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Disruption Through Complements

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Abstract. We expand the perspective on disruption by going beyond substitute products to consider the ways in which complements can impact the competitiveness of incumbents. Complementors represent a different kind of disruptive threat, one that is latent within the initial structure of value creation: complementors that disrupt are not new entrants but, rather, established actors that can shift their impact from positive to negative. With this perspective, we consider how ecosystem dynamics can clarify aspects of disruptive competition, and we use the dynamics of disruption to illuminate dimensions of competition in ecosystem settings. We elaborate three processes through which disruption through complements can occur: commoditization, adjacent entry, and value inversion. For each process we discuss specific examples, and we illustrate their interaction in the context of the automotive industry, which is fast evolving in response to technological change. In so doing, the paper fills a critical gap in the literature, which is so far missing a systematic examination of how complementors can disrupt established firms.

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Keywords: ecosystems • industry dynamics • technology strategy • technological change • entry strategies

1. Introduction

In his classic 1997 book *The Innovator's Dilemma*, Clayton Christensen coined the term *disruptive innovation*. Although there is universal agreement that disruption negatively affects industry incumbents, Christensen's work touched off a lively, two-decade debate about what innovations qualify as disruptive (e.g., Christensen et al., 2015), what organizational factors hinder timely incumbent response (e.g., Danneels 2004 and Gans 2016), what the economic drivers of the dynamic are (e.g., Adner 2002 and Adner and Zemsky 2005), and numerous other lines of inquiry.

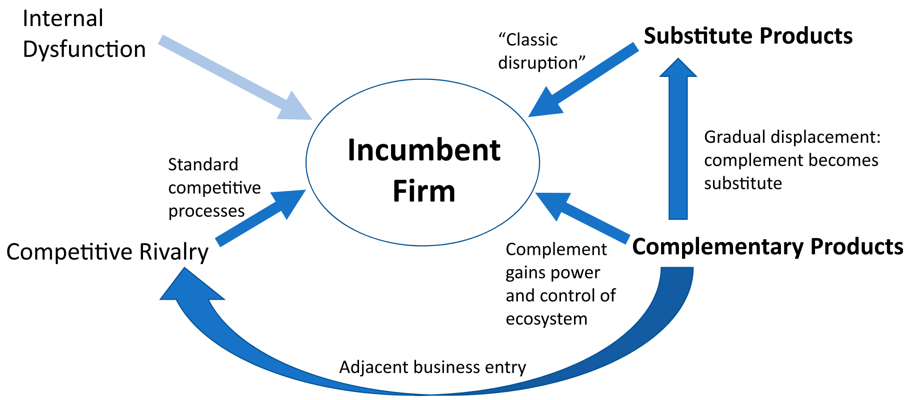
Stepping back, however, we can see that the debate on disruption has focused on a category of competitive *substitution*. An attacker, stealthy or not, introduces a product that customers increasingly find preferable to the established offer in the market. The attacker is different from a regular industry rival in that attackers create their value using a different technological approach.

In this article, we suggest that we can better understand disruption when we expand our perspective beyond substitutes to consider the ways in which complements impact the competitiveness of incumbents. This matters because complementors represent a different kind of threat, one that is latent within the initial structure of value creation: complementors that disrupt are not new entrants but rather established actors that can shift their impact from positive to negative. The role of complementors extends beyond enhancing joint value creation (e.g., Rosenberg and Frischtak 1983 and Teece 2018) and impacting value capture (e.g., Teece 1986, 2006). With disruption through complements, the value created by the incumbent diminishes—and can even be destroyed—despite the delivery of enhanced value to the end user.

We invoke ecosystem dynamics to clarify aspects of disruptive competition, and we use the dynamics of disruption to illuminate dimensions of competition in ecosystem settings. In so doing, we help fill a critical gap in the literature, which is so far missing a systematic examination of how complements can disrupt established firms.

Our main arguments are illustrated in Figure 1, which characterizes the four primary mechanisms that can lead to a decline in the market share or profitability of incumbent firms: loss of competence

Figure 1. (Color online) Threats to the Profitability and Market Share of Incumbent Firms



(internal dysfunction), loss to existing rivals (which improve their offerings relative to those of the focal firm), loss to a substitute (which delivers a similar value proposition on the basis of a different set of activities and technologies), and loss to a complement (through direct and indirect processes, which we specify in the following paragraphs).

The two threats on the left-hand side of Figure 1 exist within the boundaries of an established competitive industry, lying within and among the existing set of participants. They have been extensively studied in the management literature and are generally considered to be separate from disruption:

- *Internal dysfunction*: A leading firm may lose market share and profitability as the result of destructive internal processes, inertia, or organizational complexity that weaken its competitive position, independent of external threats (e.g., Haveman 1993 and Dobrev et al. 2003). For example, the chief executive officer (CEO) may make poor strategic choices, or the firm may succumb to internal political and organizational conflicts.
- *Competitive rivalry*: A firm may lose market share and profits to established competitors through standard processes of competitive rivalry. This occurs when established rivals improve their competitive position by cutting costs or by introducing superior products or services.

These two processes may operate jointly; inertia makes the firm more vulnerable to competitive rivalry. Incumbent firms lose market share and profitability when they succumb to these threats.

By contrast, the two threats on the right-hand side of Figure 1 come from outside the existing set of competitors. First is the threat of *substitute products* (or services). An important form of substitution is characterized by the classic disruption literature (e.g., Christensen 1997): An attacker introduces a substitute product or service that gains a foothold in the market. As the substitute improves, incumbents fail to adequately respond, leading to a substantial decline in their market share and profitability.[1] This dynamic of classic disruption has attracted a great deal of managerial and research attention in recent years and has led to much deliberation about exactly how *disruptive innovation* should be defined (e.g., Danneels 2004, Sood and Tellis 2011, Kumaraswamy et al. 2018, and Christensen, et al. 2018).

Second—the focus of our paper—is the threat of what we characterize as *disruption through complements.* Here, the threat to the success of incumbents arises from complementors that initially play a value-enhancing role but ultimately displace a focal firm or capture much of that firm's profitability. Not all complementors can or will disrupt. But those complementors that do disrupt represent a different kind of threat because they reside within the initial structure—not as new entrants but rather as established actors that can shift their role and impact.

