Revisiting Disruption:

Lessons from Automobile Transformation and Mobility Innovation

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ABSTRACT

Will the ongoing transition from Internal Combustion Engine Vehicles to Battery Electric Vehicles (BEVs) disrupt the incumbent automaker manufacturers, and lead to a new, modular production structure with new players, including value migration towards battery makers? What about the rise of various Mobility-as-a-Service firms leveraging connectivity and software prowess? While projections on the decline of automotive incumbents from pundits and analysts abound and the rhetoric of disruption is rife, a closer look reveals a subtler picture. Using the automotive sector and its adjacent mobility ecosystem, we critically consider the nature of technological disruption and how it affects the existing industrial order. We find that BEVs are not as modular as predicted, which is in turn reflected in both organizational structure (of assembly) and industry architecture in spite of efforts to modularize by some new entrants. In the broader mobility ecosystem, we discuss how efforts of Big Tech firms and ride-hailing companies to advance the CASE (connected, autonomous, shared, electric) vehicles will impact the automakers and what they are doing to defend their value proposition. In so doing, we put forth a thesis to temper undue enthusiasm with disruption. Specifically, we propose a third way of looking at innovation in addition to the classic dichotomy of Schumpeterian Mark I and Mark II, which represent disruptions through innovative (de novo) entrants and persistence of leading firms' dominance through their internalization of innovation, respectively. This structure, which we dub "Mark III", is characterized by a much tighter connection between incumbents and new entrants, with incumbents acquiring, allying with, and forming ecosystems around such agents of change. Mark III, prevalent in cases of blurring industry boundaries also sees an increasing role of incumbents in sectors powered by data, digital analytics and access to the customers (a.k.a. Big Tech) in the new industrial order, though here, too, this works through a collaboration with existing leading firms. This helps us contextualize and expand onto recent work on "disruption through complements", and offer some bounds to the expectation of disruption, while raising concerns about the exercise of market power. We argue that focusing on such Mark III dynamics will help us better understand the increasingly common morphing of physical goods with digital elements taking place in various contexts.

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? 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?

Drawing on the evolution of the automobile sector and its broader context, mobility, 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 (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), sometimes irrationally, 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, and Righi, 2020).

In this paper, we provide a sectoral 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)—and use mobility to showcase the particularities of the digital world (Adner & Lieberman, 2021) in the broader context of mobility services. We synthesize findings from recent papers on automotive production and the shift from internal combustion engine vehicles (ICEVs) to battery-operated electric vehicles (BEVs) such as 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 the shift from ICEVs to BEVs changes the underlying technology of production and interdependencies in the sector, (b) how these shifts alter the Industry Architecture (IA), and (c) the consequences in terms of "winners and losers." To a lesser extent, we consider the (still-emerging, not yet commercialized) developments with fully autonomous vehicles, the most potentially disruptive technological change, from the point of view of our broader argument.

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 I" innovation) and his later perspective (Schumpeter, 1945) where leading firms internalize innovation to perpetuate their dominance ("Mark II"—see Breschi, Malerba, & Orsenigo, 2000). We find that the emergence of innovation – and subsequent competitive dynamics - seen in many contemporary sectors, including automobile production, or webs of sectors including mobility, belong to a new category that we dub "Mark III." In this development path, which embodies elements of both Mark I and II, 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. It also relies on incumbents in some sectors (especially those powered by data and access to the customers) to expand onto other sectors, as illustrated by the Big Tech expansion onto "multi-product ecosystems" (Jacobides, 2022). This more evolutionary and less revolutionary pattern expands the canon of innovation research (Breschi et al., 2000).

Widening our view from automotive to mobility services in general, we then consider the shift from automotive services to Mobility as a Service (MaaS). With MaaS, technology giants seek expansion into adjacent sectors, ride-hailing businesses and other digital startups bid for a place in the ecosystem, and drivers and car owners enter the frame alongside automotive manufacturers (Llopis-Albert, Rubio, & Valero, 2021; Kivimaa & Rogge, 2022; Zhao & Malikopoulos, 2022). Applying Adner and Lieberman's (2021) valuable typology of disruption in substitutes vs. complements, we find that while disruption may be easier in the context of complementary services, incumbent carmakers (usually known as Original Equipment Manufacturers or "OEMs") are very much involved in such services as both actors and investors. We argue for setting some limits on speculation over the potential dynamics of the sector and how radically different its future is likely to be. We also identify the crucial role of regulation—an underrated force in shaping the dynamics of industry structure and value migration.

2. The Automotive Sector as a Testbed for Theoretical Development in Management Research

By any measure, Tesla's success has been remarkable. The firm's market capitalization easily eclipsed all traditional OEMs and briefly made its maverick owner the richest man on earth—even though nearly all its revenues, for many years, came from OEM payments for government-imposed regulatory credits sold by Tesla itself, and until 2020 it lost money on every car it made (Isidore, 2021). The wider 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. Over 10 million BEVs were sold worldwide in 2022, and sales are expected to reach 14 million in 2023, expanding BEVs' share of the overall market from around 4% in 2020 to 14% in 2022 (IEA, 2022). This explosive growth has not gone unnoticed by the financial markets, where BEV firms' market cap has outweighed that of traditional OEMs since 2019. There is also optimism for battery-related firms, as market valuation of these firms are expected to reach US$365.4 billion by the end of 2031, with many analysts expecting around 20% CAGR in global market size between 2023 and 2031 (Transparency Market Research, 2023). Together, these numbers suggest a strong belief that BEV entrants will ultimately outperform incumbents and that battery makers will prevail in terms of value creation.

For the skeptics, this excitement over disruption and dislocation is all too familiar. Indeed, such fervor has often turned out to be misplaced—like the ’90s excitement over the rise of mega-suppliers who were expected to upend the industrial order, yet ultimately proved incapable of transforming either the architecture of their sector or the concomitant value migration (Jacobides et al., 2016). This time, however, pundits insist it will be different (LaMonica, 2012; Murphy, 2020). But why should this be so? And how can we marshal evidence from the industry to both test and advance existing theory?

The automobile sector has long served as a distinguished laboratory for management research and practice. 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 (Klepper, 2002).

In *The Machine that Changed the World*, Womack et al. (1990) recount how the MIT-based International Motor Vehicle Program enlightened us about “lean production” (a term it coined) and associated management practices, disentangling the idiosyncrasies of Japanese management from a new way to organize production that was diffusing globally. More recently, analysis of the automobile sector has been crucial in understanding modularity (Campagnolo & Camuffo, 2010; Cabigiosu, Zirpoli, & Camuffo, 2013; MacDuffie, 2013). It has also shed light on the dynamics of value migration (Jacobides & MacDuffie, 2013) and the interplay between agency and structure that drives the architecture of production and the distribution of value (Jacobides et al., 2016).

After over a century under a single dominant design (the internal combustion engine vehicle or ICEV), the automotive sector is being challenged by the emergence of a new technology—the battery electric vehicle (BEV). 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). Recent research, though, 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.

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. This also opens up new opportunities for considering how mobility challengers such as Grab were able to challenge traditional actors while also enlisting their support, and how strategic change takes place in such high-velocity settings (Teng & Jacobides, 2023).

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 I" model and his later revision "Mark II," 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; 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 I" and others with "Mark II" (Fontana, Martinelli, & Nuvolari, 2021).

The literature on industry evolution considers how firms draw on process or product innovation (Klepper, 1996; Aggarwal, Audrestch, & Sarkar, 2007), leading to an industry life-cycle comprising early growth, variety, shakeout, and finally consolidation. The implication is that industrial change "resets" the life-cycle clock, setting off a new wave of entry that is followed by consolidation, presumably by new actors. 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 corporate heroes 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 has probably 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). 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 a wide range of sectors including automotive, Birkinshaw (2023) shows that incumbents are able to 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 success 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)- even though research argues that architectural innovation may *require* re-integration (Jacobides & Winter, 2005; Cacciatori & Jacobides, 2005; Helfat & Campo Rembado, 2016). Be that as it may with modularity, 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). This accelerates experimentation without any necessary coordination from a central organization, leading to significant entrepreneurial entry (Funk & Luo, 2015). Even in the context of an ecosystem, innovation can occur in the absence of a hierarchical structure, given orchestrators that help align the different modules (Jacobides, Cennamo, & Gawer, 2018, 2023).[1] Modularization is thus expected to transform dynamics at the level of the sector. In the automotive industry, this generated 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. We will consider this later in the context of our evidentiary basis.

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 et al., 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

[1] 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).

existing asset base and cement their leadership (Fixson & Park, 2008). In a paper illustrating the key ideas of the IA literature, Jacobides, MacDuffie, and Tae (2016) examine the struggle in the automotive sector. 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 has changed the automotive sector and value distribution within it (Murmann & Schuler, 2023).

