theory

Generalizing beyond this case, we see that the ICEV–BEV transition may have more in common with previous frustrated hopes of radical industry transformation (Jacobides et al., 2016) than originally anticipated. This is interesting in and of itself, as the automotive sector brings out an implicit bias shared by analysts and entrepreneurs alike—and also, perhaps even more consequentially, by capital markets that have rushed to fund failed ventures like BetterPlace (Woody, 2013) or have greeted Tesla's eventual success at scaling with extraordinarily high valuations.

The reality is that established IAs are not quite so quick to unseat or unbundle, and value does not subsequently migrate to the extent that many analysts predicted. This may have more to do with an inappropriate use of existing theory tools, which, if examined more assiduously, could give some advance hints on the extent of industry change. The folklore in academe and in particular the advisory sector (which, after all, makes money from incumbents alarmed by prophecies of their imminent demise), and the sector itself is that big, established players are flat-footed, fail to spot important technological developments, and are duly "disrupted," with new waves and new parts of the value chain stealing their margins.

As the new capabilities that are required emerge from other fields, we see firms expanding partly by acquisition, and partly by alliances and forming ecosystems. This has become so prevalent that in a number of technology areas, new firms are not so focused on establishing sales functions and what would ensure their longevity or ability to grow organically, as they expect that some large industrial buyer will invest and / or keep them captive, or they expect that their ecosystem connections will be a crucial element of their competitive success. Thus incumbent firms evolve their footprint and leverage the fact that there is a greater need for integration and (as we will also see below) that regulation places additional barriers to industry and ecosystem mobility. This leaves space for an "innovative fringe" whose objectives are to either be acquired or to benefit from their position in a strong ecosystem, which co-exists with incumbents whose role shifts over time, but persists.

This image is consistent with Birkinshaw's (2022, 2023) observations about the perhaps surprising resilience of incumbents in contemporary economies, and at odds with the broadly held rhetoric on disruption, itself motivated by advisors and management pundits whose images of impending doom are understandable given their own monetization options. This set of industry dynamics is what we dub "Mark 3", which itself is a regime that combines the independence and ambition fueled by entrepreneurs in "Mark 1", as well as the ability of large incumbents to drive innovation of "Mark 2". Mark 3 has the added twist of significant acquisitive activity of incumbents (which is raising regulatory concerns- see Kwoka & Valletti, 2021) and in particular showcases the role of alliances and ecosystems – and in some instances, as we will see below, the engagement of Big Tech, too.

5. Value Creation and Value Capture Dynamics: Making the Case for Mark 3

Observing the transition from ICEVs to BEVs, many pundits and analysts have predicted that there will be a mass transfer of value similar to the one that happened with the advent of the Wintel combination in the computer sector. Specifically, many expect the ICEV OEMs to relinquish their control, influence, and subsequent value-capturing prowess to battery manufacturers, the participants responsible for the most important part in BEVs.

Looking only at the financial markets, it seems all but certain that such value migration has already taken place. Stocks of EV-related firms have outperformed ICEV OEMs since 2019. Tesla's market capitalization has long surpassed those of big 7 ICEV OEMs' like VW, Toyota, Ford, GM, Mercedes-Benz, BMW, and Honda combined and stands at 58X PE ratio as of December 2023.[12] Other BEV OEMs' valuations are similarly high with BYD, the Chinese BEV/battery manufacturer's PE ratio for fiscal years ending December 2019 to 2023 averaging 99.3X. Looking at battery manufacturers, we

[12] Tesla also benefits from being seen as a Big Tech company with advantages in CAS as well as electrification.

see a similar pattern that reflects a highly optimistic view of the value migration patterns. In 2021, the index for battery firms' performance in the financial market outperformed that of EVs, reflecting the increasing importance of battery supply chains in the sector.[13] In contrast, incumbent tier-1 suppliers have suffered: Their share prices have, since 2017, have underperformed both OEMs and the wider S&P 500.[14] Only the top performers have made any gains.

It is unclear whether such valuations will be sustainable in the future. For BEVs, many projections were based on them being modular in design, built by contract manufacturers, and battery firms assuming the role of both certificator of vehicle quality and legal liability, subsequently dominating the new sector. Thus far, none of these projections have been met. In the event that some or most of these projections do not materialize as the transformation continues, it is likely that the market will adjust its valuations accordingly and things may look very different from where they are now.

The fact that the anticipated (by some) transformational disruption of the automotive sector hasn't occurred to date is valuable for our purposes. The disruption that hasn't happened reveals that neither of the two Schumpterian modes of technological change's impact on value creation and capture, i.e. Mark 1's creative destruction by startups or Mark 2's dominance by the largest firms providing the most advanced technologies (aka Big Tech) describes the current moment of transition for the mobility sector. This sets the stage for us to dive deeper into showing how our proposed "Mark 3" mode of innovation dynamics fits the moment better.

Under "Mark 3" dynamics, as introduced above, incumbents are able to adjust and adapt to significant technological change, despite the (empirically unfounded) predictions of "disruptive change" (Birkinshaw, 2022, 2023). Incumbents pursue Mark 3 by leveraging the new technologies produced by startups, acquiring or allying with them to assimilate their technologies. In the Mark 3 pattern,

[13] https://www.iea.org/reports/global-ev-outlook-2022/financial-performance-of-ev-related-company-stocks (Accessed on August 22, 2023)
[14] https://www.bcg.com/publications/2023/growth-strategy-tier-one-suppliers-auto-industry (Accessed on August 25, 2023)

incumbents start by "knowing more than they make" via massive R&D investments. This enables them to absorb and commercialize the new technologies more quickly.

Further, in Mark 3 mode, incumbents work with complementors to offer new services but also to learn new technologies and business models. Following a period of coopetition, incumbents risk having complementors become competitors but are not powerless to combat these risks; indeed, under Mark 3, incumbents leverage the assets they control to prevent value migration. As such, complementors may end up being more sustaining than disruptive despite intending the latter. Value is being created in new segments, and while there are clearly skirmishes to capture the joint value, with data access and ownership playing a key role, the division of the pie may be relatively balanced rather than lopsided in favor of complementors.

Finally, the lens of Mark 3 spotlights incumbent advantages both in dealing with regulatory requirements and in controlling the key decisions affecting end product differentiation (Jacobides et al., 2016). New entrants may not want the legal responsibility or cost and organizational burden associated with taking on the validation of regulatory requirements. Rather their web of ties to incumbents leads them to be supportive players in an ecosystem rather than as true challengers of the existing industrial order. As for adjacent sector entry, rather than a bid for dominance and replacement via end product differentiation, Big Tech may simply leverage their skills and already-existing customer relationships and interfaces to grab a piece – but not all – of value created by technological innovations and captured via successful hardware-plus-software integration and the addition of new services to existing ownership experiences. Figures 3 and 4 shows examples for both BEV and CAS.

-- Insert Figures 3 and 4 about here --

Adapting to technological change. Incumbents do not enter the era of electrification with no prior knowledge. Recall that automotive is a sector where OEMs definitely "know more than they make" (Brusoni, Prencipe, & Pavitt 2001) in order to bolster and maintain their role as system integrators. Automotive is ranked among industries investing the most heavily in R&D, behind IT hardware/software and health care. Although ICEV OEMs only recently began to introduce BEVs into the market, they have invested heavily in R&D for electrification in the past and have collectively published more than 62,000 EV-related patents between 2002 and 2020, with Toyota as the leader with more than 27,000 patents.[15]

In addition, many OEMs have announced that they will be investing heavily to further develop EV technology. For example, GM is spending $6.6 billion and Hyundai/Kia has pledged $16 billion. They are also undertaking various initiatives to update their value chain, especially for battery manufacturing and for the raw materials needed to do so. Such investment does not make the transition away from ICE all that much easier for OEMs but it does mean they have a solid base of expertise that provides absorptive capacity for whatever new technological knowledge they need.

As described above, the same statements can be made about OEMs and the application of software to vehicle operations. But while electrification knowledge was developed through R&D, automotive software knowledge has evolved slowly from function-by-function application to software-mediated controls for electro-mechanical technologies.

Working with complementors – value capture, learning, coopetition. From the perspective of OEMs, batteries are a critical bottleneck technology for BEVs design and production while charging infrastructure is a critical complement. As of 2023, there are a handful of battery manufacturers that dominate the BEV value chain. CATL, LG Energy Solution, BYD, and Panasonic, the top 4 battery manufacturers in 2022 together commanded 77% of the global market. At the national level, manufacturers from China dominate the space with 6 of the world's top 10 manufacturers being Chinese. Although CATL, the world's largest battery producer with a 34% market share, clearly outperforms all others, competition among other major producers remains fierce. Moreover, the quest to improve the performance of batteries, which can also enhance the performance of BEVs, is on with new entrants such as Quantum Scape and Factorial Energy focusing on solid state

[15] https://www.globaldata.com/data-insights/automotive/global-top-electric-vehicles-patents-holders-in-the-automotive-sector-2131722/ (Accessed on July 29, 2023)

batteries, Chinese incumbents such as CATL and BYD focusing on making lithium iron phosphate (LFP) batteries, and other big players focusing on lithium nickel manganese cobalt (NMC) batteries.

How are incumbent OEMs responding with batteries? They form multiple joint ventures with these battery manufacturers (e.g., GM with SK On, Honda with LG Energy Solution); they invest in new entrants focusing on developing solid state battery technology (e.g. VW in Quantumscape, Hyundai/Kia in Factorial Energy); and they establish alliances with legacy competitors to share investment burden and learn together (e.g., Honda and GM; Ford and VW).

For charging infrastructure, some private firms are backed with OEM funds, e.g. ElectrifyAmerica which uses funds secured in the U.S. government's lawsuits against Volkswagen for Dieselgate); other private firms are independent, e.g. Chargepoint; some initiatives are collaborative, e.g., a consortium of 8 global OEMs' working on charging network standards; and governments will be increasingly large investors themselves, e.g. via tax credits under the Inflation Reduction Act to encourage manufacturers to build charging equipment in the U.S. and via contracts to install high-speed superchargers along the interstate highway system via the Infrastructure Bill.