We define disruption as a substantial decline in the sales, market share, or profitability of established incumbents, *resulting from actions taken by firms that are not initially direct rivals of the incumbent(s)*. With this definition we can accommodate traditional Christensonian substitutes (whose initial performance inferiority renders them initially irrelevant/nonthreatening but can later become "good enough" threats), as well as the possibility of complements, which play an initially supportive role that ultimately shifts to undermine the incumbent's position. This occurs through either strategic action (commoditization and adjacent entry) or continued improvement that becomes "too good" and substitutes for the focal offer.

Our definition clarifies the boundary conditions for the focus of this paper: it excludes incumbent losses as a result of competitive imitation, shifts in customer preferences, changes in factor prices or tariff protection, and other regulatory or legal changes. Because our definition requires the existence of one or more well-established incumbents, a further boundary condition is that disruption occurs only in industries or markets that are reasonably mature. Thus, we rule out shifts that commonly occur in nascent industries or ecosystems—for example, shakeouts driven by the emergence of a dominant design (Utterback and Abernathy 1975, Klepper 1997). These are important events in the evolution of industries, but they are fomented by firms that are directly competitive with other incumbents, rather than firms that start out off the radar.

The example of ride-sharing platforms shows the value of this expanded definition: the literature has held an active debated regarding whether Uber should be considered a disruptor to the taxi fleets with which it competes directly (because it entered the market with an arguably superior value proposition to the incumbents; see Christensen et. al. (2015)). Adding the perspective of disruption through complements highlights that the shift to ride sharing also holds the potential to impact car ownership and, through it, the fortunes of carmakers. This disruption of manufacturers by service providers breaks from the mold of traditional substitutes and can be understood only through the lens of complements, as we discuss in detail below.

We begin with a summary of substitution processes and classic disruption. We then elaborate three different processes by which disruption through complements can occur and offer examples. In Section 4 we illustrate these dynamics and their interactions in the context of the automotive industry, which is fast evolving in response to technological change. The automotive context is attractive because it allows us to consider substitution and all three types of disruption through complements within the context of a single industry.

2. Disruption Through Substitutes

Disruptive technologies à la Christensen originate in low-end or new-market footholds and then enter the mainstream markets when the lower, but good enough performance of their offers, allows them to capture share from incumbent producers (Christensen et al. 2015). In this regard, they follow a pattern that differs from previous models of substitution by emergent technologies. Christensen's model of disruption led to a lively debate about the technological and competitive processes that fit the term "disruptive innovation."

Prior to Christensen (1997), generations of researchers had uncovered processes of technological substitution that often led to the entry of new firms and the downfall of established incumbents. The historical literature on technological change had, through the 1980s, focused on the rise of emerging technologies that offered substantial performance improvement over their predecessors, either immediately or eventually. One strand of the literature characterizing innovations along lines such as radical versus incremental (e.g., Cooper and Schendel 1976) or competence enhancing versus competence destroying (e.g., Tushman and Anderson 1986) studies settings where the emergent technology offered superior performance to the old. Thus, for example, whereas the competence-destroying float-glass process that Tushman and Anderson (1986) studied was difficult to master, its performance advantage was clear from the start. Similar "attacks from above" characterize the substitution of propeller-driven planes by jets and mimeograph machines by xerographic copiers. Here, the question was about whether incumbents would be able to muster the required capabilities to participate in these technological shifts.

A departure from the assumption of superiority gave rise to a second strand in the literature that examined the specific dynamics that arose where the emerging technology offered inferior performance at the outset. Foster's (1986) model of technology S-curves highlighted both the investment challenge associated with pursuing innovation that offered *initially* inferior performance and the risk to incumbents of waiting until the technology matured to the point where its superiority was established, at which point the attackers would be harder to outcompete, having gained both experience and market position with the new technology (e.g., the replacement of sailing ships by steamships). An important premise was that the new technology would *eventually* achieve superiority—the crossing over of the S-curves—and take over the market. Here, the question was whether incumbents would be willing to invest early in an emerging technology, before its superiority was established, or risk ceding the market to newer entrants, which did not face the opportunity cost associated with shifting resources away from the old technologies (Foster's "attacker's advantage").

Christensen's (1997) model introduced the novel idea that an emerging technology that would *never* offer superior performance could nonetheless take over a market. This seeming paradox was resolved with the introduction of the notion of a good enough performance level, a notion that could come into existence when technological performance overshoots customer requirements.

Here, the incumbent's investment dilemma was even more acute than in Foster's context: Foster's innovations offered the promise of enhancing a sustaining performance trajectory once they had reached superiority and so could muster support among visionary customers seeking ever higher performance. Christensen's innovations, by contrast, came with the promise of inferiority, making support and resource allocation within the incumbent organizations even harder to come by (Bower and Christensen 1995).

A great deal of discussion has focused on how incumbents can and should respond to disruptive innovation.

Christensen argued that successful disruptors typically grow from a niche at the low end of the market, whereas the incumbent fails to understand the threat or effectively respond. Gradually, the disruptive product improves, winning over an increasing share of buyers until, eventually, the incumbent's most important and profitable customers find the entrant's value proposition compelling.[2] Gans (2016) identified supply-side organizational factors (e.g., Henderson and Clark 1990) and demand-side economic factors (e.g., Adner 2002; and Adner and Zemsky 2005, 2006) that underlie these responses. Although the mechanism differs, they all ultimately lead to a process of substitution in which the attacker's product replaces that of the incumbent(s).

While acknowledging the debate in the literature, here we broadly classify the explanatory models previously outlined, in which the incumbent firm or firms lose substantial market share to new entrants producing a substitute product, under the banner of *disruption through substitutes*. As the disruption unfolds, incumbents either dismiss the substitution threat of the new technology or find themselves unable to adapt. Ultimately, the substitution process may (or may not) be complete, with incumbents either fully driven out from the market or potentially holding on to smaller, niche positions.

Depending on how long the disruptive new entrants have been in the market, there can be some ambiguity as to whether this threat to incumbents should be classified as disruption through substitutes or competitive rivalry. One can split hairs on such delineations, but that is not central to this paper. Our focus is on disruption through complements.