Finally, a more recent stream of work relates to *changes in complements.* Adner and Lieberman (2021) note that disruption often arises not from specific substitute products or technologies, but from a proliferation of *complements.* As a result of digitalization, and its power to connect previously distinct sectors into webs of interrelated products and services, we now see important changes such as the ongoing transformation of many industries based on physical goods into ecosystems in which products serve as platforms for a digital overlay of services. With respect to the automotive sector, this is exemplified by Mobility as a Service ("MaaS") (Avramakis, Anchen, Raverkar & Fitzgerald, 2019). Using the MaaS space as an illustration, Adner and Lieberman (2021) argue that complementor innovation should not be ignored or overlooked by focal firms lest they be dethroned. They demonstrate three distinct strategies by which digital complementors who initially work cooperatively with OEMs specializing in the physical product can become competitors. In the most disruptive scenario they outline, in which a digital operating system (a "brain" for the vehicle) becomes essential and the OS of a digital-native complementor wins widespread adoption, once-dominant automobile OEMs could be rendered secondary and dependent as the value of their assets is eroded and the complementor takes over the system integrator roles they previously filled.

This recent work sketches out the different types of disruption but stops short of working through the implications in terms of winners and losers. There is a loose expectation that new entrants in the complementor space may be able to leverage their strength, and some research (Teng & Jacobides, 2023) documents how total outsiders manage to overcome formidable obstacles to build a position of strength. Yet, this still leaves open the broader Schumpeterian question of who should be able to benefit in this broader-than-the-sector, complements-included picture. Indeed, even the question of who the focal ecosystem orchestrator will be is not resolved. As evidenced by recent research (e.g., Svahn et al., 2017; Halveston et al., 2018; Reischauer et al., 2023; Teng & Jacobides, 2023), legacy OEMs are actively taking steps both to protect their product-related advantages and to acquire or develop the digital capabilities to compete with non-automotive sector participants. Relatedly, the role of complementors such as charging stations, dealership networks, and insurance companies in shaping the evolutionary trajectory of the emerging ecosystem (Murphy, Pütz, Mullins, Rohlfs, Wrana, & Biermann, 2019; Adner & Lieberman, 2021; Anderson, Bhargava, Boehm, and Parker, 2022) is an important question that can inform and complement our current understanding of ecosystem and platform governance (Jacobides et al., 2018). That is, the emergence of an ecosystem based on physical vehicles can shed light on whether and to what degree digital transformation unfolds uniformly across all settings (Yoo et al., 2010; Reischauer et al., 2023).

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 also that new, modular technologies will drive sectors towards the fate of the PC sector (Baldwin & Clark, 2000), where profound structural disruption heralded significant value redistribution and the emergence of new bottlenecks (Ethiraj, 2007) and kingpins (Jacobides & Tae, 2015). Historically, the automobile sector anticipated several waves of disruptive change that never arrived (Jacobides et al., 2016). Yet, BEVs are still expected to deliver such a transformation—even though, as we shall see, the actual change to date has been far less extensive than is generally perceived. Is this misapprehension due to a misapplication of existing theory, or have our theoretical frameworks themselves led us astray? As we contemplate the "high-level" question of continuity and concentration, as articulated by Schumpeterian researchers, can we articulate a third canonical set of dynamics, as exemplified by today's automotive sector, and dub them "Mark III"?

Moreover, we see significant changes of a different nature, in the shift to MaaS, where the theoretical framework is newer and less developed. Here, we can draw a more grounded understanding of how incumbents and new actors engage when technology changes and new opportunities arise. Again, we will argue that we must distinguish among the changes to emerging roles in the sector and ask who carries them out. How do these changes relate to the ability of incumbents and entrants to succeed? In other words, how should we change our approach to industry dynamics (and our view of "Mark III") when it comes to innovation in *complementary* segments?

4. The Transformation from ICEVs to BEVs: Changes in the IA

The transition from ICEVs to BEVs has been 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, which constitutes 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 related technologies of autonomy and connectivity relying heavily on software (e.g., telematics, 3D mapping, 5G Wi-Fi) and hardware new to the auto industry (e.g., cameras, sensors, LiDar, edge computing CPUs) and platform business models (e.g., Uber/Lyft/Didi, Turo) providing mobility services (Helveston et al., 2019; Bai & Velamuri, 2021), all the elements for disruptive digital transformation appear to be in place (Yoo et al., 2012; Reeves, Bergman, Gourevitch, & Ortiz, 2016; Hanelt, Bohnsack, Marz, & Marante, 2021)—especially given the interest and investments of tech giants such as Alphabet and Apple in this sector (Keith & MacDuffie, 2020; Reischauer et al., 2023). In this view, the impact of new and more modular technologies on industry evolution and strategy will ultimately depend on whether it is harder for incumbent OEMs to cope with the challenges of digital transformation or for tech firms to learn to become global manufacturers (Adner & Lieberman, 2021; Murmann & Vogt, 2022; Reischauer et al., 2023).

The transition to BEVs is commonly characterized as a shift in dominant design away from ICEVs after a century of stability. It is then further characterized as a shift from a primarily integral architecture to a fundamentally modular one. Early evidence suggests that the claim about dominant design is on the mark, but that initial moves towards electrification are more often characterized by increased integration in both product and production architecture than by modularity. All aspects of the architecture are in transition, however, so we will aim to assess the trajectory of change and not merely current facts.

Confusion in interpreting these trends 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 1000 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 demonstrably 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.

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.

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. The misguided presumptions about BEVs driving modularity, which overestimate new entrants' capacity to compete, may be the result of the selective or superficial application of the knowledge we have accumulated so far.

Looking at the structural/IA strategies of individual firms, we also observe significant heterogeneity, which might also reflect "the few exceptions against the established and emerging norm." 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 mobility 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 an innovative BEV OEM in its own right and has announced three models (a sedan, SUV, and city bus); and three, it was the initial orchestrator of the Mobility in Harmony (MIH) ecosystem.

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 2,673 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 towards modularity (MIH Consortium, 2023). 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). Overall, Foxconn seems intent on rivaling the existing way of producing BEVs by sponsoring an entire ecosystem that will be able to counter the established status quo—suggesting that different ways of organizing may coexist even within a single IA.

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-primary firms such as BYD (a battery maker that got into automotive manufacturing via acquisitions and now challenges Tesla’s #1 sales position), 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—possibly more so.

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 (cf. Jacobides & Tae, 2015; Hannah & Eisenhardt, 2019; 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.[2]

Third, production is occurring entirely in wholly owned assembly plants rather than via contract manufacturing (Alochet, MacDuffie, & Midler, 2023a). 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. However, this is not to say that manufacturing processes will never change. Tesla's manufacturing innovations (such as a three-piece chassis design with massive giga-castings for the front end and back end and the battery module in the middle – rather than the status quo stamping and welding) are being closely followed by incumbent

[2] CATL received considerable financial assistance from the Chinese government, either directly or indirectly via subsidies given to the Chinese OEMs purchasing CATL batteries. Also CATL 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 also innovated to improve 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 now in the US) as well as most Chinese OEMs and they now occupy a prominent place in the battery strategies for the OEMs now closely overseeing production of their own batteries, e.g., GM, Ford, and VW.

OEMs and increasingly imitated, even by Toyota. Yet these innovations, even when they advance modularity in production, are still vertically integrated and aren't necessarily mirrored in more modular designs.

As we consider the coexistence of integrated and modular architectures for BEVs, we must acknowledge two factors. First, the purely modular approach as pursued by Foxconn and MIH is only just being undertaken—and it reaches beyond BEV to pursue a strategic vision tied to the full set of CASE technologies (Connected Autonomous Shared Electric). It is too early to evaluate this vision, and premature to assume that it will fail. 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. Strategically and organizationally, integration is often chosen during a period of learning about and mastering new technologies (Jacobides & Winter, 2005; Cacciatori & Jacobides, 2005). Once this initial learning period is over and the competition among alternative product and production architectures is resolved, a shift to greater modularity could ensue, possibly leading to a change in industry architectures (Jacobides, 2005).

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, 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. While value migration is undoubtedly important (Jacobides & MacDuffie, 2013, Hannah & Eisenhardt, 2019), it is not all that pervasive—partly because, at the level of the sector, we see incumbents who are not acting as either of the two Schumpeterian extreme models (Marks I and II) would assume. These incumbents are not displaced by new waves of entrants, with their model of production obliterated—but neither do they dominate all innovation. Rather, pushed by new developments, they react through a combination of organic expansion, acquisitive growth, and close alliances with key suppliers (e.g., of batteries), following what we call the "Mark III" model of industrial renewal.

Insert Figures 1a and 1b about here.