As Figure 2 (above) illustrates for Ford, Tesla, and Bosch, a core Tier-1 OEM Supplier, for both BEV and CAS technologies, there is a high level of interpenetration within the sectors across legacy automotive incumbents; new entrant startups; and specialists in new technologies, both hardware and software.

Legal liability and regulatory accountability. As products, automobiles have certain unique characteristics: they are heavy, fast-moving objects that operate almost entirely in public space and can kill or injure people and destroy property, which is why they have been heavily regulated virtually since their emergence in the mass market. Safety and reliability have been, and will be paramount in every vehicle, regardless of its source of power. With CAS, the technological transformation towards connected and autonomous services will bring new regulations for vehicles (albeit slowly, as described above) that will affect product design and manufacturing but also preventive maintenance and post-accident repair. Furthermore, new definitions of responsibility and liability for autonomous vehicles will be needed; these will affect other participants in the sector such as insurance firms as well as the government-led licensing of drivers and maintenance of roadways.

Incumbent ICEV OEMs have long experience in managing the resulting issues, pressures, and constraints of meeting regulations and dealing with legal liability; any *de novo* OEM (whether primarily focused on BEV or CAS technologies) must learn to the same. Such capabilities take time to acquire. Firms that have scaled rapidly, such as Chinese BEV OEMs may be able to move up this learning curve more quickly, although the institutional setting can differ greatly by country. For startup OEMs in other parts of the world still operating at very low scale, there is a minimum threshold of capability needed to sell vehicles at all in a given market but otherwise small size and slow growth limits opportunities to learn from experience and develop related capabilities. Tesla, ironically, has leveraged its direct sales model to insulate itself from legal pressures[16], and has used founder Musk's bravado and ability to create headlines to cement its position in the sector. Auto incumbents have the resources to create teams dedicated to formulating and influencing regulations and legislation. Consortia of large and small firms may also have a role, but while many of these already exist, few have emerged as key powerbrokers.

As noted above, battery manufacturers are complementors to OEMs but don't appear to be seeking a larger role in vehicle design, manufacturing, branding, or support. The competition that is taking place on both market and technology fronts reflects battery manufacturers' prioritizing competition within their segment in lieu of shaping the sector IA to their advantage (Jacobides & Tae, 2015). In other words, they are more concerned with addressing the technical bottleneck, viz. battery performance, than leveraging their position to be the strategic bottleneck replacing OEMs from their current position along the value chain. The earlier quote from a director at one of the major battery manufacturers elucidates this. Although BYD is an integrated firm that produces both batteries and

[16] Tesla is able to reduce the number of class action lawsuits by unhappy drivers compared to legacy OEMs because of their direct-to-consumer model. Tesla buyers' terms and conditions include a clause that says that the buyer forfeits the right to sue and any issues will be resolved 'individually' by a Tesla-paid one-person arbiter. OEMs can't do this because their cars are sold through dealership networks, not direct B2C links. In China, the biggest EV market in the world, all vehicles are sold through dealerships regardless of the power source type.

BEVs and Tesla announced that it will produce the 4680-type battery for all future Model Ys, they seem to be the exceptions than the rule as no other BEV OEMs or battery manufacturers have made moves to integrate the other part of the value chain. Despite the excitement around the eventual transfer of power and dominance from OEMs to battery manufacturers, at the moment, battery manufacturers seem neither willing nor able to assume the legal liability and regulatory accountability that the incumbent OEMs have dealt with.

End-product differentiation. When Tesla first introduced Roadster in 2008, the vehicle had not only the 1st mover advantage, but also the differentiator advantage as it was the only car in the market that was purely electric since the ICEVs became the dominant design in the early 1920s. ICEV OEMs, on the other hand, have become used to differentiating their vehicles in various areas such as function, fun to drive, safety, environmentally friendliness, style, and desirability. Customers have certain expectations about different OEMs, the brand image that the OEMs have developed over the years. For example, Ford's F-150 is the gold standard for truck enthusiasts, Toyota and other Japanese OEMs are considered to make the most reliable vehicles with the slowest depreciation in value, and BMW and Mercedes-Benz vehicles target affluent customers who want an understated status symbol. Nowhere in these characterizations is any mention of what's inside vehicles to make them 'different' from others. That is, OEMs have served as the differentiator who know how to assemble vehicles with different characteristics. The only time customers would become aware of the supplier was when there was a safety issue that was heavily publicized, e.g., the Takata airbags.

The situation looks little changed for pure-play BEV OEMs. Customers buy Tesla because it's Tesla, not because of who manufactured the battery pack that is installed in the vehicle. Lucid's vehicles attract customers who want high-end, rare-to-find BEVs. Those who are interested in BEVs by ICEV OEMs choose their vehicles because of the history behind these OEMs or the incentives offered (e.g., Ford's and GM's BEVs eligible for the $7,500 tax credit). The same seems to hold true in China. Due to government mandates, every OEM, both domestic and foreign, are required to use batteries made by a Chinese manufacturer, to qualify for purchase tax exemption (30,000 yuan or $4,170). While there are many small-scale battery manufacturers in the country, most OEMs rely on CATL and BYD. For example, NIO, Li Auto, and XPeng all use CATL batteries inside their vehicles. This means that Chinese OEMs cannot differentiate themselves from competition based on the battery suppliers, but need to find something of their own such as brand image, vehicle design, and functionality to attract customers who have a lot of choices in the market.

-- Insert Table 1 about here --

To summarize, our focus on the BEV transition (see Table 1) suggests that in Mark 3 is characterized by incumbent adaptation, organically and inorganically, and in particular by working with complementors, often if not exclusively entrepreneurial organizations to learn, produce and capture value and, inevitably, both cooperate and compete. We also highlight two critical features that underpin Mark 3. One, often underplayed, is legal liability and regulatory accountability, which we believe will be a potent force for a number of sectors that, especially with GenAI, will face drastic pressures for change. From healthcare to law, our framework suggests that what *could in principle* be disrupted may be held more integral given these sector-level centripetal forces. We also see that end-product differentiation (akin to the notion of “differentiability” discussed in Jacobides & MacDuffie (2013) and reprised by Adner (2021) and Adner & Lieberman (2021) plays an important role in industry dynamics, and offers some support to otherwise challenged incumbents, enabling them to survive via a web of relationships.

6. CAS Innovations and the Rise of “Phygital” Ecosystems: Shared Mobility Services, Software-Defined Vehicles, and Battles Over Data at the Customer Interface

While the analysis above and our paper focuses on the E part of CASE, we briefly review CAS innovations as well, even though the evidence is more scant, tentative and emerging. There are two reasons for this choice. First, unlike the shift from ICEV to BEV, CAS relates to services where physical meets digital (or, “phygital” per the unfortunate if established neologism), which brings up the role of data, and the issues of integrating one service (mobility) into a suite of other services, a trend that characterizes many settings. Second, because in the case of CAS transition, OEMs are much less well positioned to take advantage of their existing skills and assets, thus making it a more contestable terrain, which can shed light to the boundary conditions of our conclusions, and also enable us to see how our "Mark 3" lens applies – and, crucially, how we may want to adjust it.

CAS innovations span a broad range. "Connected" is an important aspect that gives rise to varied monetization opportunities, brings up the role of data, and begs questions about how OEMs and others in the mobility space are positioning to take advantage of the expansion opportunities that emerge. "Autonomous" is moving slowly for a host of reasons – not least, regulatory concerns around safety and infrastructure and accountability, as our framework would predict – and a full review would require a paper in and of itself. "Shared" brings up the question of monetization and business model, and also the questionn of how complementary innovations affect the focal market (Adner, 2021; Adner & Lieberman, 2021). Our analysis here is selective, focusing on two particular facets of CAS innovations: The role of Shared Mobility services such as ride-hailing, where developments have been sufficiently advanced for us to form initial conclusions, and role of "Software-Defined Vehicles" where we see the early stages of the contest between Big Tech, OEM incumbents, and other specialists, but which bring up issues a number of sectors face.

6.1 Mobility as a Service (MaaS) and the Response of Automotive OEMs

In terms of mobility services, Adner and Lieberman (2021) suggest complementors in the mobility ecosystem could siphon value from vehicle producers, a view echoed by Anderson et al. (2022) for BEVs as a platform business. Yet so far, there is limited evidence of this happening even if customer surveys indicate some customers would defer purchasing a vehicle in the presence of such shared mobility options. What has become more visible by way of direct use of OEM product is the demand for vehicles for MaaS use, since the original idea of the circular economy use of existing vehicles has largely given way to a more commercial set of operations offered by the large mobility platforms (which mostly utilize independent contractors as drivers but are considered employers in particular jurisdictions, and require licensing). This has led to a new segment of the market for OEMs who have targeted now see MaaS as a particular use case for their vehicles.

Turning to our Mark 3 framework, we see that in the expansion of MaaS there has been a significant interpenetration between OEMs and ride-hailing firms. Consider for instance Toyota's $1 billion and Hyundai's $250 million investment in ride-hailing firm Grab, which, as Teng & Jacobides (2023) report, was promoted on the grounds that it would allow Toyota to have direct access on car usage in the MaaS sector, and also provide it connection to the drivers in the sector. Other large OEMs have also engaged, be it by alliances and/or equity investments, such as GM's $500 million investment in Lyft. The role of regulation (in this case, of the MaaS services) is seen to play a noticeable, if not critical, role and the question of differentiability and the ability to convince the end-customer of the value of an offering is an important and still contested area. While there is little evidence to date that ride-hailing is displacing private ownership of vehicles[17], OEMs have clearly sought to understand and learn from this potential challenge through investment in and engagement with MaaS firms.