3. Disruption Through Complements: The Role of Ecosystems

Whereas substitutes are defined by their negative impact on the added value of the focal industry, complements are products or services that enhance or enable an industry's core offer; complementors are the firms that provide them. The role of complements and complementors has long been recognized by scholars concerned with value-based strategy (e.g., Brandenburger and Nalebuff 1997) and by historians of technology, particularly in the context of systemic innovation (e.g., Hughes 1982). As Rosenberg (1979, p. 28) rightly noted, "The social payoff of an innovation can rarely be identified in isolation." In recent years, complements have become an increasingly central concern in the strategy literature (e.g., Adner and Kapoor 2010, Adner 2017, Jacobides et al. 2018, Kapoor 2018, and Teece 2018).

An important stream of research has focused on the general question of how the nature of complementary assets (e.g., Teece 1986, 2006) and the threat of holdup by partners (e.g., Williamson 1985) affect the ability of innovators to profit from their own innovations. A key issue has been to identify impediments and bottlenecks that affect value capture in transactional relationships. Such conceptualizations of appropriability, as rooted in the inability to write complete contracts, have yielded meaningful insights. Even so, the focus on immediate contractual questions leaves unaddressed the impact of complementors on long-term competitive dynamics that do not rely on the details of intimate exchange.

Our emphasis is not on the question of appropriating returns to innovation but rather on forces that impact the continuity of incumbent profitability and market share. We look beyond transactional constraints on value capture to consider more generally the impact of complements on competition in the focal arena.[3] Here, we distinguish between the ability to increase or decrease access to complements (control of bottlenecks) from the contributions of a complement to the focal firm's value creation (impact on differentiation). As others have noted, bottleneck assets and the threat of holdup can shift over time within the ecosystem as a result of technological changes and the evolving capabilities and strategic actions of the players. Our novel contribution is to flesh out the dynamic processes that turn "friends" into "foes" within business ecosystems. The pathways we describe convert initially positive relationships between complementors into something more adversarial.[4] To be sure, prior studies have addressed processes by which complements can prove disruptive (e.g., Eisenmann et al. 2011, Ansari et al. 2016, and Jacobides and Teng 2019), but the literature on disruption through complements remains highly fragmented and underdeveloped.

Unlike traditional attackers, disruptive complementors are not new entrants; rather, they already occupy a position within the structure of value creation. In Table 1, we categorize three different processes by which disruption through complements can occur—commoditization, adjacent entry, and value inversion—and contrast them with disruption through substitutes.

Disruption through complements arises from a combination of dynamic forces: technological change alters the calculations of cost and benefit of entry over time (e.g., Adner and Kapoor 2010), organizational learning alters the understanding of opportunity (e.g., Levitt and March 1988), and capability building alters the complementor's effectiveness in pursuing new goals (e.g., Helfat et al. 2009). As a complementor builds these key strengths, it is possible that its equilibrium calculations and options change such that, at some point, the complementor acts at the expense of another firm in the ecosystem.

Table 1. Modes of Disruption by Substitutes and by Complements

Form of disruption	Period 1 (predisruption)	Period 2 (postdisruption)	Examples
(1) Initially inferior substitute captures market share (*classic disruption*)	Incumbent technology A offers superior performance to new technology B: —For most customers, the value of A exceeds the value of B. —B enters a market niche. —A ignores B or fails to respond effectively.	• B improves to the point of replacing A in the main market by achieving good enough performance (e.g., Christensen 1997). • Replacement can be partial or total. **Impact: Core demand for technology A declines. Incumbents producing A may maintain market share in a shrinking market.**	• 14″ computer hard-disk drives are replaced by 8″ hard-disk drives. • Cable-operated earth-moving equipment is replaced by hydraulic earth-moving equipment.
(2) Complement drives down added value (*commoditization*)	• The offers of industry incumbents A benefit from the availability of complement B. • A is central and powerful. • Improvements in B increase the value creation of A.	• Complement B becomes the locus of differentiation and/or reduces barriers to entry to compete in A. • A loses uniqueness and holds a weaker negotiating position in the system, but it is not replaced: A and B continue to coexist. **Impact: Incumbent A loses margin, bargaining power, and influence. Demand for A does not change, but new entry can decrease market share of incumbents.**	• PC assemblers (IBM, Dell) are commoditized by Wintel. • Integrated handset makers (Nokia, Sony) are commoditized by the Android operating system. • Book publishers lose power as Amazon's online bookstore enhances the capabilities and reach of smaller publishers.
(3) Complement enters as direct rival (*adjacent entry*)	• The offers of industry incumbents A benefit from the availability of complement B. • A is central and powerful. • A and B do not compete.	B enters directly into A's business, offering both the complement and the core, and thus —can exploit cross-subsidies to sell bundled A–B offer; —can keep A and B separate but drive down prices in A, increasing market size and asymmetrically benefiting from growth in demand for B; and —unlike a new entrant with no industry experience, B can benefit from known brand and relevant channel and consumer relationships. **Impact: Incumbent loses market share, influence, control, and/or bargaining power. The size of market is maintained or grows.**	• Amazon enters package delivery, competing with UPS and FedEx. • Netflix and Amazon enter movie production, competing with established film studios. • Microsoft bundles Word and Excel to outcompete WordPerfect in word processors and Lotus 1-2-3 in spreadsheets. • Microsoft "envelops" Netscape by offering both home and enterprise buyers free browser/server to maintain dominance of Windows.
(4) Complement becomes substitute (*displacement through value inversion*)	• Products A and B are complements. • Improvements in B initially increase the value creation of A.	Continued improvement in B eliminates the need for A. Thus, —B gradually replaces the combination of A and B, and —"the assistant replaces the boss." **Impact: Core demand for A declines as B replaces A.**	• 3D printers shift from prototyping enablers that increase demand for manufacturing capacity to becoming production engines, substituting for machine tools. • Software simulators initially make physical testing more productive, but as they become increasingly accurate and predictive, they reduce the volume need for physical testing (e.g., wind tunnels, crash tests). Physical tests are relegated to certification rather than a core part of optimization. • Smart tractors reduce waste in planting and hence volumes of seeds and fertilizer used. • LinkedIn shifts from being a helpful source of leads for headhunters to enabling corporate recruiters to identify leads on their own. • Higher-resolution computer and phone screens reduce demand for paper and printers. • Book publishers lose sales as Amazon allows authors to self-publish.

Notes. Note that technology need not be physical. It can be a business model or a process, among other things.