5. Who Stands to Win and Lose in the Transformation from ICEVs to BEVs?

To address the disruption question—not just "how the sector looks," but also "who benefits"—we need to consider the evolution of old and new capabilities in incumbents and entrants alike and develop a composite view, informed by theory, of how the sector will evolve. While our predictions (like any others) may prove incorrect, we feel that the ability to articulate our expectations for the dynamics of failure and success in a sector is an important litmus test of our approach.

First, to consider the future dynamics in the sector, we need to set out a perspective on the recent phenomenon of Tesla—by all accounts, the most successful BEV firm—growing from a 2008 startup with a single model (the $100,000+ Roadster) to a global manufacturer with four assembly plants projected to make almost two million vehicles in 2023. The market still values Tesla as a "Big Tech" firm with valuations that are 10 times those of legacy automakers such as Ford and GM. This is itself a critical factor in Tesla's success, alongside the government-based regulatory credits that have formed the vast majority of its revenues to date. Be that as it may, it has been the first OEM since Hyundai/Kia (founded in the 1970s) to join the exclusive club of "global automotive OEMs," given that the largest Chinese OEMs are not quite global as yet. This achievement required it to master a range of capabilities—product design, manufacturing, supply chain management, sales and distribution, after-sales service—as well as taking on the system integrator role that delivers a consistent value proposition to consumers and meets societal expectations in terms of regulatory compliance. No other BEV startup can yet make the same claim—promising new entrants Rivian, Nio, Xpeng, and Lucid have struggled with scaling up and mastering these same capabilities (Boigon, 2023a, b).

So Tesla's achievement should not be underestimated—but nor, in our view, should it be overestimated. The firm's sky-high valuation appears to rest on two assumptions relevant to our analysis: (i) that it will continue to scale up at the rate its founder has promised; and (ii) that it will dominate the "autonomous and connected" vehicle space as thoroughly as it has dominated the BEV space so far. Focusing on the first assumption, legacy automobile OEMs suffered the implications of a fragmented software infrastructure (which we discuss in more detail below), whereas Tesla developed a fresh, made-for-purpose software-centric vehicle design from its early years—but this source of advantage may wane over time. This may dent the firm's ability to capture market share.

Furthermore, consider the global automotive market and the announced goals for electrification. Worldwide, close to 100 million new vehicles are sold each year; ambitious policy goals aim for 30% of them to be BEVs by 2030 and 50% by 2040–50. Even by Tesla's most optimistic forecasts, it would only manufacture 20 million vehicles by 2030, attaining twice the size of present-day Toyota or VW.[3] This is only 20% of global auto sales, and two-thirds of the BEV sales goal—not enough, given the urgency of climate concerns.

With government policy around the world now converging on incentives to speed the transition to electrification (see below), there is a golden opportunity for Tesla's rivals to win a sizeable portion of this demand. Over 200 new BEV models are being launched in 2023, with another 180 planned for 2024 (Economist, 2023); while not all will succeed, we still anticipate that Tesla's market share will

[3] Many analysts think it is more realistic to envisage Tesla building 6–8 million vehicles a year by 2030. Even this would require it to overcome diseconomies of scale and the disadvantages of its current limited product range. With only five models (including the Cybertruck), two of which (Model 3 and Model Y) account for 95% of its sales, Tesla could only hit its target of 3–4 million sales per year if those models had 50% market share in their segment ($40,000–$60,000 mass market sedans and $45,000–$65,000 SUVs). No carmaker has ever had more than 10% in those two segments (*Economist*, July 18, 2023).

take a substantial hit. While Tesla's demonstrated willingness to cut prices may slow the decline, it will also eat into the high margins that have earned such staunch loyalty from investors.

Which firms will benefit in this "rising tide lifts all boats" scenario? We anticipate that some legacy ICEV OEMs, some pure-play BEV firms like BYD (which transitioned quickly away from ICEVs after acquiring the firms that provide its automotive capabilities), and some new entrants will do well—and others will fail. Rather than attempt precise predictions, we offer some theoretically grounded speculation based on the capabilities needed to survive and thrive.

Furthermore, 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 that survive the electrification transition will be those that 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.[4]

In terms of product positioning, startups at the premium end of the BEV market will have decent survival prospects if they produce a product that wins acclaim and generates consumer excitement. Yet they will still need to master the rest of the capabilities that every automotive OEM needs. Premium pricing potentially allows fat margins and access to consumers who are less sensitive to price—but scale is difficult to achieve, forcing these firms to offer successive products at lower price points. This is the Tesla playbook, but so far, no other firm has been able to execute it fully (Boigon, 2023a, b). Rivian and Nio are burning cash while production languishes below forecasts; Xpeng's

[4] 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; so far, GM has said it will not follow Ford, given its perception of the greater advantages of integration at present.

production numbers are dropping; and Lucid is priced so high that is likely to stay a niche producer. In short, earlier predictions that Tesla's success would provide the template for many more successful BEV startups (Perkins and Murmann 2018) now appear unwarranted.

Meanwhile, the low-priced end of the product spectrum is challenging for startups, in spite of the urgent need to tackle the affordability challenge given the stubborn reality of high battery prices. Despite the ferment in battery design and experimentation with new chemistries, we see no "Moore's Law" breakthrough on the horizon for batteries vis-à-vis a price/performance ratio that would fuel disruption in the classic Christensen mode: low prices coupled with performance that begins below what incumbents can provide and then exponentially improves. Instead, the success of Chinese OEM BYD appears to offer the template for offering BEVs at lower price points. Here the key is designing small, lightweight vehicles with wide variety in form factor and functionality, all produced at high scale with pre-established supply chains for batteries and supported by excellent battery management system software that helps extend range.

Incumbent legacy 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 require 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, 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.

This rosier picture for incumbents has an important proviso, and one that may undermine their dominance. One important capability shared by pure-play BEV entrants is that they all leverage an innovative software architecture that potentially allows them to outpace incumbents. The disruptive concept for vehicle development is to start with the software (i.e., a vehicle operating system) and build the hardware around it. The goal is to start with Firmware Over The Air (FOTA) updates, wide connectivity to almost everything, vehicle-wide energy management, and autonomous driving as native software functions, all informed by the application of AI and machine learning to data collected from past and current vehicles.

In contrast, incumbent OEMs have historically taken a function-by-function approach to developing software. Integrating across these functional silos is a difficult task that these legacy OEMs have begun to tackle, but it is a fundamentally different approach to start with an overarching and integrated software system design before enabling its control of physical components. This raises the question of whether incumbents will be able to develop the capabilities to compete in software-centric mobility as they have, so far, been able to do with electrification.

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. Jim Farley, the CEO of Ford Motor Company acknowledged the problem in a recent interview as the following: "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). The challenge of in-house software is that Ford, just like other ICEV

OEMs, lacks the appropriate talent that will be too time-consuming to develop organically from scratch, not to mention the risks involved. As more incumbents struggle and try to address the dual issues of lacking software R&D and relevant talent, we may see more partnerships and investments in the form of equity investment, joint ventures, and M&A by these incumbent OEMs.

The creation of the Mobility-in-Harmony (MIH) consortium, as mentioned above, is premised on the idea that software-defined vehicles will be best achieved via an open-source software approach, in part to avoid the massive cost duplication of each OEM developing its own vehicle operating system to integrate connectivity, autonomy, and electrification. MIH draws upon an existing global open-source software initiative governed by the Autoware Foundation in Japan. As yet, it is too early to tell whether Autoware's full software stack will be adopted by MIH members or if its stem will be the starting point for proprietary operating systems. Either way, however, this approach to software-defined vehicles is a distinctive challenge to the OEM-centric approach to product development. In a very real way, incumbents' survival will depend on their ability to leverage their existing approaches or adopt those of their rivals. We explore this further below when considering the complex relationships between OEMs and complementors providing mobility services.

Predictions and implications for theory. Based on the above, we predict successful competition from legacy ICEV OEMs during the transition to BEVs, for three reasons. First, OEMs' system integrator capabilities continue to be highly relevant both in optimizing new BEV designs and in all other ongoing design changes linked to new technologies and new consumer wants/needs. Second, OEMs can build on past investments in the knowledge needed for electrification, based on a time-honored R&D investment strategy of "know more than you build" (Brusoni, Principe, & Pavitt, 2001). Most of the largest global OEMs hold a surprising large number of patents related to batteries and electrification, despite only recently moving into the commercialization of those technologies. Finally, OEMs also know how to deal with legal liability and regulatory requirements linked not only to electrification but also the emerging technologies of connectivity, autonomy, and shared mobility services. On the downside, we also find that incumbents are missing a critical component: software capabilities. This will remain the key open issue for them and might pose the biggest threat to their ability to capture value and continue their dominance. Their ability to do so may hinge on their link with emerging complementary segments, whether structured through a collaborative ecosystem or not.