Mercedes Benz's approach is a textbook case of a diversified incumbent, experimenting with both solutions it incubated and investments in entrepreneurial ventures such as car2go or TaxiBeat. Mercedes Benz and BMW, traditional rivals, co-invested $1.1B in 2018 in merging their respective car sharing units. This has created FREE NOW, which has become one of the largest vehicles for hire aggregators, working with numerous mobility brands and vehicle options to make them bookable within one app. This jointly-owned industry leader offers car sharing and further micro-mobility options such as eScooters, eMopeds, and eBikes with its partners TIER, VOI, EMMY, Cooltra, Miles, DOTT, felyx and SIXT, showcasing coopetition in new markets. FREE NOW has also used as a partner its sister company SHARE NOW, a pioneer in car leasing and another unit of the

[17] See Mercer (2024), from his blog Car Charts, on the impact of ride-hailing on private ownership of automobiles in the U.S. Comparing data on "vehicles available per household" in 2005 (pre-ride hailing), 2015 (after 5+ years of ride-hailing growth), and 2022 for the key metro areas that have embraced ride-hailing most enthusiastically (Boston, Chicago, San Francisco, Los Angeles, New York City, and Dallas), he concludes that "influx of ride-hail and other new mobility options has not translated to lower vehicle ownership rates" and that "American households have in fact mostly added cars to their personal fleets since modern Mobility Services emerged on the scene."

BMW/Mercedes JV, which the JV decided to sell to Stellantis in 2022.[18] The third unit of the German luxury car tie-up was CHARGE NOW, a firm which brings together drivers of electric vehicles and charging station operators in 31 European countries with product offerings ranging from comprehensive access to charging infrastructure to complete billing.

CHARGE NOW provides an interesting link between Mobility-related services and BEVs, since one of the key challenges of BEVs is the need to charge them in the absence of a clear grid structure and of pricing that makes this attractive. While the market is only now emerging in this regard, we should note that a number of manufacturers are being more proactive in offering solutions that move beyond the BEV car itself. Tesla has been a pioneer in this regard, as it had to convince its customers that there would be an adequate charging infrastructure.

While Tesla started by offering an exclusive set of charge stations, which many pundits have credited with protecting its dominance of the BEV market, it is currently offering its charging stations to other cars in a bid for additional revenues. Tesla, like other manufacturers (e.g., Porsche), offer particular arrangements for charging as inducements to buy their own BEVs, making such services true complements (Adner & Lieberman, 2021). A few players and Tesla in particular are active not only in managing this set of complements, but also have expanded to offer an all-in-one solution that helps customers manage their energy. Tesla has been working to advance an encompassing solution for at home energy production, for energy storage and management. This illustrates the shift from a product like a BEV to a multi-product ecosystem (Jacobides, 2022; Jacobides et al, 2024) that allows it to capture greater part of the customer wallet and also ensure the customer is stickier and does not evade the boundaries of its offering.

6.2 The Challenges of the Software-Defined Vehicle for OEMs and the role of Big Tech

Another fascinating part of CAS innovations is the shift towards Software-Defined Vehicles (SDV), which pose a greater challenge for OEMs. New entrants such as Tesla have started from scratch with

[18] See https://www.ft.com/content/5a5351eb-3007-4268-8636-6a4f42ee9a57 and https://www.mercedes-benz-mobility.com/en/who-we-are/stories/sell-share-now/ (Accessed March 31, 202)

innovative software architectures and these benefit CAS as much, if not more, than what is needed for E (electrification). Software has been present in automobiles since the 1980s but OEMs have taken a siloed approach with function-by-function software development and heavy reliance on outsourcing to a large number of specialized software vendors.[19] Converting integrated electro-mechanical knowledge to integrated software development requires not just new hires but changes in processes and culture, which poses a real challenge to OEMs and suggests that there may be a limit to the ability of incumbents to adapt, even if they employ Mark 3 tactics, if the capability bases are too different.[20]

The answer we see, however, is not to fully outsource areas of relative weakness, as one might have expected, but rather to reintegrate in strategically important areas. Incumbents now seek to bring software development more fully in-house but are struggling to develop the necessary capabilities for software-defined vehicles (SDV). Mobility services, whether enabled via advanced connectivity outside the vehicle or provided via autonomous systems, are often inherently modular in design, yet the new primacy of software-defined vehicles aims to establish an integrated foundation that services can be layered upon. This approach sits uncomfortably with OEMs' prevailing service models. To quote one Ford executive who spoke recently, "SDVs require a rewiring of the brain" while also providing "tons of opportunities to amplify and advance the driving experience"; so far "we have only scratched the surface" (Hoyal, 2024).

Bringing CAS into vehicles through SDV also involves challenges related to in-vehicle interfaces and other changes in physical design. The limits to change in this regard may partly explain why efforts by Google and Apple to establish a “vehicle OS” via Android Auto and Apple CarPlay have had moderate success. Some mobility services require no (or minimal) physical changes while others are

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[19] Jim Farley, the CEO of Ford Motor Company acknowledged the problem in a recent interview: “We’ve farmed out the software modules that control the vehicles to our suppliers because we could bid them against each other…the problem is the software is written by 150 different companies and they don’t talk to each other…we can’t even understand it all.” To address this problem, Ford is opting for ‘make’ rather than ‘buy’ for its future software: “That’s why at Ford, we decided in the second-generation product to completely in-source the electrical architecture. To do that, you need to write all the software yourself, but just remember, car companies haven’t written software like this ever…We’re literally writing the software to operate the vehicle for the first time” (Farley, 2023).

[20] There is already evidence that incumbents are struggling. VW, which created a separate software subsidiary known as Cariad and located it in Berlin to help attract technical talent, has had well-publicized issues with the software in its new BEVs. Two major leadership changes at the company—the CEO and head of Cariad were both replaced—are attributed to difficulties in mastering software-centric design.

more hardware-intensive (Alochet, MacDuffie, Midler, 2023b).[21] Applying AI, whether in the provision of partial-autonomy driver assistance or full-autonomy (no human control) driving, requires access to large amounts of driving data, both real-time and accumulated during past mileage. Aggregating vehicle data from many sources to fuel AI-powered advances is now a hotly competitive space.

Indeed, control of user data (i.e., on consumer preferences for services, opportunities for shopping, and real-time experiences while mobile) is contested terrain, with all participants in the mobility ecosystem both needing certain data for their services and seeking additional data to enhance their own value propositions.[22] OEMs are forming various relationships with Big Tech firms as well as smaller suppliers in these areas, and data generated by vehicles will increasingly be monetized.[23] These relationships often proceed along a dynamic of "coopetition" with OEMs needing to collaborate with Big Tech at first but then competing through establishment of data firewalls (i.e. some data are shared and some data are not) and creating parallel services.[24]

Finally, it is important here to mention the keen interest of Big Tech where Google, Amazon, Microsoft, and Apple's automotive investments have centered on the in-vehicle experience, autonomous driving, vehicle electrification, and connected vehicle infrastructure, at an increasing rate

[21] Consider usage-based auto insurance with policies priced based on driving data (time of day, location, speed, acceleration rate, and braking intensity). While initial rollout by Progressive Insurance used data collected via a device plugged into a car's OBD II port (developed for OEMs to gather maintenance-related data), many insurance companies now require only an app that uses only smartphone-gathered data to generates usage-based pricing. More obtrusive are new car rental business models, e.g., ZipCar, and Peer-to-Peer car sharing, e.g., Turo, that require vehicle modifications to allow locking and unlocking from a phone app. Most radical will be the changes needing for vehicles to provide autonomous robotaxi services.

[22] A 2016 report from AAA showed that Americans spend an average of 17,600 minutes a year behind the wheel, which would generate 1.8 TB of driving data per driver per year. Bring in additional sensors and vision systems such as cameras, radar and LiDar, and connect these vehicles to the cloud, and Intel's claims that autonomous vehicles will produce 4 TB of data in one and a half hours on the road gains plausibility. McKinsey believes there could be as much as $750 billion of value in vehicle data by 2030 (Peters, 2019).

[23] The first step was the acquisition of car data services firms by OEMs, e.g., Ford's acquisition of TransLoc and Autonomic; and GM taking a 17.3% stake in Wejo, both in 2018. Yet by 2021, Ford sold TransLoc to data aggregator Modaxo, while Wejo went public via a SPAC. And by 2023, Wejo has gone into administration (bankruptcy) and competitor Otonomo lost 95% of its value before being acquired by Urgent.ly. Some speculate that the car data market is still nascent, with ample data supply but little demand, with few willing to pay. Another view is that OEMs have decided that if data can be monetized, they want to gain the revenues themselves. In either case, perhaps these brief investments – another hallmark of "Mark 3" dynamics - were simply a way for OEMs to experiment, learn …, and exit.

[24] Reischauer et al., 2023, provide a detailed longitudinal case study of InnoCar, pseudonym for an incumbent OEM that first cooperated with Apple and Google, then imposed barriers on what data could be collected via CarPlay and AndroidAuto, and ultimately developed its own apps to complement (and occasionally compete) with the Big Tech offerings.

since 2017. For Big Tech this expansion, which brings them into a co-opetitive relationship with automobile OEMs, is both an understandable by-product of the desire to leverage their strengths and monetize their assets in a newly contestable market, mobility and the management of the interface with the driver, and also part of their effort to manage the customer "User Interface" (UI) so that they offer a seamless "User eXperience" (UX), where the car is an integral part of an individual's time.

The path followed by Ford, leading it to sign a recent contract for Google to provide its in-vehicle software for managing UI/UX, is an instructive case, particularly for illustrating Mark 3 dynamics.