Within in an ecosystem, firms may or may not be explicit partners, but their relationship is defined by some element of joint value creation. As is characteristic of all ecosystem settings, which firm is core and which is complement is a matter of perspective (Adner 2017). A given firm can conceive of itself as core and see the rest of the system as complementary to its value creation (e.g., personal computers are a complement to spreadsheet software, and spreadsheet software is a complement to a personal computers). Standard competition takes place at each position (e.g., computer makers compete with computer makers; spreadsheet software makers compete with software makers). More broadly within the ecosystem, competition from one domain affects competition in the other—as was the case in early computing, where the availability of the Lotus 1-2-3 spreadsheet for the IBM/Wintel platform boosted its competitiveness in the enterprise market relative to Apple and the pioneering VisiCalc spreadsheet.[5]

3.1. Commoditization: Complement Drives Down Added Value

The first mode of disruption through complements involves commoditization of the core offer. Unlike traditional substitution, the impact here is not reduced demand for the core but, rather, reduced influence and margin. Commoditization shifts the "locus of differentiation" from one position in the system to another (Jacobides and MacDuffie 2013). Firm A, which produces the core offer, is initially dominant in the ecosystem, but a strategic change empowers firm B, which produces the complement. As the power of the complement rises, the added value of firm A falls, contributing to a commoditization of firm A's role. Commoditization occurs when (1) the complement reduces the entry barriers to participation in the core, for example, by reducing the fixed costs of operation required for entry, or (2) the complement becomes a key driver of differentiation, determining the pace and direction of innovation, or (3) the complement becomes the guarantor of quality, increasing the substitutability among core producers in the eyes of consumers.

These factors are not mutually exclusive; for example, IBM lost its early dominance of the personal computer industry to the combination of all three. In the early days of the PC industry, assemblers—IBM in particular—held great sway over consumer choices. IBM benefited from its role as guarantor of quality through its brand and guarantor of software optimization through its control of the BIOS (basic input-output system) chip. This dominance was eroded by the entry of other computer makers, which initially had imperfect compatibility, leading to errors and bugs in some programs. Once IBM's BIOS was cloned—enabling the entry of hordes of "100% IBM PC-compatible" entrants—the assemblers' ability to capture more of the value they created collapsed.[6] The broad availability of cloned chips meant that BIOS was no longer a bottleneck that could be controlled by a single actor.

Contributing to IBM's downfall in PCs was a key provision in the company's contract with the supplier of its operating system, Microsoft, which allowed Microsoft to license the operating system to other computer manufacturers. With access to Microsoft's operating system, a flood of PC makers entered the market with computers essentially undifferentiated from those of IBM. Moreover, this gave Microsoft control of the key drivers of differentiation and product quality for virtually the entire industry. To further reinforce these drivers, Microsoft formed an alliance with Intel, producer of the microprocessor, another key complement in the PC ecosystem. As Microsoft continued to expand its capabilities in software development and distribution, its power and centrality in the PC ecosystem grew.

The market opportunity for computer assemblers continued to grow exponentially for many years. But the profit opportunity was limited by a lack of differentiation, as well as the collapse of entry barriers enabled by the Wintel complement.[7] This decreasing ability to innovate in ways that bolstered consumers' perception of value impacted profitability not through a mechanism of bottlenecks but rather a more fundamental maturation in being able to drive improvement in marginal utility through innovation. As Intel CEO Andy Grove noted, "The laws of thermodynamics, applied to the computer industry, [mean] that everything gets commoditized eventually. Grove's law is that the last one to get commoditized wins," (quoted in Burgelman (2002), p. 234).

In a different context—the restaurant industry in 2020—improved delivery services such as Uber Eats and DoorDash have been able to capture an increasing amount of total value. These services simultaneously reduce the value of restaurant location and facility, make restaurants more substitutable, and enable the entry of a new class of competitors: "dark kitchens," which specialize in delivery orders, enabling smaller footprints in (cheaper) less attractive locations.

Table 1 notes two other examples of complements driving down added value. Google's Android operating system commoditized the position of handset manufacturers in the smartphone arena, enabling a host of new hardware makers to enter the market. Amazon's entry into the online sales of physical books—by reducing distribution challenges and eliminating the shelf-space limitation associated with brick-and-mortar retailers—reduced entry barriers into book publishing, enabling the rise and competitiveness of smaller publishers relative to the dominant majors.

3.2. Adjacent Entry: Complement Enters as Direct Rival

A second mode of disruption through complements entails the direct entry of the complementor into the production of the core offer. Motivation for direct entry can be rooted in the classic transaction cost concerns around appropriability and holdup risk; Williamson (1985, 1999) characterized the incentives for firms to substitute vertical integration for market transactions in the face of incomplete contracts. Alternative rationales include the quest for synergy and scale (e.g., Levinthal and Wu 2010) and the unknown value of exploration and optionality that comes with new activity (e.g., Teece 2018).

Regardless of the complementor's motive for entry, demand for the core is maintained, or even expanded, if price competition intensifies, but the impact on incumbents is a loss of market share, margin, and, potentially, control. Complementors that enter as direct competitors differ from traditional diversifying entrants in that they are already rooted in the ecosystem. This can give them assets normally associated with incumbents—knowledge, brand, relationships, and distribution—that are more closely related to the core activity than what a typical entrant, de novo or diversifier, could be expected to possess. Close proximity in the ecosystem may also help the complementor learn details about the core business of the incumbent and thus provide an advantage in building capabilities required to successfully enter that business. Helfat and Raubitschek (2000) described how such learning and capability building can support a strategy of vertical or horizontal product sequencing.

Complementor entry can take the form of a dedicated business unit when a complement producer integrates to compete directly with its partner. The complement producer makes a strategic decision to expand in scope to gain leverage and value within the ecosystem. Recent examples include Netflix's and Amazon's upstream entries into film production and Amazon's downstream entry into package delivery. Such vertical entry, even if it is only to gain a small foothold in the incumbent's business, enhances the bargaining power of the complementor (e.g., Wan and Wu 2017). Vertical integration moves of this sort may be incentivized by efficiency-based motives commonly emphasized in the literature, such as reduction in transaction costs and moral hazard, as well as efficient allocation of property rights (e.g., Williamson 1985, Hart 1995, and Lafontaine and Slade 2007). Our framework suggests that these can be supplemented by more dynamic, opportunistic motives, as the complementor learns more about the incumbent's business and develops capabilities that increase the profits that can be captured. Moreover, the cost and risk of entry are reduced when the complementor can integrate gradually into the incumbent's business, an option normally unavailable to diversifying entrants that come from outside the ecosystem.