This is an illustration of "Mark III" dynamics, whereby incumbents are more or less able to adjust and adapt to significant change, despite the (empirically unfounded) rhetoric on "disruptive change" (Birkinshaw, 2022, 2023). Incumbents pursue Mark III by leveraging the new technologies produced by startups, acquisitions, alliances, and assimilation, as well as links to emerging, orbital but associated ecosystems that clearly raise additional issues of their own. For example, as explored further below, incumbent OEMs now allow data from their vehicles to be aggregated by one of several data intermediaries who anonymize the data and return it to all customers for analytic use, particularly in the training of autonomous vehicle software. Without going it alone (as Tesla does, given its headstart in product sales) or joining an open-source consortium (such as MIH), OEMs are finding ways to accumulate access to valuable complementary resources without ceding control of the data to the complementors.

All told, these developments suggest that this will not be an industry revolution, but rather an evolution. Some incumbents will make the transition successfully, as will some start-ups, with plenty of failures in both categories. This "Mark III" pattern, which might more aptly be called "Mark 1.5" as it sits between Schumpeter's "Mark I" (entrepreneurial creative destruction) and "Mark II" (established firms dominate) may characterize sectors well beyond cars.

In the Mark III pattern, incumbents start by "knowing more than they make" via massive R&D investments. Subsequently they undertake exploratory initiatives to learn about new technologies (e.g., Ford investing in Rivian; Toyota investing in Uber and Grab); they acquire startups to boost their capabilities in key areas (e.g., GM acquired Cruise; Ford acquired Argo); they ally with suppliers who control key components (e.g., battery cell suppliers) and establish alliances with legacy competitors to share investment burden and learn together (e.g., Honda and GM; BMW and Mercedes-Benz); and they work with complementors such as Google to offer new services but also to learn new technologies and business models, yet are prepared to draw lines in the sand (e.g., of the boundaries of the data that will be vs. won't be shared) as necessary, as Figure 2 illustrates for a traditional OEM, for Tesla, and for a core Tier-1 OEM Supplier, Bosch. Tech incumbents are doing the same thing, e.g., Google creating Waymo and established Android Automotive; Amazon acquiring Zoox and investing in Aurora, which earlier absorbed the assets of Uber's autonomous vehicle program.

Insert Figure 2 about here

What is distinctive to Mark III is this high level of interpenetration within and between sectors across legacy automotive incumbents; new entrant startups; Big Tech firms seeking adjacent entry opportunities; and specialists in CASE technologies, both hardware and software. Another distinct feature of Mark III (and the reason we preferred this terminology to Mark 1.5) is that it is characterized by dominant firms from other, data-and-technology based segments which try to extend their dominance in managing customers' experience onto established sectors, to enhance their "multi-product ecosystems (Jacobides, 2022). The current angst amongst OEM leadership revolves around Google and Apple's efforts to expand their customer immersion in cars, rendering cars yet another arena that allows them to connect to customers and offer them customized solutions, commoditizing other participants along the way. Thus, Mark III also raises important questions not just in terms of strategy, but also on competition and antitrust (Jacobides & Lianos, 2021).

6. From Automotive to Mobility: How do Bundles of Complements Change the Picture?

So far, we have focused on trends affecting vehicles *qua* vehicles, i.e., the physical objects that provide mobility. But what of the vehicle as a platform for mobility services? Here, mastery of physical products and processes is less important, as evidenced by the experience of Chinese BEV start-ups (Helveston et al., 2019). The modularity inherent in mobility service applications that operate on a multi-sided platform is much better suited to the capabilities of tech giants, which are indeed sniffing around the possibilities in the sector. Adner and Lieberman (2021) elaborate their distinction between disruption in substitutes and in complements through a detailed analysis of the automotive sector and its connection to mobility services. They review the nature of technological changes relating to CASE technologies and consider the distinct features in terms of disruption through complements, looking at services such as ride-hailing. They suggest that firms entering a mobility ecosystem as complementors could siphon value away from firms that design and produce vehicles—a view echoed by Anderson et al. (2022), who argue that "electric vehicles are a platform business" given complementarities with charging services and the underlying infrastructure.

In the future, physical vehicles are likely to be connected and electric with some degree of autonomy. While they will not be highly modular in themselves, the services offered via vehicles-as-platform and MaaS probably will be. How do we make sense of such a scenario? A classic example of manufacturing prowess is morphing and merging into what may become an epitome of digital transformation and servitization, raising interesting questions about who, if anyone, will end up dominating the mobility ecosystem. Will technical and strategic bottlenecks emerge in physical manufacturing, in the integration of software that provides autonomy and connectedness, or somewhere in between (Bohnsack, Pinske, & Kolk, 2014; Svahn et al., 2017; Lopez-Vega & Modysson, 2023; Reischauer et al., 2023)?

In a future world that runs on CASE vehicles, which firms from which sectors will provide overarching governance, and how will value be distributed among central hubs (platforms) and diverse complementors? Might we see, for example, an uneasy truce or carve-up between automotive OEMs and Big Tech? The advantage of studying mobility is that we already have a base of robust evidence to draw on, allowing us to explore the fascinating strategic, technological, and organizational dynamics of "phygital" (physical + digital) sectors. Yet again, automobiles and mobility are poised to help us push the boundaries of our theoretical understanding.

First, we should reflect on the challenge of bringing mobility services into vehicles, which has several facets.

In-vehicle user interfaces. Historically, automakers were slow to bring mobile phones into vehicles once the technology had become available. While they drew criticism for missing an opportunity, they were facing the certainty of installed phone hardware becoming obsolete, since mobile technology was evolving much more quickly than the design cycle or replacement frequency of automobiles. Today, the unavoidable reality of automobiles having a slower clock speed than digital devices makes obsolescence an ongoing concern for legacy OEMs.

As vehicle owners brought their cell phones into cars, raising new risks of distracted driving, the automakers' search shifted to connected services, i.e., access to outside vendors that could respond on demand to a driver's needs, from faster emergency response time after an accident and navigation advice to guides to local attractions and infotainment. Both relied on advances in vehicle connectivity and in the telecom infrastructure.

The advent of smartphones brought a new demand from consumers: the ability to hook up their device to the vehicle, mirroring its screen on a larger and visible-while-driving display offering easy access to their favorite apps, from Google Maps to music streaming services. Initially, automakers responded by developing proprietary user interfaces, insisting that they had to control the interaction with the customer to gain more "share of wallet." Unfortunately, the software was not executed to the same standard as that on drivers' phones, provoking frustration and lower quality scores for new vehicles.

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. An early suspicious that Google was collecting data on vehicle speed via Android Auto was a key reason why Toyota, notably, chose not to install these operating systems until well after other automakers (Estes, 2015). But when vehicles with better OS integration began to receive much higher consumer ratings than those with automakers' own systems, even Toyota eventually gave in and began to offer both options as standard on all vehicles from 2020. This continues to be a competitive differentiator; Consumer Reports, as of 2023, ranks car brands on how well their in-car user interfaces link to these two operating systems.

Ford made a different strategy choice, opting to develop its own software partnerships to connect a driver's smartphone to the vehicle display and duplicate phone functionality on-screen via a (relatively) safe user interface. 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."

Meanwhile, 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—though notably not Toyota, VW, or GM, which are pressing forward with developing their own internal vehicle software capabilities.

Indeed, 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 in order to offer (and gather data generated by) subscription-based software services. This strategic move is similar to the actions of InnoCar, an incumbent OEM that first cooperated with Apple and Google, then imposed barriers on what data the tech companies could collect, and ultimately developed its own apps (Reichauer et al., 2023).

Google is not standing still, of course. 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.

The OEM response has been mixed.

Android Automotive is being 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). Many automakers are not agreeing to adopt the GAS bundle at this stage.

What can't be easily known is 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; the autonomous "driver" being developed by Waymo is entirely separate.

Software for mobility services. Many believe that Apple and Google are ultimately aiming to offer the entire software suite for future electric and autonomous vehicles. Here, though, automakers are much less likely to yield to tech firms. Vehicles have already had software in them for decades, and a modern vehicle contains multiple wired communication networks, each with well-established standards and generally effective firewalls against hacking. This internal network, running on cables, is physically separated from the telematics-and-smartphone oriented external WiFi networks.

Automakers could accept, and even embrace, tech companies' operating systems for the external network while maintaining control over the internal one. But the tech companies will press for internal access too, seeing advantage and opportunity in the additional data they could glean. This is an important arena for competition that merits close attention. It will be affected by technological advances, company strategies, consumer responses, and possibly regulatory issues around privacy and who owns vehicle data.