When both Apple and Google offered apps to connect their smartphone operating systems to in-vehicle screens—Car Play (2014) and Android Auto (2015) respectively—some automakers moved quickly to incorporate the software into their vehicles, while others resisted. Ford opted to develop its own software partnerships at the User Interface (UI), i.e., to connect a driver's smartphone to the vehicle display and duplicate phone functionality on-screen. Ford's first effort, with Microsoft, yielded the flawed MyFordTouch (2011), which dramatically worsened Ford's JD Power quality scores for a time and led to a class action lawsuit by unhappy customers in the US (Szymkowski, 2019). Ford's next effort, called Sync, drew on the QNX operating system developed for Blackberry devices and involved Panasonic as system integrator. By version 3 of Sync (2018), Ford vehicles were getting top ratings for their in-car interfaces. Despite this success, however, Ford changed horses yet again, announcing in 2021 that from 2023 forward, its vehicles would all be "Google Inside."

Apple and Google keep advancing their automotive operating systems to take on more and more functionality. The latest announcement about Apple CarPlay promises, in 2023, multi-display support, instrument cluster integration, climate controls, widgets (similar to phones), FM radio apps, and more. Many brands have already signed up..

On the Big Tech side, Google's strategy is most fully developed – and most visible. Google's stated intent is to combat unsafe driving while keeping your digital life tied closely to your vehicle, using three methods: Android Auto, Android Automotive, and Google Automotive Services.

Android Auto, released in 2014, provides a projection of your smartphone; the 2023 update features a homescreen for selecting third-party apps and an app switcher for easy swapping between full-screen versions of maps, music, and communication tools. But it is walled off from the rest of the vehicle's infotainment system and prone to synchronization problems.

Android Automotive, released in in 2017, bypasses the smartphone via a full operating system that controls all functions affecting the driver's environment (heating/cooling; display of back-up camera and other sensor data) and becomes the infotainment system. The "look and feel" of the interface is controlled by the automaker; essentially the automaker is the customer, with the driver using a product offered as part of the vehicle.

Google Automotive Services (humorously, GAS) provides the Google app package that runs on the Android Automotive OS; it controls the parameters under which the apps are used.

Given this set of offerings, it is increasingly rare for OEMs to have cut off interaction with Big Tech altogether. Indeed, OEM initiatives to take the lead and put a brand stamp on the software in their vehicle doesn't necessarily mean no role for Big Tech. GM recently announced that it will phase out both CarPlay and Android Auto in future vehicles and replace them with a proprietary infotainment system, albeit one co-developed with Google. Reaction from technology writers was swift and unequivocal: "Everybody hates GM's decision to kill Android Auto and Apple CarPlay" read one headline (George, 2023). Defenders of the move cite GM's need for control to offer (and gather data generated by) subscription-based software services.

Android Automotive is the fast-growing choice of OEMs seeking better CAS functionality. It is adopted by more and more automakers, including Polestar (2018), Renault/Nissan (2018), GM (2019), Stellantis (2020), Ford (2021), BMW and Honda (2022), and VW (2023). Providing access to Android Auto (and Apple CarPlay) is becoming ubiquitous. However, most automakers are not agreeing to adopt the GAS bundle at this stage, showing the lines that OEMs are prepared to draw to remain in control of operating data.

It is not easy to know what agreements are being established between Google and each OEM about access to the data generated during driving. As noted above, this is one place where automakers can draw a line and limit access. However, Google has considerable bargaining leverage given the ubiquity of their OS vis-a-vis the interior functions that require an interface to the driver.

Note that no actual driving features are contained in Android Automotive. Thuseven if Android Automotive continues to make in-roads into an increasing number of vehicles, this is still a long way from Big Tech providing the "brain" for the entire vehicle, as Adner and Lieberman (2022) speculate. OEMs will strenuously oppose relinquishing control of their vehicles, operating data, and customer information. This marks the continuation of a protracted contest between OEMs and Big Tech (Apple and Google) who have tried to enter the in-car entertainment and communication system for a long time, and who are now a step closer to being reluctantly allowed in with the interfaces of Android Auto (see Reischauer et al., 2023) and Apple's CarPlay.

6.3 CAS Innovations and Mark 3: Applications, Implications and Extensions

As the preceding analysis suggests, for CAS innovations much like for BEV, Mark 3 offers a robust framework – even if CAS both show the framework's limits and suggest some important additional considerations. Starting with the application of Mark 3, summarized in Table 2 below, we see that incumbents are, again, proactively involved in expanding their activities to be relevant in areas which are clearly outside not only their traditional areas of competence but also their monetization. Automotive incumbents are investing via multiple paths to build up the new software capabilities needed, both for software-defined vehicles and Mobility-as-a-Service, i.e., hiring software talent, putting software activities in a separate organizational unit for better focus, acquiring startups and/or former suppliers, and setting up alliances and joint ventures with other firms, including competitors.

As a result, at least at present, the incursion of dominant firms from related sectors who are seeking value capture in the mobility ecosystem has occurred without significantly disrupting incumbents. As for the possibility of complementors such as Big Tech firms entering from adjacent sectors, it is made difficult as they must catch up with automotive incumbents in many aspects of product design, supply chain management, manufacturing, dealership networks, and dealing with regulatory requirements, as we are reminded by Apple's recent decision to shut down its AppleCar program (Gurman and Bennett, 2024)..[25]

In terms of the source of differentiation for the end customer, it is interesting to note that for a long time, OEMs (like, e.g. Toyota) had resisted the effort of Big Tech (Apple and Google) to integrate CarPlay (2014) and Android Auto (2015) into the car and succeeded. Then again, vehicles with better smartphone integration began to receive much higher consumer ratings than those with automakers' own systems, even Toyota gave in and now offers both. The fact that Consumer Reports, as of 2023, ranks car brands on how well their in-car user interfaces link to these two operating systems shows the magnitude of the pressure and the desire of customers to keep the simplicity of one UI/UX. However, regulation in terms of data and interfaces may be what may slow down Big Tech and allow it not to play a keystone role.

-- Table 2 about here –

Our cursory analysis of CAS innovations also brings up some challenges for OEMs, making their adaptation less than certain, and it also brings in some additional features which can expand the boundaries of our approach. First, we see that OEMs seem to struggle with software, perhaps because their processes are not well equipped in this regard. In terms of hardware needed for the CAS transition, OEMs are likely to identify new suppliers – and managing hierarchical supply chains is a well-established capability for OEMs. The real test will be competing with digital ecosystem firms in software and services. Indeed, software may be the key bottleneck for CAS innovations, and OEMs seem to be sufficiently far from being efficient in this regard. It is interesting that their response is to *fully* integrate and consider such software as a "strategic capability" to develop and foster given

[25] Often their business model is premised on finding a capable contract manufacturer, but as noted above, there are remarkably few such firms (e.g. Magna, Valmet) and their volume is low; Magna has just begun making BEVs for Fisker, which is near a second bankruptcy. Chinese firm Foxconn, contract manufacturer for Apple, intends to fill this role but its capabilities for building vehicles at scale is so far untested. On the other hand, BAIC, which will manufacture for Xiaomi, has extensive manufacturing experience.

innovation potential (Jacobides & Winter, 2005; 2012). But, the CAS evidence reminds us that innovation transforms the capability bases enough to endanger even open minded behemoths.

Second, we find that UI/UX and data play a critical role in determining the potential outcome of the Mark 3 tugs-of-war, and that another powerful set of players are those whose UI/UX is so ubiquitous that even powerful OEMs, steeped in new technologies and able to offer alternatives may find their hand twisted. This suggests that in many of the Mark 3 setting the battle to dominate the sector and benefit from innovation isn't only one where the incumbents engage with smaller firms, but where Big Tech have an important role to play, and where their power is driven by the customer acceptance and adherence to their UI/UX and to the regulations limiting the flow of data.

Third, our analysis suggests that legal interpretations will shape the mobility landscape. OEMs are growing cautious about Big Tech's control over data, as are consumer groups. Recent disputes highlight tensions over data control between Big Tech, OEMs, data aggregators, and vehicle owners, with consequences for possible digital services.[26] Regulation may shape the industry architecture beyond existing legal considerations. Big Tech faces inquiries into their data monopoly from smartphones and policymakers have expressed concern over potential dominance of Apple and Google in vehicle data collection. Their ability to prevail in the Mark 3 mobility evolution may be limited. The automobile's regulated history places liability with OEMs as system integrators. This liability may bring control benefits in the digital realm, preventing typical Big Tech disruption patterns. As in other regulated sectors, Big Tech may coexist with incumbents in specific profit pools alongside OEMs, and ecosystem regulation (Jacobides & Lianos, 2021; Caffarra, 2023) may play a role on the relative role of Big Tech, OEMs, entrepreneurs, and how they can all interact.

[26] Some foretell a new ecosystem organized around gathering, analyzing, and reporting on user data. Modaxo, Wejo, and Otonomo offer access to millions of miles' worth of driving data, aggregated from multiple OEMs, and anonymized or delivered to clients via customized arrangements that obtain driver permission to share personal information. The business model is based on persuading OEMs that there is little benefit in them working only with their own data. Yet the potential of a centralized data marketplace hasn't yet been realized. Carmakers equivocate on what data they want to share; when the aggregators only get cherry-picked data and/or only from a subset of their customers, the aggregate data aren't as valuable. Furthermore, OEMs see the potential for more revenue by selling different data to different customers at more differentiated prices. For example, Ford sells data through multiple channels — startups, insurance companies, data aggregators — and retains the Blue Cruise subscription service data for its own use (Coppola, 2023).