Beyond vertical integration, there are many types of adjacent entry, particularly in today's digital-based ecosystems. One such form has been termed *platform envelopment* in the literature (Eisenmann et al. 2011, Parket et al. 2016). Firm A's product or service starts as a complement to firm B's platform; if A proves successful, there may be an incentive for firm B to extend its platform to incorporate a wholly owned version with the same functionality as A's offering. For example, Netscape developed the world's first commercial internet browser, which operated in the mid-1990s as a powerful complement to Microsoft's operating system. Initially, Netscape held a dominant share of the browser market. As a complement, Netscape's browser made Microsoft Windows more valuable to PC users. But as browsing grew in importance, Microsoft introduced its own browser and integrated browsing functionality directly into Windows, ultimately driving Netscape from the market.

The economics of competition can look quite different for a complementor than for a traditional entrant. Whereas the latter will be maximizing profits on the same landscape as other industry rivals, the complementor, maximizing profits on a joint landscape, can find different optimization points. This allows the complementor to cross-subsidize its positions in ways that traditional diversifiers, which rely on supply-side rather than demand-side synergies, cannot. Such cross-subsidization can be implemented through various strategies. The complementor can sell a bundled A–B offer at a lower price than specialized rivals, as a result of capturing volume on both sides (Heeb 2003). For example, by bundling the browser into its operating system, Microsoft sold the browser at a net price of zero. Similarly, by bundling Word and Excel, Microsoft was able to undercut the prices charged by WordPerfect and Lotus for similar products sold separately. Alternatively, the complementor can keep the A and B offers separate, driving down prices in the A market to increase consumption, which drives up demand growth in the B market, where they may have greater market and pricing power.

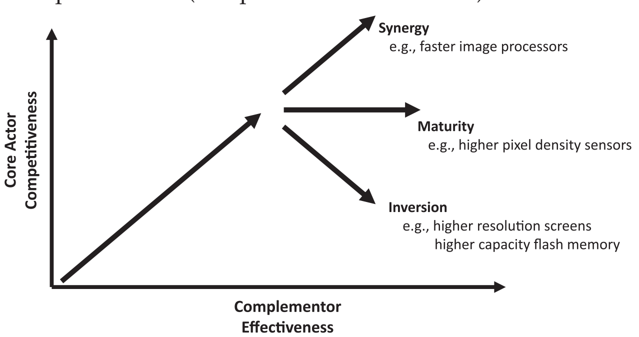
Although adjacent entry by a complementor can lead to implosion of an incumbent, as in the case of Microsoft versus Netscape (Greenstein 2015), more often it leaves the incumbent intact, albeit in a weaker state. Indeed, it is rarely in the complementor's interest to fully replace its partner. Rather, adjacent entry can serve as a vehicle to further enhance the bargaining power and influence of the complementor relative to the incumbent, in effect adding to the process of commoditization. Once a foothold has been established in the incumbent's business, continued integration by the complementor becomes a highly credible threat. Adjacent entries by Intel into motherboards (Gawer and Henderson 2007), Amazon into logistics and delivery, and Amazon and Netflix into movie production (Chavda 2020) can be viewed in this way. Similarly, many internet platform businesses have flexed their muscles with adjacent entries vis-à-vis their primary partners. For example, Zillow entered, in a limited way, into the sale of residential homes with "instant offer programs," where Zillow purchased houses directly from users who were looking to move quickly, thereby competing with real estate agents, who continue to be Zillow's main commercial partners (Levy 2019a, b). Another internet platform, the music service Spotify, made licensing deals with independent artists, bypassing the major music labels, which continue to be Spotify's primary partners (Sisario 2018).

3.3. Displacement Through Value Inversion: Complement Becomes a Substitute

A third mode of disruption through complements arises through the continued development of a complement along its own natural trajectory. In contrast to Christensen's notion of an inferior substitute technology becoming good enough, here we see an improving complementary technology becoming "too good," crossing over from a regime where improvements enhance the value of the core offer to a regime where—without switching trajectory or competitive focus—the complement undermines the value of the core offer. Adner (2021) terms this dynamic, through which a complement becomes a substitute, *value inversion*.

Although the *initial* contribution of all complementors to the value creation of the core offer is, by definition, necessarily positive, their continued development can give rise to three distinct paths (Figure 2).

Figure 2. The Three Possible Relationships Between the Effectiveness of Complements and a Focal Firm's Own Competitiveness (Adapted from Adner 2021)



On the first trajectory, *continued synergy*, complements continue to enhance the focal offer's value as they improve. On the second trajectory, maturity, complements reach a point beyond which their own continued improvement stops impacting the focal offer. Most critical for understanding ecosystem disruption is the third trajectory, *value inversion*, whereby the complement's continued improvement beyond a certain point begins to undermine the focal offer's value. Displacement through value inversion identifies the possibility that the relationship between a focal actor and an initial complement can reverse, even without a shift in the strategic intent of the complementor (which is the case in modes 1 and 2). This is the dynamic through which complements are transformed into disruptive substitutes.

Consider the relationship between digital photo printers (core offer A) and smartphone screens (complement B). Here, improvement of the complement had a uniformly positive impact on the core (continued synergy): in this instance, better image processing increased the quality of pictures and hence the volume of photos printed (i.e., the upper trajectory in Figure 2). In contrast, in the case of sensor resolution, continued progress resulted in a form of decreased marginal utility (DMU) from these performance improvements as regards the value creation of the core (maturity).[8] Thus, while initial improvements in pixel density were critical for less grainy, more printworthy digital images, beyond a certain point, however (say, 6 megapixels), resolution ceased to matter for any but the largest printing format such as posters or bus-side advertising (i.e., the middle trajectory in Figure 2). Note that while the marginal utility from performance improvements decreased, it never turned negative.

Value inversion occurs when, after an initial period of synergy (requisite for anything to be categorized as a complement), the complement begins to eliminate the value of the core (i.e., the lower trajectory in Figure 2). In the digital imaging realm, this inflection point was reached as the image quality displayed on smartphone screens began to match that of printed output. Crossing this threshold undermined the core's value creation (printers), an effect that was magnified by improvements in other dimensions such as storage capacity (allowing phones to store more pictures—with better resolution—than most picture albums) and image management (allowing for better, more efficient organization compared with most albums and shoeboxes).