Physical changes in vehicles to support mobility services. As Alochet et al., (2023b) observe, there is a wide range of possibilities in terms of the changes to physical product architecture that mobility services might require. Consider a usage-based business model for auto insurance that provides customized quotes 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), both Progressive and startup competitor Root Insurance now need only smartphone data to generate a usage-based policy. No physical vehicle changes are needed.

More obtrusive are new car rental business models, e.g., ZipCar, and Peer-to-Peer car sharing, e.g., Turo, that require moderate vehicle modifications to allow locking and unlocking from a phone app. Most radical will be the modification of vehicles to prepare them for autonomous robotaxi services; Waymo's retrofit of vehicles purchased from Jaguar, Lexus, and Chrysler installs a hardware suite that includes chips, sensors, cameras, and radar and lidar (light-based distance detection) units (and wipers to clean them).

While legacy OEMs would appear to have the advantage in any tasks involving physical changes, the capabilities needed to modify vehicles for mobility services are far less extensive than those needed to design and produce an entire automobile. Waymo already operates a small factory in Michigan that installs its self-driving hardware suite, while Avis (which owns ZipCar) is just one of the major rental car companies that is gradually converting its entire fleet to phone-based app-controls for access and operation.

Designing a hardware-plus-software system that performs flawlessly in autonomous mode does appear to favor integrative over modular design. Waymo, for example, after initially using third-party LiDar units, decided to bring LiDar design in-house, enabling it to reduce unit size and cost and improve overall system performance. In contrast, the MIH consortium is betting that it will be too expensive for each firm (e.g., Waymo, Cruise, Zoox) to develop its own autonomous driving hardware and software system; instead, it advocates the advantages of its own open-source, modular design, bidding to become the turnkey system of choice for smaller OEMs and other potential customers. Time will tell, but as with electrification, integration is dominating these early years for connectivity and autonomy.

Control of user data. OEMs have concluded that data collection is crucial to their sustained competitive advantage and that data will play a pivotal role in deciding their fate in the increasingly digitalized auto ecosystem (Svahn et al., 2017). 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).

As Reischauer et al. (2023) describe, Innocar's first competitive move against Apple and Google was to lock them out of internal network data on detailed operational metrics, the status of the vehicle interior, and the location and identity of vehicle occupants. The richest data set for vehicle-specific data is recorded on the CANBUS (the first hard-wired internal network) and OEMs have the easiest access to that data, putting them in the ideal position to decide who can utilize it and how.

Many OEMs are going far beyond data collected from vehicles they produce themselves, and have begun to acquire or invest in mobility-related tech firms in an effort to gather as much driver-related data as possible and leverage it into fee-based mobility services. One case in point is BMW's 2018 acquisition of ParkMobile, a contactless parking meter system that operates in North America. Also in

2018, Ford acquired TransLoc and Autonomic to develop internal capabilities related to transportation software and data management. In the same year, GM bought a 17.3% stake in Wejo, a British data, analytics and software-as-a-service provider that analyzes data from almost 11 million vehicles connected to the internet.

However, OEM strategies in relation to automotive “big data” beyond their own vehicles are changing rapidly. In 2019, BMW and its key rival, Daimler, formed a billion-euro joint venture to leverage the ParkMobile acquisition; the resulting PARK NOW Group promised to promote an all-electric, self-driving fleet of vehicles that would charge and park autonomously. However, in 2021, PARK NOW Group was sold. Ford also sold TransLoc to data aggregator Modaxo, while Wejo went public via a SPAC, showing that these “Mark III” strategies are often a vehicle for companies to experiment, learn—and sometimes exit.

These recent moves foretell a new ecosystem organized around gathering, analyzing, and reporting on user data. Modaxo, Wejo, and Otonomo offer the advantages of access to millions of miles’ worth of driving data, aggregated from multiple OEMs, and either anonymized or delivered to clients via customized arrangements that can include gaining driver permission to share certain personal information. These data intermediaries are likely here to stay, since they can scrub, standardize and organize data originally collected in different formats; there’s little benefit in OEMs working only with their own data (even though that has been Tesla’s approach from the start).

Yet the potential of a centralized data marketplace hasn’t yet been realized, for multiple reasons. 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 isn’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).

To the extent that these brief periods of ownership provided learning opportunities for OEMs, they may well have accomplished their primary purpose. This may be similar to the earlier investment by OEMs in ride-hailing services (e.g., Toyota in Uber and Grab, GM in Lyft and Turo, Daimler in Mytaxi, Hyundai in Grab and Ola). While the OEMs did not gain access to these MaaS firms' data or the algorithms, they did learn how to shift towards services while ushering in CASE technologies in their vehicles. The real test will come when OEMs roll out their own mobility services that compete with offerings from firms squarely embedded in the digital ecosystem of smartphone operating systems and apps. Will their software be found wanting (as per the discussion of software-defined vehicles above)? Will consumer demands for better technology experiences prove to be the area where OEMs are least able to compete?

From mobility to the theory on complementors

The rise of MaaS, especially in the form of ride-hailing or peer-to-peer car sharing, highlights the role of complementors who are well-established incumbents within a setting adjacent to the sectoral incumbents, and hence not subject to liability of newness. Adner and Lieberman (2021) highlight that complementors can commoditize the offering of the focal firms, directly enter their realm of value creation, or just have a superior offering through continued improvement, as discussed earlier. Complements such as vehicle software developers and MaaS providers have been projected to materially change the market share, value capture, influence, and control of the focal firms, i.e., OEMs, or market size altogether. Yet, so far, complements seem to fulfill the role of providing synergies to the focal firms with continuously improved offerings that enables OEMs to improve their offering and horizontal specialization of different firms perpetuate.

Complementors may end up being more sustaining, in a Mark III sense, than disruptive. Value is being created in new segments, and while there are clearly skirmishes to capture the joint value, with data ownership playing an important role, OEMs are so far able to maintain their share.

New entrants in such a "Mark III" scenario work mostly as complementors who support, rather than as true challengers of the existing industrial order, and they tend to be closely related to incumbents.

The same applies to incumbents from other areas – Big Tech who, like in other sectors, leverage their skills and customer relationship and interfaces developed elsewhere.

While Waymo has driven its fleet of vehicles for over a million miles without fatalities, Uber has abandoned its autonomous vehicle efforts. Similarly, Apple and Google both provide software that plays a crucial role in vehicles, but there are no signs of these 'software' complementors substituting or becoming direct competitors to OEMs, especially given that there are no contract manufacturers available to enable these complementors to build the physical vehicles and assume regulatory responsibilities and legal liabilities. In the meantime, OEMs have forged various partnerships, set up JVs, made equity investments, and carried out acquisitions to access capabilities they lack. In sum, the behavior of various participants in the automotive sector and mobility ecosystem thus far is in line with the way we characterized Mark III where dominant firms of different, but related contexts such as vehicle manufacturing, software development, and MaaS, move beyond their original context to create and capture value while not displacing or disrupting incumbents altogether.

7. Understanding the Role of Regulation and Policy in Shaping IA and Disruption

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).

The fast-emerging technology of autonomy has been relatively lightly regulated by comparison. This will start to change as the first wave of driverless robotaxis hits the road in various jurisdictions. In the U.S., the federal government has been unable to reach agreement on legislation governing how autonomous vehicles should be regulated and has instead negotiated limits on how many such vehicles can be tested on public roadways at this time. State regulations, particularly in California, have stipulated that the companies testing robotaxis provide information about every accident or traffic incident. Autonomous trucks raise even greater safety concerns, with some groups advocating that safety drivers be required in such vehicles for many years to come as the technology is refined.

Connectivity is dramatically affected by the status of 5G wireless networks in different operational domains. While infotainment and communication can withstand occasional dropouts, autonomous vehicles are more dependent on ongoing contact with GPS and detailed 3D mapping data. Two technologies that would greatly improve autonomous vehicles' ability to handle the most difficult "edge" cases are vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. The former would require agreement on a communication standard and the installation of transponders in all vehicles for full coverage. The latter requires major investments in infrastructure, but most governments have not even allocated adequate funding for basic maintenance, let alone advanced communications capability. To date, U.S. public policy does not appear to be moving towards promoting V2V or funding V2I. The funding in recent infrastructure bills is dedicated to installing BEV chargers and, to some extent, improving Internet accessibility in rural areas via programs for high-speed broadband.

New business models for mobility services emerged and diffused quickly at first, but are now receiving more scrutiny from the public and policymakers. Uber's rapid global growth, often in defiance of existing rules and regulations, provoked a backlash that led to rigorous scrutiny—for Uber itself, its competitors, and its complementors—in every area from passenger safety to whether drivers should be regarded as employees or independent contractors. Mobility services that intersect with public modes of transportation such as buses, subways, and urban bike-sharing will always be affected by regulations and public policy. Witness the pendulum swing of city policies on modes of micromobility such as e-scooters: encouraged at first, but later sometimes banned as attention turned to risks from battery fires, sidewalk congestion, and collisions with pedestrians.