Fourth, we see that Mark 3, especially in "phygital" contexts such as CAV leads both incumbents such as OEMs and other firms to develop "multi-product ecosystems" (Jacobides, 2022; Jacobides et al, 2024) which provide all-in-one solutions to customers, and which change the nature of the offering broadening it from a product to a bundle with more convenient if opaque pricing. This expansion means that inevitably, many sectors will come in contact with both Big Tech and with other firms they did not have much engagement with, and our impression is that this will revolve around a core of incumbent firms that find their boundaries and value propositions evolve and expand, Big Tech who explicitly cut across sectors and entrepreneurial firms ready to engage in collaboration. In this regard, both happenstance and willing partners, and regulations will play a key role.[27]

7. Discussion and Conclusion

This paper took a birds-eye view on both automobile production and mobility, looking at the nature of IA change and disruption, and how this can help us revisit the concept of disruption and how it relates to the surprising persistence and permanence of incumbents that we see in a number of sectors, or ecosystems. Our findings suggest that, as digitization proceeds, sectoral boundaries increasingly overlap and intersect, and the patterns can be better understood when we look not only at the level of an industry but an interrelated set of sectors. We find that the canonical representation of disruption, which is increasingly receiving scrutiny (King & Baatartogtokh, 2015, Birkinshaw, 2022), is not an effective lens nor is it empirically founded in our sector, whether narrowly or broadly construed. We find that even in rapidly shifting sectors such as mobility, the very interconnections new products and services require mean that there is a link between existing actors and the new services. This may be why we identify the Mark 3 pattern , i.e. the prevalence of a form of innovation which is close to neither the "Mark 1" archetype of Schumpeter (1911) of entrepreneurial firms causing industrial

[27] For mobility services, regulatory and legal issues around data will significantly influence feasible business models. The plausible "rules, roles, and relationships" defining the IA for offerings to customers and interfaces among mobility service providers, OEMs, and Big Tech are in question. There is a difference between technologically feasible services and those supported by a strong player constellation and sufficient customer attraction. Feasibility may not guarantee market success.

renewal, nor his "Mark 2" (Schumpeter, 1945) of large firms internalizing innovation. It is distinct and may be characteristic of many currently digitizing sectors.

The theoretical contribution of this paper is to provide more clarity on what underpins this structure, which we dub "Mark 3", expanding the relevant literature (Malerba & Orsenigo, 1995; Breschi et al., 2021). This is useful as it helps contextualize the arguments about disruption (Christensen, 1996) which we find has been significantly overplayed, distorting the empirical record not only conceptually (King & Baatartogtokh, 2015) and in cross-sectional research (Birkinshaw, 2022, 2023; Bessen et al., 2020) but also in the context of one detailed, in-depth investigation of automotive production as well as the broader mobility sphere. Figure 5 summarizes the Mark 3 dynamics for the mobility sector as we witness them at present.

-- Insert Figure 5 about here --

We find that disruption is partial at best, and we showcase how disruptors are invested in by and tightly interwoven with incumbents, yielding a composite picture which differs from the overly stylized rendition often taken at face value. We also find that new technologies, at least in this sector, are not as modular as is assumed, and that their interdependencies require, if not integration, then alliances, web of alliances, or ecosystems to resolve them (Jacobides et al., 2018). We also find that established incumbents from other, tech-enabled and customer-facing segments (a.k.a. Big Tech) have an important role to play in such Mark 3 dynamics. Their power (and potentially the power of other incumbents) raises the question of regulation to ensure fair competition (Jacobides & Lianos, 2021).

While our analysis drew primarily on the ICEV-to-BEV transition, we also considered the other elements of CASE given our interest to not focus exclusively on a physical product, but rather also consider overlaying digital services on a physical product. Here we found that much of the previous analysis held, in that incumbents with system integration capabilities (and precious few startups, i.e., primarily Tesla to date) would dominate. We also found that for both sets of innovations, to date, all participants (automotive OEMs, *de novo* firms doing CAS and/or E, and adjacent incumbents from Big Tech) realize that they need each other to make things work for the future of mobility.

At the same time, focusing on "phygital" products we found that the distance between traditional ("hardware") and digital ("software") skills may place a limit to the ability of incumbents to adjust, especially if they are challenged by digital natives or Big Tech that span many different sectors. Here Baldwin's prediction (2023) that a rapid pace of technical change favors the organizational form of platform-with-options over the flow production paradigm that dominates the persistently-integral automotive industry is telling. Could this fact lead, for the complex multi-technology "phygital" product of a car, to ongoing coopetition dynamics between auto incuments and Big Tech (even though none of the parties would fancy that outcome)?[28]

Big Tech desire to engage is driven both by their effort to find new markets to exploit, and to protect their franchise in terms of management of the UI/UX which, along with data, becomes a key bone of contention. In this regard, too, we find that regulation and question of data ownership and access may play a pivotal role in shaping sectoral and ecosystem dynamics. We also find that incumbents, Big Tech and aspiring entrants compete in digitally connected sectors by creating multi-product ecosystems (Jacobides et al, 2024) that require yet more collaboration between players.

We think that our results are particularly important as we are in the process of preparing companies and policy makers to address the disruption that GenAI may provoke in a number of industrial sectors. Whether incumbents should be expected to perish (and, if not, when and why not) is a question that will help us get a much better guide to what we should expect about the future, and how the *technological* disruption may lead to organizational disruption – or, more plausibly, to a continuation in many respects and changes in a few. It also sheds light to underappreciated factors including regulation and norms which may drive the future of many a sector.

[28] The possibility that a Big Tech firm will design digitally-advanced vehicles that are built by contract manufacturers, consistent with the "Designed by Apple, Built in China" approach of digital devices, suffered an apparent setback when Apple recently announced the closure of its multi-year AppleCar program (Bloomberg cite). Yet Xiaomi, the second-ranked smartphone maker in China, quickly drew attention for announcing it would begin taking pre-orders for its own branded SUV that will utilize the same operating system found in its phones and even its appliances. As noted above, the Xiaomi SU7 SUV will be built by BAIC, a long-established state-owned automaker that is the JV partner of both Daimler and Hyundai (Li, 2024). Huawei, the leading smartphone firm, is making a similar effort, albeit by acting as a "full-range solution provider" that helps OEM partners develop EVs that are known to the public as "Huawei cars" regardless of OEM brand (see Mercer, 2024b for a critical assessment).

Finally, our findings contextualize the important distinction of Adner & Lieberman (2021) in terms of disruption in complements, and showcase the mechanics of such a disruption, which we consider to be increasingly relevant. Of the scenarios for disruption that they highlight, our analysis provides some early indication of which are more (or less) likely; for example, there's no evidence at this time to support their scenario in which ride-share companies replace OEMs with contract assemblers (Figure 7, p. 104).

However, we acknowledge that these are early days and more than one future path is possible, and indeed even likely. We hope to guard against the common cognitive bias of anticipating a "one best way," i.e. that industries will tend to converge on one solution – more modular or less modular, more integrated or less integrated. Indeed, there may be a variety of coexisting solutions. Semiconductors has clearly demonstrated this point with the coexistence of fabless and integrated approaches. Skirmishes about the "right future structure" of a sector aside, we agree with Adner and Lieberman that we should be ready to see a number of alternative coexisting arrangements. Furthermore, our goal here is not prediction of an uncertain future but rather to understand, based on deep study of context and dynamics, how innovation, more broadly seen, is changing the mobility sector. In this regard, the more disruptive experiments (a la Foxconn) are highly instructive whether or not they survive.

In summary, our paper is by necessity exploratory in nature and is meant to offer deep empirical context as the basis for theoretically relevant observations. Much more systematic work, both in terms of theory and empirics, will be needed to better understand these important dynamics. In this regard, we hope our unconventional paper will encourage much needed follow-on work.

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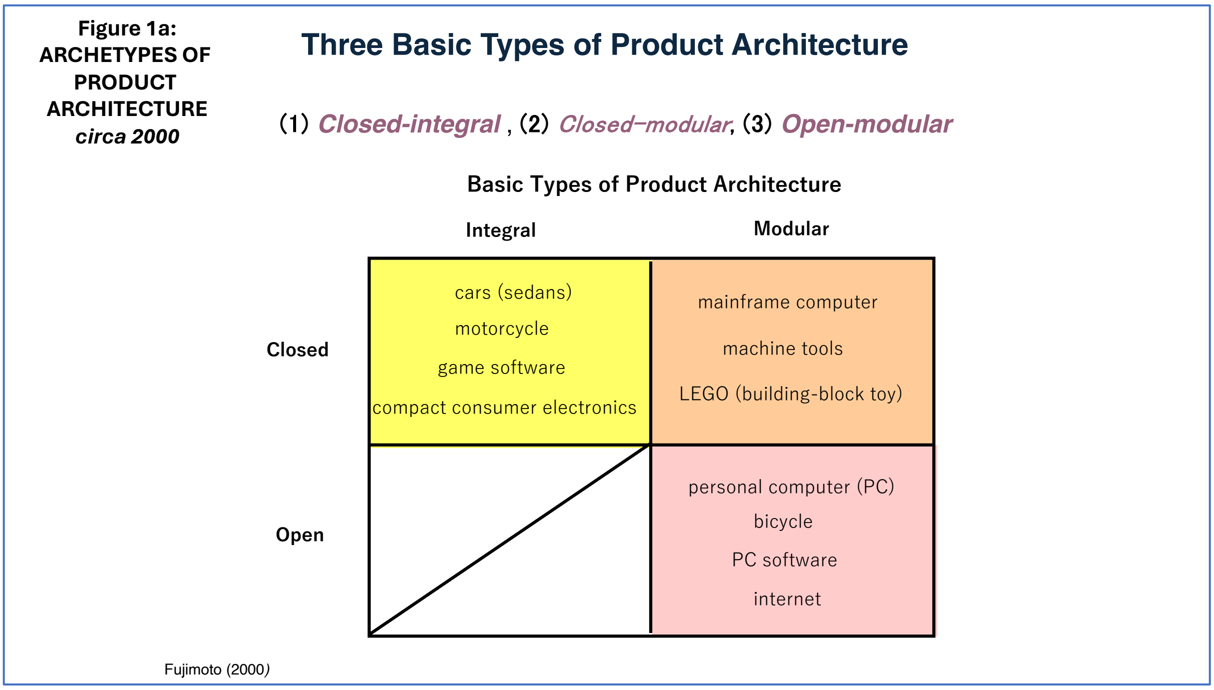
Figures 1a and 1b: Product Architecture: Archetypes and CASE Vehicles circa 2024