This dynamic is far from unique to digital imaging. In the 19th century, for example, the telephone was initially regarded as a clear complement to the long-distance telegraph, allowing untrained operators to send and receive messages over short distances, thus increasing traffic into the long-distance telegraph network.

With improvement in transmission distance, telephony pushed out telegraphy from the long-distance communication market—the complement became a substitute, ultimately replacing the telegraph for most messaging uses (Smith 1985). Arguably, a similar process may be unfolding today as tablets and smartphones—which began as complements to the personal computer—increasingly serve as substitutes.

Other examples abound: three-dimensional (3D) printers are shifting from prototyping enablers that increase demand for manufacturing capacity to becoming production engines, substituting for machine tools. Software simulators initially made physical testing more productive but, as they have become increasingly accurate and predictive, reduce the volume need for physical testing (e.g., wind tunnels; crash tests, where physical tests are increasingly relegated to certification, rather than being a core part of optimization). Smart tractors reduce waste in planting and, hence, volumes of seeds and fertilizer used. In the professional services sector, LinkedIn initially was a helpful source of leads for headhunters, but eventually the headhunters were displaced as improvements to LinkedIn enabled corporate recruiters to identify leads on their own.

Although the three modes of disruption through complements represent discrete, distinct pathways toward disruption, they are often present simultaneously within a system. Furthermore, although we have presented them in dyadic form—core A, complement B—contexts often entail a higher level of interdependence. Ecosystems are defined by "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize" (Adner 2017, p. 42). In this regard, in real-world contexts, a given complementor can threaten multiple modes of disruption at the same time, and disruptive threats can arise simultaneously from different locations within the ecosystem. In the following section, we explore these multilateral interactions in the context of the evolving automotive industry.

4. Transformation of the Automotive Industry: Alternative Scenarios of Disruption Through Complements

4.1. Industry Overview

Several decades ago, the automotive industry was viewed as technologically mature, following a post-dominant design path that was increasingly evolutionary and incremental (Abernathy 1978). By contrast, today's automotive industry is seen to be on the cusp of radical change. Four technologies are combining to fundamentally reshape the structure of the mobility ecosystem: (1) electrification of the vehicle powertrain, (2) autonomous driving, (3) shared-use mobility platforms, and (4) data connectivity. These are collectively known as CASE (Connected, Autonomous, Shared, and Electric).

Incumbent global automakers such as Toyota, GM, Ford, Volkswagen, and BMW—commonly called original equipment manufacturers (OEMs)—have long dominated the traditional automotive industry. OEMs have played the role of "system integrator" by controlling final assembly, directing complex supply chains, overseeing brands and marketing, coordinating with dealerships, responding to safety and regulatory requirements, and bearing ultimate responsibility for product quality and liability (Jacobides et al. 2016, Keith and MacDuffie 2018). Jacobides and MacDuffie (2013) argue that the continuing need for such integration has enabled the OEMs to avoid the fate of PC assemblers in recent decades. The OEMs have maintained power, control, and market value relative to others in their ecosystem, whereas PC assemblers (except for Apple) have been displaced by suppliers of complementary components, such as Microsoft and Intel.

Although the OEMs have so far maintained their central positions, a key question is whether they will be able to thrive—or even survive—in the new era, as the four emerging technologies reshape the industry. Will the incumbent OEMs be disrupted by new entrants, such as Tesla, Waymo, Uber, and others, which are attempting to leverage one or more of these technologies? Many authors have tried to predict how the automotive ecosystem will evolve (e.g., Collie et al. 2017). Our goal is not to suggest any particular path but rather to point out several ways in which disruption by complements might take place as the industry is transformed. Thus, we are not making predictions; rather, we present the auto industry as an illustrative example of our framework. The changing automotive ecosystem is particularly attractive because it allows us to illustrate all four categories of our framework within the context of a single industry.

Before discussing future possibilities, it is useful to consider some industry history. The period spanning the late 19th and early 20th centuries was a time of enormous technological ferment in the automotive industry, with hundreds of entrants and many competing technologies and designs. Applying our definition, the entry of these automotive firms proved disruptive (via substitution) to horse-drawn carriage producers, all of which failed to survive. The auto industry eventually coalesced around the dominant design of the Ford Model T, leading to a shakeout of most companies. This was not, however, a disruption based on our definition, given that Ford was one of the automotive incumbents in the industry at the time.

4.2. The Four Emerging Technologies

In the following subsections, we summarize the status of each of the four emerging technologies in the context of today's automotive industry; then we consider their potential role in driving disruption through complements.

4.2.1. Electrification of the Vehicle Powertrain. The internal combustion engine (ICE) has served as the auto industry's dominant technology for over a century. The transition of the vehicle powertrain from ICE to battery-powered electric (EV) has been slow because of high production costs and the limited distance ranges of early EVs. By 2019, global sales of plug-in passenger cars had achieved a mere 2.6% market share of new car sales (International Energy Agency 2020).

Nevertheless, by 2020, virtually all the major automotive OEMs had introduced commercial EVs, experimenting with models to make the transition from ICE to EV. Moreover, Tesla, the most successful EV company, achieved a stock-market capitalization higher than any of the established OEMs. Thus, despite the small market share of EVs, expectations are high that the EV will become a major powertrain in the automotive sector, if not the dominant one.

4.2.2. Autonomous Vehicle Technology. Whereas EV technology is pursued primarily by OEMs, autonomous vehicle (AV) technology is being pursued by actors throughout the ecosystem. They have been integrating cameras, radar, and sensors with an onboard computer, data, and advanced software to create AV systems, using different approaches. Tesla's "autopilot" can (as of 2020) guide the car "from a highway's on-ramp to off-ramp"; it can also automatically park the car and summon it from a parked position. Waymo (a subsidiary of Google) is focused on developing an AV operating system and has integrated its technology into vehicles from the OEMs Jaguar Land Rover and Fiat Chrysler. Uber, the dominant ride-share player, is pursuing a similar integration approach, whereas traditional OEMs General Motors and Ford have tied themselves, respectively, to AV start-ups Cruise (through acquisition) and Argo AI (through equity investments). Component maker Intel/Mobileye, which produces modules that provide ADAS (advanced driver-assist systems) to more than 25 global automakers, is developing partnerships with OEMs and tier 1 suppliers to develop production-ready fully autonomous vehicles (https://www.mobileye.com/about/).