Legal interpretations will also shape the mobility landscape. Big Tech companies currently cooperate with major OEMs on software services that result in data creation related to vehicle operation and user (driver) behavior and preferences. However, many OEMs are getting cautious and skeptical about Apple, Google, and Amazon vis-a-vis the ownership and control over such data with consumer groups also expressing some concerns. Recent announcement by OEMs like GM to remove Apple CarPlay and Android Auto from their vehicles or BMW limiting access only through mirroring illustrates this point. In the US, a group of congresspeople expressed their concern over the potential dominance of Apple and Google on vehicle data collection and urged the regulatory bodies to prevent that. Similarly, Senator Elizabeth Warren wrote to the FTC and DOJ to stop the Big Tech companies from being the "one-stop shop for automakers." The recent skirmish between OEMs and the Commonwealth of Massachusetts over telematic data on the 'right-to-repair' legislation similarly highlights the tension on who owns and controls which data, not just between big techs and OEMs, but also between these firms and vehicle owners. These ongoing disputes are very consequential as they will play a large role in determining which digital services are possible.

Likewise, the extent to which regulators will request standard interfaces in automobile telematics or mandate interconnection in mobility services can significantly affect the desirability of each of the proposed segments and business models. As such, regulation may not only shape the IA, as existing research has considered (Jacobides et al., 2016), but will also determine the conditions of competition in the mobility space, directly driving patterns of value migration.

Cross-cutting pressures are evident here. Big tech companies are facing congressional inquiries into their monopoly position with respect to user data collected from smartphones, although this hasn't yet extended to data acquired via vehicle operating systems. The ability of Big Tech to prevail in the "Mark III" scenario of mobility evolution, though, may be limited. There is a long-regulated history of the automobile, in which the OEM, as system integrator, bears the liability, not the supplier (Jacobides et al, 2016). This mirrors dynamics in smartphones, where OEMs, not software producers, were liable. This liability may come with the benefit of control in the digital realm, as it did in the physical, so that we do not see the typical digital disruption pattern where Big Tech disrupts existing sectors. Like with other regulated sectors (see Ozalp, Ozcan, Dinckol, Zachariadis and Gawer, 2022), we may see that Big Tech, unable to maintain unhindered scale and method of data acquisition, and fearful of liability, may coexist with incumbents focusing on specific profit pools, working alongside OEMs.

While startups can certainly learn to cope with regulatory demands, such capabilities take time to acquire. The era of Big Tech companies following a strategy of "move fast and break things" threw up problems vis-à-vis privacy, lack of competition, and equity of access, ultimately creating a climate of wariness and skepticism over many new technologies. Tesla, ironically, has leveraged its direct sales model to insulate itself from legal pressures[5], and it's used PR (including Twitter purchase) and Musk's bravado to cement its position in the sector. Large incumbents, whether automotive or Big Tech, 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 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. While incumbent OEMs have long experience in managing the resulting issues, pressures, and constraints, the same is not true for their Big Tech counterparts. Until we reach some distant future where autonomous technology eliminates all accidents—a future that may never come—safety and reliability will be paramount in any mobility ecosystem. As a corollary, such ecosystems will also need robust mechanisms to handle insurance and legal liability for vehicles and drivers (the latter being particularly complex when algorithms are doing the driving).

Will institutional forces favor a more integrated or more modular product and industry architecture? By the 21st century, ICEVs had become so complex that it took a tightly integrated production system to deliver a product that ticked every box: functional, fun to drive, safe, environmentally friendly,

[5] 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 his 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.

stylish, and desirable. While the simple e-drivetrain of BEVs may pull towards modularity, set against that will be the added complexity of combining electrification with advanced connectivity, new autonomous capabilities, and new mobility services that enhance the experience of driving and ownership. That complexity will require system integration capabilities, broad knowledge boundaries ("know more than you make" a la Brusoni et al., 2001), and the ability to function in a multi-stakeholder institutional environment.

Regulators and policymakers may want to avoid "picking winners" from a technology point of view. But they won't sit on the fence when it comes to guaranteeing that vehicles are safe, meet emissions standards at a time of heightened awareness about climate risk, and fulfill the basic human need for mobility in a broadly accessible way. We anticipate that integrated product designs, produced in vertically (or quasi-vertically) integrated organizations and supply chains, will continue to do the best job of fulfilling these societal expectations as well as consumer wants and needs. This doesn't preclude widespread innovations in products, services, and production systems. But we predict that the digital transformation template that has turned other industries on their heads is less likely to take hold and succeed in automotive.

As for mobility services, the way that regulation and legal challenges around data will be resolved will have a very important role to play in determining what business models (Markides, 2023) will be feasible. As such, what are the plausible "rules, roles and relationships" that will define the IA in terms of what will be offered to the customers, and also what will be the interfaces between mobility service providers, automobile OEMs and Big Tech, the three key actor categories? Our analysis also suggests that there is a significant difference in terms of what services are *technologically feasible,* or even interesting to customers, and which will be supported by a sufficiently strong constellation of existing players, that some of the literature may be taking for granted .

In all, our focus on regulation brings up a largely overlooked but potentially crucial aspect of industry evolution and value migration. Given that data can be used in many different ways, and regulation can directly shape and structure the value-add in sectors from mobility to education and healthcare, we argue that regulation should play a central part in any theory that aspires to describe the process of industry change and how incumbents (vs. entrants) are able to succeed.

8. 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, drawing on research and sectoral experience alike.

Having described the future technological and strategic possibilities for vehicle-based mobility, we conclude that its product and industry architecture will remain relatively integral—despite the pull towards digital transformation dynamics from software-based mobility services and the involvement of Big Tech firms hoping to migrate value away from incumbent, legacy ICEV OEMs.

Phenomenologically, many observers have advanced plausible future scenarios of a radically transformed mobility ecosystem based on a modularized product architecture and standardized hardware produced by contract manufacturers. Here, competitive differentiation would be based on digital services that connect mobility seamlessly to the rest of users' digital experience. Early indications of this scenario can be seen in Foxconn's modularity strategy, plans for contract manufacturing, and orchestration of a consortium that uses open-source software for connectivity and autonomy; in Google's bid, via Android Automotive's, to become every OEM's choice for a vehicle operating system – paralleled by Waymo's bid to provide the algorithmic "driver" for all robotaxis; and in consumers expressing a strong preference for having the full functionality of their smartphones available to them during mobility experiences.

Might consumers gravitate towards for an automotive (and robotaxi) software system designed by a digital-native tech company, which thereby grabs sufficient value, profitability, and bargaining leverage to get OEMs to build vehicles on a contract basis? Or could greater modularity in both product and industry architecture allow "mix-and-match" combinations of a standardized skateboard chassis that provides electrification, a standardized vehicle operating system, and various body types, along with software-based mobility services that can be customized to each owner or passenger?

Our evidence shows little sign of either scenario. Rather, we see that integrated approaches to technology and strategy, aligned with a legacy of integrated product architecture and integrated industry architecture, are providing value creation and value capture opportunities for both legacy OEMs and the few entrants that are mastering the capabilities to join their ranks.

While this could constitute a transitional stage of technology learning while awaiting a new dominant design, and hence a mere pause in the march towards digital transformation, we anticipate that the learning process will not end even after technological convergence occurs. Coping with the limits of physical objects and real-world physics, meeting the many criteria to achieve mobility, adapting software services to integrate flawlessly with hardware for superior performance, meeting regulatory requirements and dealing with legal liability where both are changing quickly —these aren't problems that can be solved once and for all, but rather perennial challenges that will be around for the foreseeable future. Some firms will succeed and others will fail—and the winners, we predict, will be characterized by skillful management of interdependencies and systemic phenomena via integrative means.

Theoretically speaking, 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 and rightfully 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 the pattern that we find, i.e. the prevalence of a form of disruption and innovation which is close to neither the "Mark I" archetype of Schumpeter (1911) of entrepreneurial firms causing industrial renewal, nor his "Mark II" (Schumpeter, 1945) of large firms internalizing innovation. It is distinct and may be characteristic of a number of the currently digitizing sectors. Our paper tracks the dynamics of change in the Industry Architecture (Jacobides et al, 2006) for such a context.

The theoretical contribution of this paper is to provide more clarity on what underpins this structure, which we dub “Mark III”, 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. We find that disruption is partial at best, and we showcase how disruptors are invested 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 modular as often as it 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 III dynamics. Their power (and potentially the power of other incumbents) raises the question of regulation to ensure fair competition (Jacobides & Lianos, 2021).

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. We find that data and regulation can have an important role in shaping the IA and the disruptive potential of these new technologies, as they combine with existing segments. That said, we acknowledge that our paper is by necessity exploratory in nature and is meant to offer more empirical context and some 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.