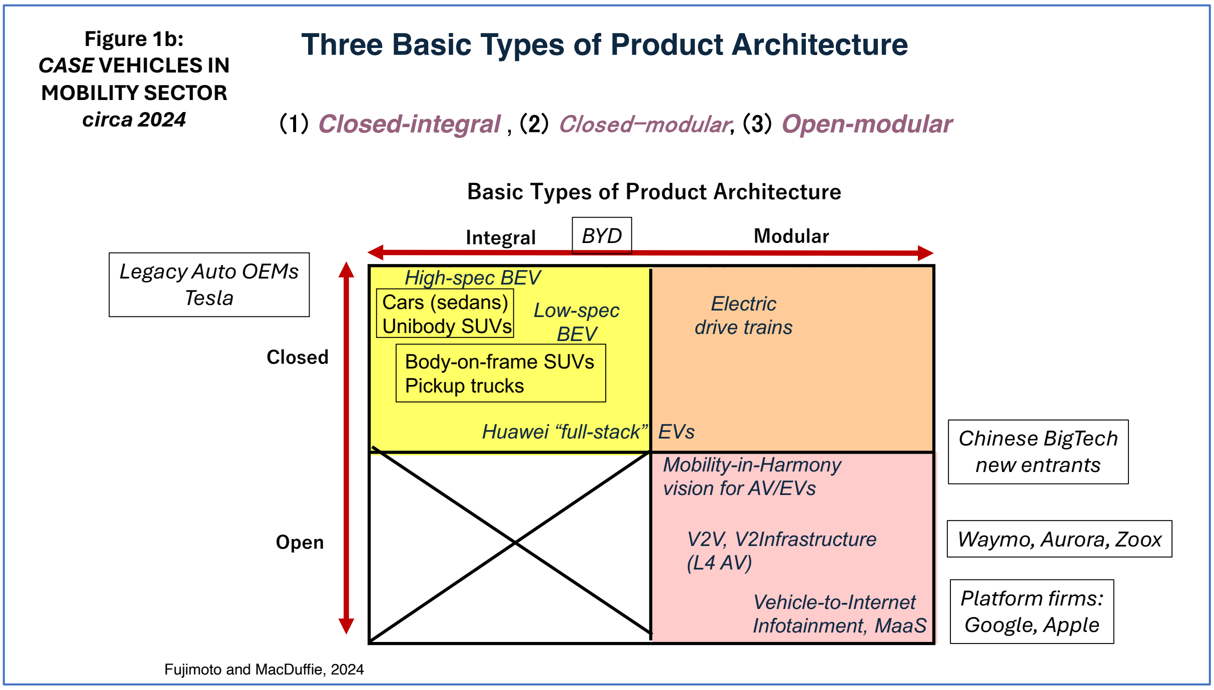


Figure 2: Map of relationships, and cooptation of other firms in the automotive space

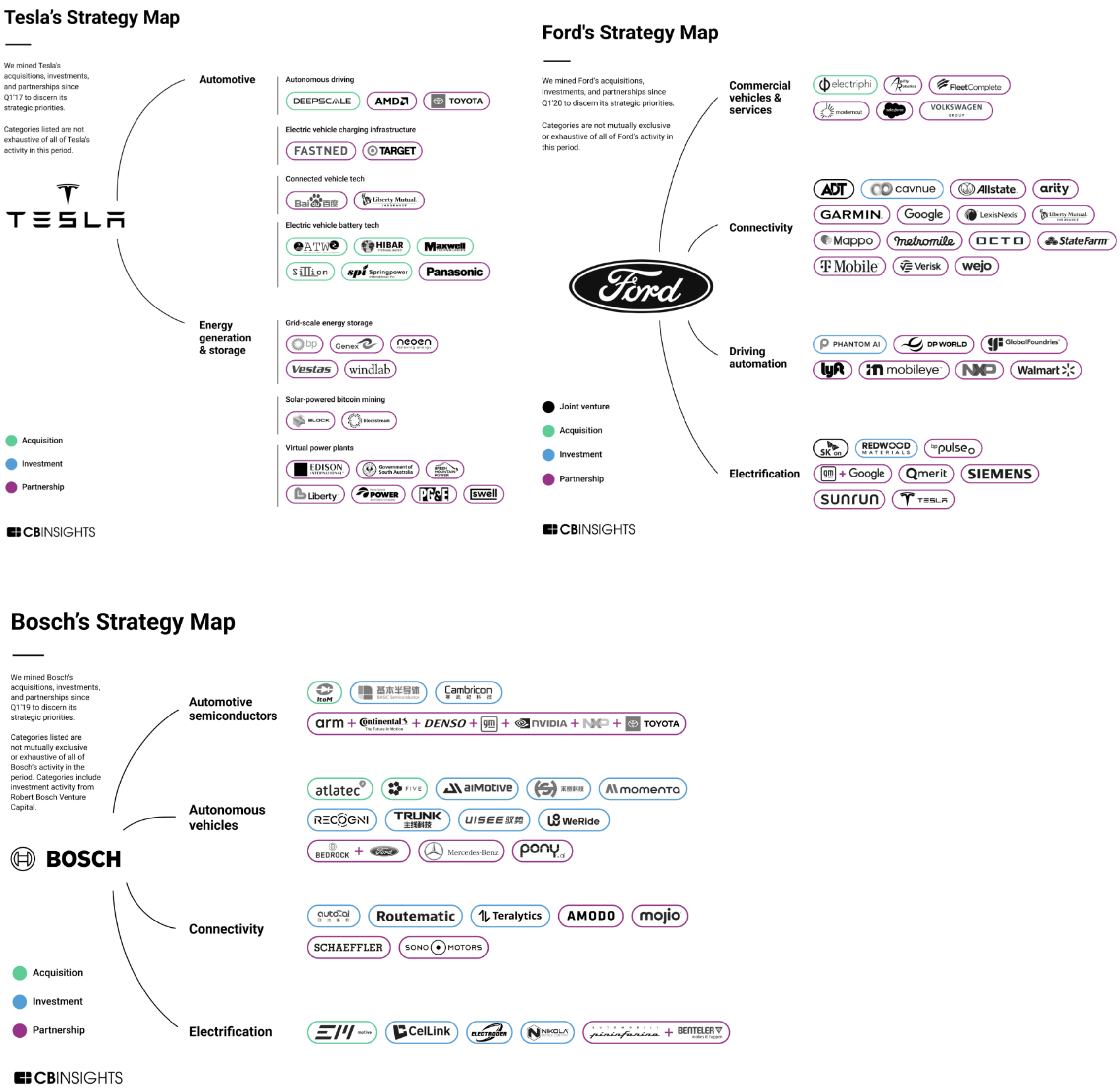


Figure 3. Summary of Mark 3 innovations in the Electrification (ICEV to BEV) transition

	What happened	Mark III Examples
Technological disruption	• Internal combustion engine to battery electric powertrain • Interdependence: BEV > ICEV → integrated vehicle design	• Investments in relevant technologies: Ford's investment in Rivian, BEV-related patent portfolio • Establish alliances with legacy competitors to share investment burden and learn together (Honda and GM; BMW and Mercedes-Benz)
Organizational implications	• Battery as the crucial input for vehicles • Assembly in-house • Push for open, modular design • No contract MFG available	• Parnerships (Ford-SK On, GM-LG Energy Solution, Tesla-CATL & Panasonic, Hyundai/Kia-Samsung SDI) • Foxconn's 3-pronged approach: contract MFG, OEM, and MIH
Sector demographics	• Various BEV start-ups (de novo, adjacent entry) • ICEV OEMs • Battery pack MFG • Battery cell MFG	• De novo entry: Lordstown, Lucid, Rivian, Nikola, Nio, XPeng • Adjacent entry: BYD, Foxconn • Battery MFG: CATL, BYD, Panasonic, LG Energy Solutions, Samsung SDI, SK On, etc.

Figure 4. Summary of Mark 3 innovations for CAS (Connected Autonomous Services)

	What happened	Mark III Examples
Technological disruption	• Importance of data and software capabilities • Mobility-as-a-Service (MaaS)	• Acquisition of data aggregation platforms (e.g.,Ford-TransLoc, GM-Wejo, BMW-ParkMobile) • Ending such partnerships by certain OEMs (e.g., GM, BMW) • Sales of data to third-parties for revenue (Ford)
Organizational implications	• Cooperation with Big Tech to integrate smartphones • Ownership of vehicles • Locus of ownership and control of data	• Parnerships with Apple, Google, and Amazon • Investments in ride-hailing and peer-to-peer carsharing (Toyota in Uber and Grab, GM in Lyft and Turo, Daimler in Mytaxi, Hyundai in Grab and Ola)
Sector demographics	• Data intermediaries • Big Tech firms • Ride-hailing apps • Peer-to-peer carsharing	• Modaxo, Wejo, and Otonomo • Apple (CarPlay), Google (Android Auto), Amazon (Alexa) • Uber, Lyft, Grab, Didi, MyTaxi, Ola • Zipcar, Turo, Getaround