Although a fully autonomous vehicle capable of operating in a wide range of environments would be revolutionary, such an achievement would follow many years of gradual improvement in automotive safety features. Full automation remains years (or perhaps decades) away, but partial vehicle automation has steadily been growing. In 2019, for example, adaptive cruise control with lane-centering steering was available on 55 models (Mays 2019).[9] Such features have enabled OEMs to differentiate their vehicles in the marketplace.

4.2.3. Shared-Use Mobility Platforms. Compared with the evolving status of AV, shared-use mobility platforms (also called "mobility as a service") were well developed by 2020. Such platforms include ride hailing (e.g., Uber and Lyft), car sharing (e.g., Zipcar), and peer-to-peer car sharing (e.g., Turo). Industry leader Uber diversified into related markets such as food delivery and invested in substantial research and development to develop its own autonomous vehicles.

4.2.4. Data Connectivity. To achieve full AV, both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) connectivity are required. In 2020, such connectivity was rudimentary at best. The required backbone for V2I, 5G internet, was just starting to be rolled out in the United States. Moreover, the required set of standards for V2V and V2I connectivity did not yet exist. In general, the lack of infrastructure and standards for data connectivity represented a major remaining roadblock to achieving full AV.

Whereas the other three technologies have potential for disruption, data connectivity seems likely to follow a path of continued synergy, with neither the technology nor its producers veering off the complement trajectory. None of the companies offering enhanced connectivity (5G and related services) in the United States or Europe is expected to directly threaten the established automotive OEMs. Indeed, absent other threats, enhanced connectivity would likely improve the OEMs' competitive position by making more services available to vehicle owners, thereby increasing the value of the OEMs' product and allowing the OEMs to offer a wider range of services. Teece (2017) characterizes 5G as an "enabling technology" that will enhance and accelerate the development of other technologies in the automotive sector, particularly autonomous driving technology.

4.3. Potential Scenarios of Disruption

We now consider how our four modes of disruption could *potentially* play out in the future evolution of the automotive industry. Table 2 reprises these four categories, now with automotive examples. The disruption threats arise from three of the transformative technologies: electrification of the powertrain, AV technology, and ride-sharing platforms. We present this discussion not as a set of predictions but rather as a demonstration of how the concepts can be applied to structure debate in an emerging context.

Table 2. Disruption Threats to the Automotive OEMs

Form of disruption	What does the incumbent lose?	Automotive example	How can incumbents respond?
(1) Substitute captures market share (*classic disruption*)	Market share	• EV and ICE are substitute powertrains. EV replaces ICE over time.	• OEMs convert their designs and production facilities from ICE to EV.
(2) Complement drives down added value (*commoditization*)	Margin, influence, control	• AV "brain" becomes the vehicle's central component; interactions between the brain producer and other AV component suppliers become key. • Ride-sharing platforms become the dominant way in which users interact with vehicles, breaking direct relationships with OEM brands.	• OEMs bring AV technology in house through internal development and/or acquisition. • OEMs develop ride-sharing platforms and/or partner with existing platforms.
(3) Complement enters as direct rival (*adjacent entry*)	Market share, influence, control, bargaining power	• Brain producers (e.g., Waymo) and/or ride-sharing platform companies (e.g., Uber) enter vehicle production (possibly using contract manufacturer).	• OEMs take steps to raise entry barriers. • OEMs sell their operations to the new entrants.
(4) Complement becomes substitute *(displacement through value inversion)*	Market size	• Ride-sharing platforms allow for more efficient vehicle utilization, reducing the number vehicles required to serve the market. • AV technology increases safety, eliminating the need to insure against driver error.	• OEMs retreat to the high-performance segment as the automotive market bifurcates into ride-sharing vehicles and recreational cars. • Insurance companies (initially providing a key complement to the automobile) are the incumbents that are displaced.

4.3.1. Classic Disruption: Substitute Captures Market Share. The ICE and the electric motor are substitute technologies; any given vehicle utilizes one powertrain or the other (ignoring hybrid cars, which most observers consider a transitional technology). Thus, the electric car serves as a substitute for the ICE car and is potentially disruptive in the classic way.

The OEMs have long been devoted to ICE technology. They hold a vast array of assets and capabilities relating to ICE. Their vehicle designs have been optimized for ICE, and they own and operate many specialized ICE engine and transmission plants, which are virtually useless for making electric vehicles. Many of their employees are ICE specialists. The OEMs have pursued "sustaining innovations" (Christensen 1997) in ICE technology for decades. Thus, a shift from ICE to EV would not entail a mere swap of powertrains; a fundamental change in product architecture and its supporting infrastructure would be necessary (Henderson and Clark 1990).

The incumbent automotive OEMs have made strong efforts to convert from ICE to EV. They have neither dismissed the substitution threat of the new technology nor struggled to adapt—two hallmarks of a classic disruption. In fact, they have demonstrated remarkable ability to adapt, at least early in the transition.

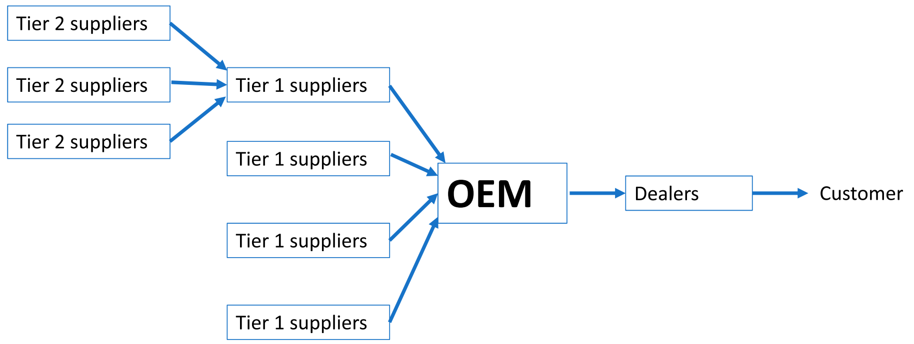
Numerous factors have facilitated the OEMs' transition from ICE to EV. The substitution threat was widely publicized, making it difficult to ignore. Government regulations (fleet fuel-economy mandates in the United States, other pressures in China and Europe) encouraged the OEMs to adopt EV. Even so, ecosystem challenges slowed EV technology's take-off, giving the OEMs years if not decades to adapt. Moreover, the OEMs can maintain both technologies simultaneously, facilitating the transformation.