References

Adner, R., & Lieberman, M. (2021). Disruption through complements. *Strategy Science*, 6(1): 91-109.

Agarwal, R., Audretsch, D., & Sarkar, M. B. (2007). The process of creative construction: knowledge spillovers, entrepreneurship, and economic growth. *Strategic Entrepreneurship Journal* 1(3-4): 263-286.

Alochet, M., MacDuffie, J. P., & Midler, C. (2023a). Mirroring in production? Early evidence from the scale-up of Battery Electric Vehicles (BEVs). *Industrial and Corporate Change* 32(1): 61-111.

Alochet, M., MacDuffie, J. P., & Midler, C. (2023b). Mobility Services and Vehicle-as-Platform: How Disruptive to Product and Industry Architecture? Manuscript in preparation.

Anderson, E. G., Bhargava, H. K., Boehm, J., & Parker, G. (2022). Electric vehicles are a platform business: What firms need to know. *California Management Review*, *64*(4): 135–154.

Avramakis, E., Anchen, J., Raverkar, A.K., Fitzgerald, C. (2019). Mobility ecosystems: Striving towards a seamless interface for customers. Swiss Re Institute.

Bai, G., & Velamuri, S. R. (2021). Contextualizing the sharing economy. *Journal of Management Studies* 58(4): 977-1001.

Baldwin, C. Y., & Clark, K. B. (2000). *Design rules: The power of modularity* (Vol. 1). MIT Press: Boston, MA.

Baldwin, C. Y. (2023). *Design rules: How technology shapes organizations* (Vol. 2).

Bessen, J. E., Denk, E., Kim, J., & Righi, C. (2020). Declining industrial disruption. *Boston Univ. School of Law, Law and Economics Research Paper* 20-28. Available at https://ssrn.com/abstract=3682745

Bigelow, P. 2020. Startups' alternate route to go public; SPAC mergers favored in automotive tech. *Automotive News* (September 7).

Birkinshaw, J. (2022). How incumbents survive and thrive. *Harvard Business Review 100*(1-2): 36-42.

Birkinshaw, J. (2023). How incumbent firms respond to emerging technologies: Comparing supply-side and demand-side effects. *California Management Review*. Forthcoming.

Bohnsack, R., Pinske, J. & Lolk, A. (2014) Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. *Research Policy* 43(2) : 284-300.

Boigon, M. 2023a. Feel the Burn: The EV startup boom is over. Companies are now trying to avoid a bust. *Automotive News* (March 20).

Boigon, M. 2023b. Cash crunch forces EV startups to regroup; Companies look for ways to stanch the bleeding. *Automotive News* (May 15).

Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal* 110(463): 388-410.

Brusoni, S., A. Prencipe and K. Pavitt (2001), Knowledge specialization, organizational coupling, and the boundaries of the firm: Why do firms know more than they make?*Administrative Science Quarterly*, 46(4), 597–621.

Cabigiosu, A., Zirpoli, F., & Camuffo, A. (2013). Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry. *Research Policy*, *42*(3): 662-675.

Cacciatori, E., & Jacobides, M. G. (2005). The dynamic limits of specialization: vertical integration reconsidered. *Organization Studies* 26(12): 1851-1883.

Campagnolo, D., & Camuffo, A. (2010). The concept of modularity in management studies: a literature review. *International Journal of Management Reviews* 12(3): 259-283.

Chandler, A. D. (1962). *Strategy and Structure: Chapters in the History of the Industrial Empire*. MIT Press, Boston: MA.

Christensen, C. M. (1996) *The innovator's dilemma: When new technologies cause great firms to fail*. Harvard Business School Press: Cambridge, MA.

Coase, R. H. (2000). The acquisition of Fisher Body by General Motors. *The Journal of Law and Economics* 43(1): 15-32.

Colfer, L. J., & Baldwin, C. Y. (2016). The mirroring hypothesis: theory, evidence, and exceptions. *Industrial and Corporate Change* 25(5): 709-738.

Coppola, G. (2023). Car-data firms flop as automakers see dollar signs in software: Otonomo and Wejo — two promising-sounding startups — are having hard times. *Bloomberg*. Accessible at https://www.bloomberg.com/news/articles/2023-02-10/car-data-firms-flop-as-automakers-see-dollar-signs-in-software#xj4y7vzkg

Drucker, P. F. (1946). Keynes: Economics as a magical system. *The Virginia Quarterly Review* 22(4): 532-546.

Economist. (2023). Tesla's surprising new route to EV domination: Become more like the industry you disrupted. *The Economist*. Accessible at https://www.economist.com/business/2023/07/18/teslas-surprising-new-route-to-ev-domination

Estes, A. C. (2015). Google swears Android Auto isn't spying on you (that much). *Gizmodo*. Accessible at https://gizmodo.com/google-swears-android-auto-isnt-spying-on-you-that-muc-1735185946.

Ethiraj, S. K. (2007). Allocation of inventive effort in complex product systems. *Strategic Management Journal* 28(6): 563-584.

Fixson, S. K., & Park, J. K. (2008). The power of integrality: Linkages between product architecture, innovation, and industry structure. *Research Policy* 37(8): 1296-1316.

Freeland, R. F. (2000). Creating holdup through vertical integration: Fisher Body revisited. *The Journal of Law and Economics* 43(1) 33-66.

Fontana, R., Martinelli, A., & Nuvolari, A. (2021). Regimes reloaded! A reappraisal of Schumpeterian patterns of innovation, 1977–2011. *Journal of Evolutionary Economics* 31(5): 1495-1519.

Funk, J.L. & Luo, J. (2015). Open standards, vertical disintegration and entrepreneurial opportunities: How vertically-specialized firms entered the U.S. semiconductor industry. *Technovation* 45: 52-62.

Furr, N. & Szerb, A. (2023) Architects and bottlenecks: Ecosystem roles in the solar photovoltaic industry. Working paper.

Gans, J. (2016). *The disruption dilemma*. MIT press: Cambridge, MA.

George, P. (2023). Everybody hates GM's decision to kill Apple CarPlay and Android Auto for its EVs. *The Verge*. Accessible at https://www.theverge.com/2023/4/4/23669523/gm-apple-carplay-android-auto-ev-restrict-access

Gilbert, C. G. (2005). Unbundling the structure of inertia: Resource versus routine rigidity. *Academy of Management Journal* 48(5): 741–763.

Grove, A. S. (1996). *Only the paranoid survive: How to exploit the crisis points that challenge every company*. Currency Doubleday: New York, NY.

Hanelt, A., Bohnsack, R., Marz, D., & Antunes Marante, C. (2021). A systematic review of the literature on digital transformation: Insights and implications for strategy and organizational change. *Journal of Management Studies* 58(5): 1159-1197.

Hannah, D. P., & Eisenhardt, K. M. (2018). How firms navigate cooperation and competition in nascent ecosystems. *Strategic Management Journal* 39(12): 3163-3192.

Helfat, C.E. & Campo-Rembado, M.A. (2016). Integrative Capabilities, Vertical Integration, and Innovation Over Successive Technology Lifecycles. *Organization Science* 27(2):249-264.

Helveston, J. P., Wang, Y., Karplus, V. J., & Fuchs, E. R. (2019). Institutional complementarities: The origins of experimentation in China's plug-in electric vehicle industry. *Research Policy 48*(1): 206-222.

Hounshell, D. (1984). *From the American system to mass production, 1800-1932: The development of manufacturing technology in the United States* (No. 4). Johns Hopkins University Press: Baltimore, MD.

IEA. (2022). *Global EV Outlook 2022.*, *IEA*. Accessible at https://www.iea.org/reports/global-ev-outlook-2022.

Isidore, C. (2021). Tesla's dirty little secret: Its net profit doesn't come from selling cars. *CNN*. Accessible at https://www.cnn.com/2021/01/31/investing/tesla-profitability/index.html

Jacobides, M. G. (2005). Industry change through vertical disintegration: How and why markets emerged in mortgage banking. *Academy of Management Journal* 48(3): 465-498.

Jacobides, M. G. (2022). How to compete when industries digitize and collide: an ecosystem development framework. *California Management Review* 64(3): 99-123.

Jacobides, M. G. & Winter, S. G. (2005). The co-evolution of capabilities and transaction costs: Explaining the institutional structure of production. *Strategic Management Journal* 26(5): 395-413.

Jacobides, M. G., Knudsen, T. & Augier, M. (2006). Benefiting from innovation: Value creation, value appropriation and the role of industry architectures. *Research Policy 35*(8): 1200-1221.

Jacobides, M. G., & MacDuffie, J. P. (2013). How to drive value your way. *Harvard Business Review* 91(7): 92-100.