Figure 5: Mapping Mark 3 Dynamics in Mobility

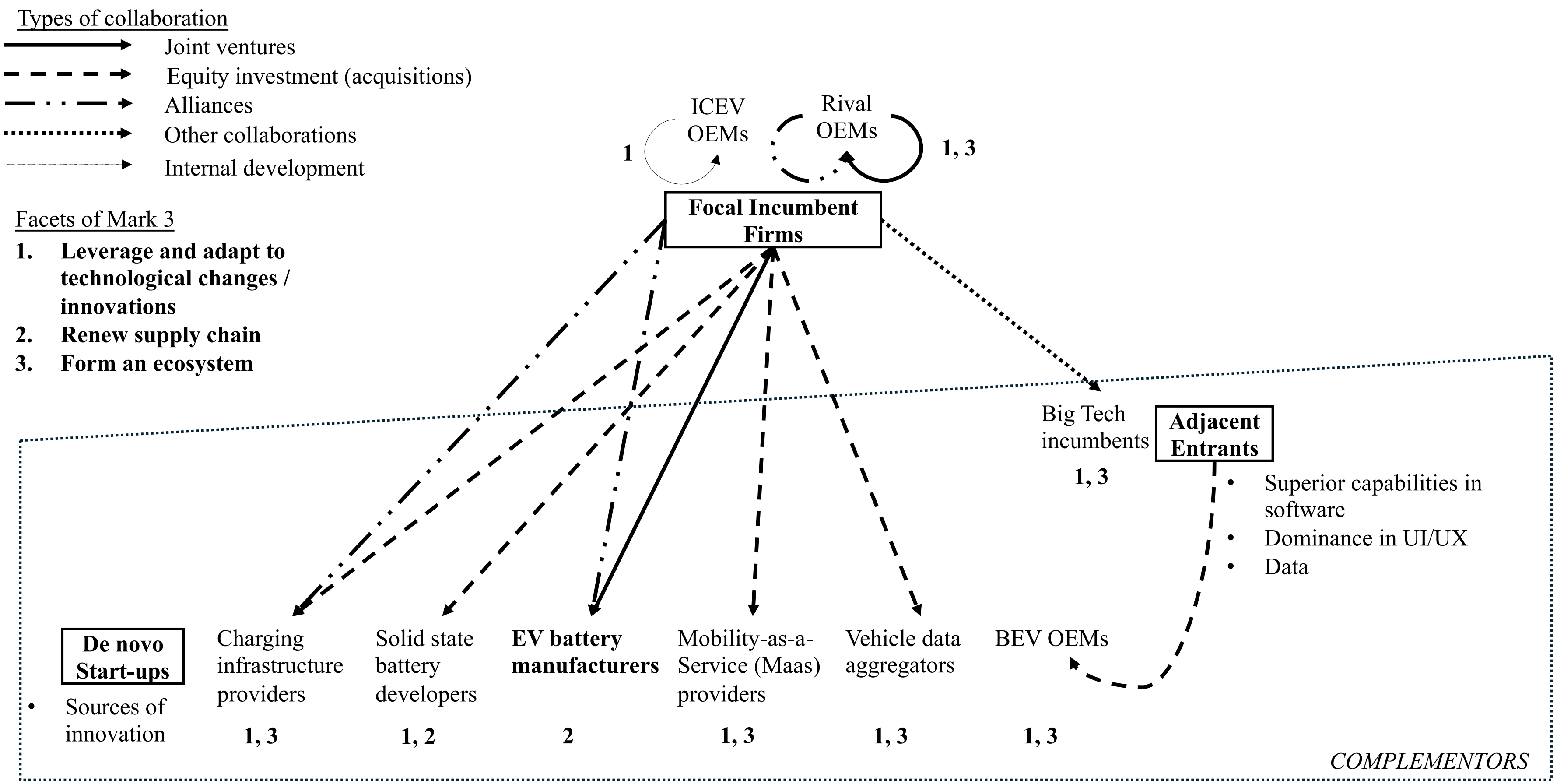


Table 1. Examples of Mark 3 for BEV Innovations

BEVs	*Incumbent OEM*	*Adjacent entry*	*Investment in capabilities*	*Partnerships w/ rivals*	*Partnerships w/ new suppliers (VC update)*
Ford	√		**Extensive patent portfolio**	**Tesla (charging)** **VW, GM**	**CATL, LG Energy Solution, SK On**
GM	√		**$6.6billion in EV technology**	**Honda, GM** **Charging network alliance**	**LG Energy Solution, Samsung SDI**
BMW	√		**Investment in AMPECO, ONE**	**MB, Toyota** **Charging network alliance**	**AESC, EVE, Northvolt**
Hyundai/Kia	√		**$16billion in electrification, patent portfolio**	**Charging network alliance**	**CATL, Samsung SDI, SK On**
Tesla			**Automation of MFG**	**GM, Ford (charging)** **Open patent portfolio**	
Foxconn		**Contract MFG diversification**	**Acquisition of Lordstown factory**	**Mobility in Harmony (MIH)**	
BYD		**Forward integration**	**Acquisition of a struggling ICEV OEM**		

Table 2. Examples of Mark 3 for CAS Innovations

CAS technologies	***Incumbent OEM***	***Adjacent entry***	***Acquire/learn new capabilities***	***Partnerships w/ other participants***
Ford	√		Cavnue, Google, Lyft, PhantomAI	
GM	√		Cruise, Microsoft, Turo, Lyft, Wejo	
BMW	√		MyTaxi (FreeNow), May Mobility	Mercedes-Benz
Hyundai/Kia	√		Grab, Ola, Aptiv, Supernal, $13 billion in software	
Alphabet		Connected & Autonomous technologies (CarPlay, Android Automotive, Echo Auto)	Waymo, Latent Logic	
Amazon			Rivian, Aurora Innovation, Zoox	
Apple			iCar	

Appendix A: Conferences/Academic Symposia presentations on the transformation of automotive and mobility ecosystems (incomplete)

Program on Vehicle and Mobility Innovation (PVMI) Conferences, 2015-2018

Venice: co-hosted by Center for Automotive and Mobility Innovation (CAMI), University of Venice, September 9-11, 2015

- Opening presentations by Francesco Zirpoli and John Paul MacDuffie
- Keynote address by Glenn Mercer, "New Markets, New (Business) Models, New Rivals: Challenges to OEM Strategic Planning in a Time of Great Uncertainty"
- Research papers, selected by referees, presented by Paolo Aversa, Florence Charue-Duboc, Paolo Bricco, Bo Chen (with discussants Andrea Stocchetti, Janell Townsend, Josh Whitford, Giuseppe Giulio Calabrese)
- Research updates by Christophe Midler, Alessandra Perri, Rram Mudambi, Heike Proff, Giovanni Vaia, Janell Townsend, Sihem Ben Mahmoud-Jouini
- Agenda-building discussion on how business models are changing and how consumer mobility behavior is evolving

Philadelphia: "Connected Truck, Connected Car," June 1-2, 2017 with support from Nicolaj Siggelkow and Christian Terwiesch, co-directors, Mack Institute for Innovation Management, Wharton School, U. Pennsylvania

- Truck Day Panel 1: "Will Trucking be a Lead Sector in Connected Vehicles?" with Brad Bartkowski, Orion Fleet Intelligence; Jon DeGaynor, Stoneridge; Dave Shaller, NACFE
- Truck Day Panel 2: "Platooning" with Josh Switkes, Peloton; Susan Alt, Volvo Truck; Bill Brentar, UPS; James Winebrake, Rochester Institute of Technology
- Keynote: "Uberization" of Freight, Bill Driegert, Uber Freight
- Truck Day Panel 3: Discussion of "Uberization of Freight," Steve Viscelli, U. Pennsylvania
- Truck Day Panel 4: "Autonomous Trucks" with Richard Bishop, Bishop Consulting, Task Force on Automated Driving, American Trucking Association; Scott Perry, Ryder Systems

- Car Day Panel 1: How the Automotive World Looked at an Earlier Inflection Point: Reflections from MIT's Int'l. Motor Vehicle Program and Implications for the Present" with Daniel Roos, MIT Engineering, founder of IMVP, James P. Womack, founder, Lean Enterprise Institute and IMVP Research Director
- Car Day Panel 2: "Future Strategies for Connected Mobility: Who Will Prevail?" Takahiro Fujimoto and John Paul MacDuffie
- Car Day Panel 3: "Faster, Smarter, Greener: Future of the Car and Urban Mobility" with Charles Fine, MITSloan School; John Moavenzadeh, World Economic Forum; Brent Fusco, Delaware Valley Regional Planning; Erick Guerra, Kleinman School, U. Pennsylvania
- Car Day Panel 4: "Prospects for Autonomous Vehicles" with Rahul Mangharam, UPenn Engineering; Flaura Winston, Childrens' Hospital of Pennsylvania, Sarah Light, Wharton

<u>London:</u> "Reshaping Vehicle and Mobility Ecosystems: Mapping the Terrain for Strategists, Regulators, and Academics," co-hosted by London Business School, November 14-15, 2017

- Day 1, Session 1: "Mapping the Terrain for Vehicle and Mobility Ecosystems" with Michael Jacobides and John Paul MacDuffie
- Day 1, Session 2: "Why Is Mobility the Big New Ecosystem?" with Juergen Rees, Accenture; Alex MacKenzie-Torres, Toyota Research Institute; Martin Bruncko, Steam Capital
- Day 1, Session 3: "One or Multiple Mobility Ecosystems? Mobility Ecosystem Strategic Dynamics" with Nikolaus Lang, BCG; Jörg Lamparter, Daimler; Philippe Colpron, Wabco; Alessandro di Fiore, ECSi
- Lunch discussion tables on morning themes, facilitated by: Michael Jacobides, LBS; John Paul MacDuffie, Wharton; Mari Sako, Oxford; Charlie Fine, MIT; Francisco Veloso, Imperial; Venkat Atluri, McKinsey
- Day 1, Session 4: "Who Will Orchestrate Vehicle and Mobility Ecosystems?" Kevin Reynolds, Ford; Hubert Lalanne, IBM; Elisa Balestra, GSMA; Nick Reed, Bosch; David Keith, MITSoan
- Day 1, Session 5: "Who Will Shape (and Contest the Shape of) Vehicle & Mobility Ecosystems?" with Iain Forbes, Centre for Connected & Autonomous Vehicles; Charles Fine MIT/ASB; Michael Hurwitz, Transport for London; Eric Thun, Oxford; Francesco Zirpoli, University of Venice

- Day 2, Session 1: "Review of Day 1 Themes and Discussions," M Jacobides & JP MacDuffie
- Day 2, Session 2: "Getting the customer needs right and managing pilots in ecosystems" with Virginie Boutueil, Sustainable Mobility Institute, Renault-ParisTech; Alex MacKenzie-Torres, Toyota Research Institute; David Wong, SMMT
- Day 2, Session 3: "(City) State as Laboratory: Setting Up Social & Economic Mobility Experiments" with Lisa Füting, Audi; Neil Fulton, Transport Catapult; Andreas Mai, Keolis NA; Mari Sako, Oxford
- Day 2, Session 4: "Getting from here to there: Dealing with organizational history & luggage" with Kevin Reynolds, Ford, Christophe Pinau and Brigitte Courtehoux, PSA, Mark Platshon, Icebreaker Ventures
- Lunch discussion tables on morning themes, facilitated by: M Jacobides & JP MacDuffie; Merieke Stevens, Erasmus; Francesco Zirpoli, U Venice; Matthias Holweg, Oxford
- Day 2, Session 5: "Managing scope: How deep, how broad? Organic or via M&A and alliances?" with Charles Fine, MIT/ASB; Max Warburton, Sanford Bernstein; Christophe Pinau and Brigitte Courtehoux, PSA
- Day 2, Session 6: "Shaping the Standards: What will (and should) be the architecture of mobility?" with Shane Rooney, GSMA; Hardy Groeger, IBM; John Aloy, Telefónica UK; Annabelle Gawer, University of Surrey

Tokyo:

PVMI Researchers Meeting, November 13, 2018

Katharina Badenhausen, Rotterdam School of Management:
"Trust 4.0? How Digitization Transforms Buyer-Supplier Relationships."