Jacobides, M. G. & Tae, C. J. (2015). Kingpins, bottlenecks, and value dynamics along a sector. *Organization Science* 26(3): 889-907.

Jacobides, M. G., MacDuffie, J. P. & Tae, C. J. (2016). Agency, structure, and the dominance of OEMs: Change and stability in the automotive sector. *Strategic Management Journal* 37(9): 1942-1967.

Jacobides, M. G., Cennamo, C. & Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal* 39(8): 2255-2276.

Jacobides, M.G & Lianos, I. (2021) Regulating platforms and ecosystems: an introduction. *Industrial and Corporate Change*, 30 (5): 1131-1142

Jacobides, M.G., Cennamo, C. & Gawer, A. (2023). Externalities and complementarities in platforms and ecosystems: From structural solutions to endogenous failures. *Research Policy*. Forthcoming.

Keith, D. R. & MacDuffie, J. P. (2020) Why 'autos plus tech' is the best path for automated vehicles. *MIT Sloan Management Review*. Accessible at https://sloanreview.mit.edu/article/why-autos-plus-tech-is-the-best-path-for-automated-vehicles//

King, A. A. & Tucci, C. L. (2002). Incumbent entry into new market niches: The role of experience and managerial choice in the creation of dynamic capabilities. *Management Science* 48(2): 171-186.

Kivimaa, P. & Rogge, K. S. (2022). Interplay of policy experimentation and institutional change in sustainability transitions: The case of mobility as a service in Finland. *Research Policy* 51(1): 104412.

Klein, B., Crawford, R. G. & Alchian, A. A. (1978). Vertical integration, appropriable rents, and the competitive contracting process. *Journal of Law and Economics* 21(2): 297-326.

Klepper, S. (1996). Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review* 86(3): 562-583.

Klepper, S. (2002). The capabilities of new firms and the evolution of the US automobile industry. *Industrial and Corporate Change* 11(4): 645-666.

Klepper, S. & Simons, K. L. (2000). The making of an oligopoly: firm survival and technological change in the evolution of the US tire industry. *Journal of Political Economy* 108(4): 728-760.

Klepper, S. & Sleeper, S. (2005). Entry by spinoffs. *Management Science* 51(8): 1291-1306.

Küpper, D., Kuhlmann, K., Tominaga, K., Arora, A. & Schlageter, J. (2020). Shifting gears in auto manufacturing. *Boston Consulting Group*. Accessible at https://afia.pt/wp-content/uploads/2020/10/2909202020SDERT.pdf

LaMonica, M. (2012). Electric vehicles: This time it really is different. *CNET*. Accessible at https://www.cnet.com/science/electric-vehicles-this-time-it-really-is-different/.

Llopis-Albert, C., Rubio, F. & Valero, F. (2021). Impact of digital transformation on the automotive industry. *Technological Forecasting and Social Change* 162: 120343.

Lopez-Vega, H. & Moodysson, J. (2023). Digital transformation of the automotive industry: An integrating framework to analyse technological novelty and breadth. *Industry and Innovation* 30(1): 67-102.

MacDuffie, J. P. (2013). Modularity-as-property, modularization-as-process, and 'modularity'-as-frame: Lessons from product architecture initiatives in the global automotive industry. *Global Strategy Journal* 3(1): 8-40.

MacDuffie, J. P. (2018). Response to Perkins and Murmann: Pay attention to what is and isn't unique about Tesla. *Management and Organization Review* 14(3): 481-489.

Malerba, F. & Orsenigo, L. (1995). Schumpeterian patterns of innovation. *Cambridge Journal of Economics* 19(1): 47–65.

Malerba, F. & Orsenigo, L. (1996). Schumpeterian patterns of innovation are technology-specific. *Research Policy* 25(3): 451-478.

Murmann, J. P. & Frenken, K. (2006). Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. *Research Policy 35*(7): 925-952.
Murmann, J. P. & Vogt, F. (2022). A capabilities framework for dynamic competition: Assessing the relative chances of incumbents, start-ups, and diversifying entrants. *Management and Organization Review* 1-16.
Murmann, J. P. & Schuler, B. A. (2023). Exploring the structure of internal combustion engine and battery electric vehicles: Implications for the architecture of the automotive industry. *Industrial and Corporate Change* 32(1): 129-154.
Murphy, M. (2020). 2023 is supposed to be the year of the electric vehicle. Now is the time to invest. *Protocol*. Accessible at https://www.protocol.com/electric-vehicle-revolution-time-to-invest.
Murphy, F., Pütz, F., Mullins, M., Rohlfs, T., Wrana, D. & Biermann, M. (2019). The impact of autonomous vehicle technologies on product recall risk. *International Journal of Production Research* 57(20): 6264-6277.
Ozalp, H., Ozcan, P., Dinckol, D., Zachariadis, M. & Gawer, A. (2022). "Digital colonization" of highly regulated industries: an analysis of big tech platforms' entry into health care and education. *California Management Review* 64(4): 78-107.
Perkins, G. & Murmann, J. P. (2018). What does the success of Tesla mean for the future dynamics in the global automobile sector? *Management and Organization Review* 14(3): 471-480.
Peters, J. (2019). Automakers have a choice: Become data companies or become irrelevant. *TechCrunch*. Accessible at https://techcrunch.com/2019/05/23/automakers-faced-with-a-choice-become-data-companies-or-become-irrelevant/
Reeves, M., Bergman, R., Gourevitch, A. & Ortiz, M. (2016). Fork in the road: Navigating industry disruption. *Boston Consulting Group*. Accessible at https://www.bcg.com/publications/2016/business-unit-strategy-forks-road-navigating-industry-disruption
Reischauer, G., Engelmann, A., Gawer, A. & Hoffmann, W (2023). Stepping stone strategy: How product-focused incumbents cooperate and compete in the face of digital platform leaders. Working paper.
Ruffo, G. H. (2020) Why the automotive industry should take Foxconn's EV ambitions seriously: That includes Tesla, the iPhone of EVs: Foxconn wants to be the Android. *Inside EVs.* Accessible at https://insideevs.com/news/449468/automotive-industry-should-take-foxconn-ev-seriously/
Schumpeter, J. A. (1911) *The theory of economic development*. Harvard University Press: Cambridge, MA.
Schumpeter, J. A. (1945) *Capitalism, socialism, and democracy*. Harper & Row: New York.
Sosa, M. L. (2013). Decoupling market incumbency from organizational prehistory: Locating the real sources of competitive advantage in R&D for radical innovation. *Strategic Management Journal* 34(2): 245-255.
Svahn, F., Mathiassen, L. & Lindgren, R. (2017). Embracing digital innovation in incumbent firms: How Volvo cars managed competing concerns. *MIS Quarterly* 41(1): 239-253.
Szymkowski, S. (2019). Ford will pay $17 million to settle MyFord Touch-related lawsuit. *CNET*. Accessible at https://www.cnet.com/roadshow/news/ford-17-million-myford-touch-lawsuit-settlement/
Teece, D. J. (2018). Tesla and the reshaping of the auto industry. *Management and Organization Review* 14(3): 501-512.
Teng, N. & Jacobides, M. G. (2023). Digital entrant scaling & dynamics: How Grab transformed & transcended the SE Asian mobility industry. Working paper.
Transparency Market Research. (2023). Electric Vehicle Battery Market Demand will reach a value of US$ 365.4 Billion by the year 2031 at a CAGR of 21.9%. *Yahoo Finance*. Accessible at. https://finance.yahoo.com/news/electric-vehicle-battery-market-demand-173000116.html
Truett, R. (2022). How EV skateboard chassis was born. *Automotive News*. Accessible at https://www.autonews.com/manufacturing/how-ev-skateboard-chassis-was-born
Tushman, M. L. & Murmann, J. P. (1998). Dominant designs, technology cycles, and organization outcomes. *Academy of Management Proceedings* 1: A1-A33.

Womack, J. P., Jones, D. T. & Roos, D. (1990). *The machine that changed the world: The story of lean production: Toyota's secret weapon in the global car wars that is now revolutionizing world industry*. Simon and Schuster: New York, NY.
Woody, T. (2013). The lesson from Better Place's bankruptcy: Be more like Tesla. *Quartz*. Accessible at https://qz.com/88214/the-lesson-from-better-places-bankruptcy-be-more-like-tesla
Yoo, Y., Henfridsson, O. & Lyytinen, K. (2010). Research commentary—the new organizing logic of digital innovation: an agenda for information systems research. *Information Systems Research* 21(4): 724-735.
Zhao, L. & Malikopoulos, A. A. (2020). Enhanced mobility with connectivity and automation: A review of shared autonomous vehicle systems. *IEEE Intelligent Transportation Systems Magazine* 14(1): 87-102

Figure 1a. Summary of Mark III in the process of 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 1b. Summary of Mark III in the mobility ecosystem

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