Merieke Stevens, Rotterdam School of Management: "Diffusing Digital Supply Chain Management Tools: The Role of Trust and Power in Successful Implementation."

Ki-Chan Kim, Catholic University of Korea:
"Future Mobility at Hyundai Motor"

Marc Alochet and Christophe Midler, Ecole Polytechnique:
"How Is the E-Traction Value Chain Affected By EV Scale-Up?"

Christophe Midler, Ecole Polytechnique:
"From transplant to reverse innovation in auto industry: the Renault case"

Christophe Midler Rémi Maniak and Theodore de Campigneulles, Ecole Polytechnique
"Ambidextrous program management: the case of autonomous mobility"

Jianxi Luo, Singapore University of Technology and Design
"Data-Driven Exploration of Innovation Opportunities for Autonomous Vehicles and Aircraft"

Masanori Yasumoto, Jimmy Shiu, and Shanke Wang, Yokohama National University
"Past and Current Mobility Research Findings, e.g., Connected Car, Mobile Tech, Car OS"

Nina Teng, London Business School
"Are Network Externalities Oversold? Lessons on Ecosystem Strategies from the Evolution of Ride-Hailing in SE Asia"

Michael Jacobides, London Business School
"Why Do Responses To New Ecosystems Differ? OEM Divergence to The Ride-Hailing Threat"

Masato Itohisa, Hosei University:
Knowledge exploration toward radical innovation: How existing firms and new entrants build their CASE-related technologies

Johan Wallin, Synocus (Finland)
"Ecosystem Orchestrators: Using Temporary Business Models for Capability-Building"

John Paul MacDuffie, Wharton School, U. Pennsylvania
"Connecting the Ground and the High Sky: Automotive Data Networks from CAN to Ethernet (Internal) and from DSRC to 5G (External)"

PVMI Conference: “The New Mobility: Opportunities and Challenges,” co-hosted by Manufacturing Management Research Center (MMRC), University of Tokyo, November 17, 2018

- “Connecting the Ground and the High Sky: Competition and Collaboration in the Integration of Digital and Physical Technologies,” Takahiro Fujimoto, U. Tokyo and John Paul MacDuffie, Wharton School, U. Pennsylvania
- “From Electromobility to Autonomous Mobility in Europe: What Is Ahead?” Christophe Midler and Remi Maniak, Centre de Recherche en Gestion (CRG), Ecole Polytechnique
- “Honda's Initiative on Automated Driving - Current Status & the Future”, Yoichi Sugimoto, Senior Chief Engineer, Automobile R&D, Honda Motor Co.
- “The Five Most Critical Research Questions in Mobility,” James P. Womack, Founder and former President, Lean Enterprise Institute and Charles Fine, MIT Sloan School and Dean of the Asia School of Business
- “What are Ecosystems and Why Should We Care?” M. Jacobides, London Business School
- “OEM Partnerships in Urban Mobility Ecosystems,” Dominic Ong, Head of Automotive Partnerships, Grab; David K. Goh, General Manager, Daimler Mobility Services; Klaus Meder, President, Robert Bosch Japan; Nina Teng, London Business School
- “New Mobility Services Beyond Ride-Hailing,” Emilie Potvin, Head of Public Policy & Gov’t Relations, North Asia, Uber; Hamid Akbari, CEO, Velocia; Kay Woo, CEO, TADA
- “Public-Private Partnerships in Urban Mobility Ecosystems,” Yiting Lin, Executive Director, Singapore Economic Development Board; Hidetada Higashi, Associate Professor, Yamanashi Gakuin University; Johan Wallin, Managing Partner, Synocus Group; Tatsuro Imai, Senior Deputy Director, City Bureau of MLIT Japan

Academic Symposia w/ industry practitioners, organized by IMVP (MIT) & PVMI (Wharton, UPenn)

Academy of Management (2011), San Antonio, “Davids & Goliaths in the Global Automotive Industry: New Technologies and New Entrants From East & South”

Academy of Management (2012), Boston, “Innovation and Strategy in the Global Automotive Industry”

Academy of Management (2013), Orlando, “From (Auto)Mobile to Mobility: Technological Change and Innovation in the Global Vehicle Industry”

Academy of Management (2014), Philadelphia, “From (Auto)Mobile to Mobility: Technological Change and Innovation in the Global Vehicle Industry

Academy of Management (2015), Vancouver, “Beyond the Automobile: Car Sharing, App-Based Transport Networks”

Academy of Management (2016), Anaheim, “Beyond the (Traditional) Automobile: New Capabilities and New Paradigm?”

Strategic Management Society (2016), Berlin, “The mobility sector on the verge of transformation: Challenges for firms and new directions for strategy research”

Strategic Management Society (2016), Berlin, Extension Conference at EUREF, “Innovation Ecosystems And Public-Private Partnerships For Sustainabile Mobility”

GERPISA (2017), Sao Paolo, “Who Drives the Change? New and Traditional Players in the Global Automotive Sector”

Automotive Policy Research Center (2018), Toronto, “The New Mobility”

Academy of Management (2018), Chicago, “Studying Fast-Moving Vehicle & Mobility Ecosystems”

Strategic Management Society (2018), Paris, “Competing in a Shifting Landscape: Disruption and Strategic Options in the new Mobility Ecosystem”

PVMI International Colloquium (2020), Paris, Planning Meeting for “Benchmark of Electric, Connected & Autonomous Mobility” (BECAM) Initiative

GERPISA and PVMI Joint Conference (2022), Ann Arbor and Detroit, “The Auto Industry Entering a Post-Pandemic World”

Academy of Management (2023), Boston, “Learning from Automobiles and Mobility Services: Modularity, Ecosystem Structure and Value Migration”

Appendix B: Interviewees for the final stage of the project: Focused interviews (incomplete)

Hamid Akbari, CEO, Blanclabs, President, Velocia

Aakash Arora, managing director and partner, Boston Consulting Group's Automotive and Mobility Practice

John Casesa, former Group Vice President, Global Strategy, Ford Motor Company, currently Senior Managing Director at Guggenheim Partners

Brian Collie, managing director and senior partner, Boston Consulting Group's Automotive and Mobility Practice

Iain Forbes, Head , UK Government's Centre for Connected and Autonomous Vehicles

Jon DeGaynor, former CEO, Stoneridge Inc., current board member Racing and Performance Inc.

Michael Granoff, Founder, Maniv Mobility

Michael Hurwitz, Director for Innovation, Transport for London

Petr Knap, Senior Advisor, CEE Automotive, EY Consulting

Laurent Kocher, Executive Vice President for Marketing, Innovation and Services, Keolis.

Satoshi Komiya, Senior Partner Boston Consulting Group, Head for Automotive OEMs, Japan

Joerg Lamparter, CEO Mooveo and COO, Operations and Digital Solutions, Mercedes-Benz Mobility

Nikolaus Lang, Senior Partner Boston Consulting Group, Head, Global Advantage Practice

Tu Le, Sino Auto Insights

Alex MacKenzie-Torres, Vice President of Business Development and Innovation, Toyota Research Institute

Glenn Mercer, independent automotive researcher, former McKinsey partner for automotive sector

Christophe PINEAU, Senior Vice President of PSA PEUGEOT CITRÖEN

Harald Proff, Global Automotive Sector Leader, Deloitte

Angela Priest, former senior vice president of strategy and innovation at wejo & senior manager at J.D. Power

Nick Reed, Head of Mobility R&D, Bosch

Kevin Reynolds, Executive Director, Business Strategy, Ford (Europe)

Arwen Smit, Co-founder, DOVU and MintBit

David Winterstein, CEO, Velocia

Peter Zhou, former Executive Vice Chairman, Telematics@China and Dean of Tencent Academy of Mobility

Appendix C: Key words used in Internet searches (partial)

Topics:

Electric vehicles, cars, transportation, mobility (EV)

EV batteries, battery electric vehicles (BEVs)

EV revolution, transition, regulation

CASE technologies

Connected cars, connectivity, Apple CarPlay, Android Auto, Android Automotive, Amazon echo auto,

Autonomous vehicles, autonomous driving, autonomous vehicles, driverless cars, remote driving, self driving cars,

Mobility services, shared services, ride-hailing, peer-to-peer,

EV charging, charging stations, charging infrastructure, superchargers

China - EV industry, charging investments, government subsidies, growth of market, exports

EU and US - zero emission vehicles, regulation, import restrictions, import tariffs, localization of battery supply chain

Firms:

Tesla, BYD, CATL, GM, Ford, Hyundai, Renault, Toyota, VW, Uber, Lyft, Didi, Grab, Ola, Turo, Zipcar, Electrify America, EVGo, Blink, nVidia,