With EV off to a slow start, the slope of the technological substitution curve has so far been gradual, easing the OEMs' transition from ICE to EV. Even so, the disruptive phase may simply lie in the future, if the substitution curve moves sharply upward at some point.

4.3.2. Commoditization: Complement Drives Down Added Value. Whereas ICE and EV are substitutes, autonomous driving systems and ride-sharing platforms complement both powertrain technologies. The companies specializing in these two complements could eventually drive down the added value of the automotive OEMs, thereby reducing OEM margins, influence, and control.

First, we consider the likelihood that the "brain" of the vehicle–the operating and control system required

Figure 3. (Color online) Historical Automotive Supply Chain



to support AV–becomes critical to the vehicle's value and functionality to the customer. This could allow brain producers such as Waymo to become central to the automotive ecosystem, diminishing the role of the OEMs. Second, we consider the possibility that ride sharing becomes the central function in the automotive ecosystem, allowing one or more ride-sharing companies to displace the OEMs in terms of margins, influence, and control.

The rise of AV technology will, at a minimum, add greater complexity to the automotive ecosystem. Figure 3 depicts the historical structure of the automotive supply chain.

This chain has been dominated by the OEMs, which play a central role. The early days of automobiles raised ecosystem alignment challenges, but the general structure of interdependence that defines these relationships has remained largely stable since then. With clear buyer–supplier ties that can be decomposed into a bilateral structure of exchange, we have observed a recognizable automotive industry for over a century: OEMs have been managing complex supply chains, not aligning multilateral ecosystems. The emergence of AVs is calling this structure into question, giving rise to a new challenge of ecosystem alignment.

The entry of AV brain suppliers such as Waymo, a new set of critical sensor suppliers, and ride-sharing companies such as Uber and Lyft all add new complexity to the system, requiring additional coordination. Questions have arisen about system integration—overseen by the OEMs, historically—leading industry observers to debate whether the commoditization of computer assemblers will repeat in the case of carmakers (Tzuo 2015).

The new relationships between the brain supplier and the complex-sensor suppliers and data providers are not bilateral; these firms will need to interact closely to continuously enhance the AV system and allow for system learning. The coordination of this interaction will be a critical determinant of AV performance, and hence its organization will determine the locus of commoditization. In this regard, the automotive industry of the future may fit into numerous alternative ecosystem blueprints. One possibility is a configuration in which the traditional OEMs continue to play their central coordinating role, as illustrated in Figure 4.

An alternative model (Figure 5) places the automation systems providers at the center of the ecosystem. Here, the brain suppliers would source vehicles from OEMs and would themselves be in direct contact with the sales channel and customers.

According to Keith and MacDuffie (2019, p. 3), "Waymo (a subsidiary of Google) is betting that controlling this OS will be sufficient to become a dominant player in the AV market. The history of the personal computer industry suggests that this strategy, if successful, will lead to considerable migration of value upstream to suppliers, just as Intel's 'Intel Inside' branding convinced consumers that the brand

Figure 4. (Color online) Potential Future Automotive Ecosystem (OEM-centric)

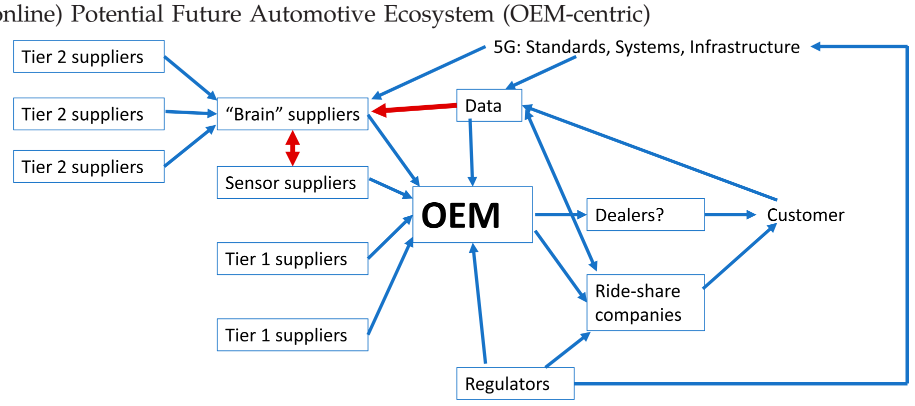
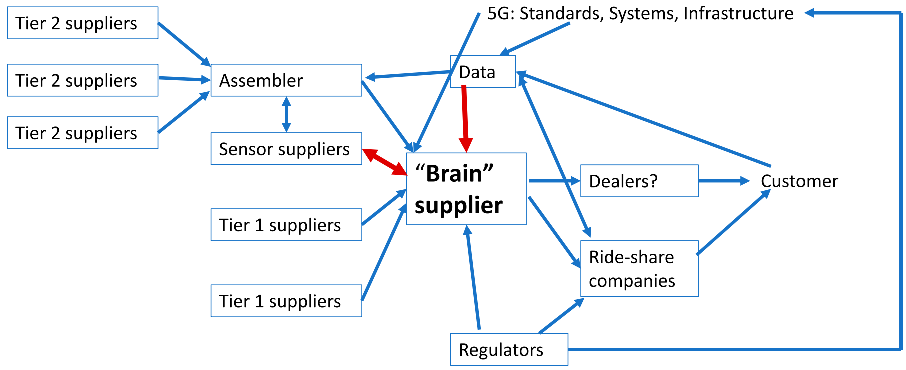


Figure 5. (Color online) Disruption of OEMs by Information Integrators



of the microprocessor was critical in the performance of the whole computer." In this scenario, the OEMs will be reduced to mere vehicle assemblers, combining various component parts with the AV system supplier's critical hardware and software.

Data are also a critical part of the AV system, but it remains unclear who will control the various types of data required for the system to function. Increasingly, data are collected from individual vehicles as they are driven; are these data the property of the customer, the OEM, the AV system supplier, or some other entity? The need for external data such as maps and road conditions has given new life to GPS mapping companies, such as TomTom, which now play an important role in the AV automotive ecosystem through the provision of high-definition 3D maps that are updated in near real time. And as connectivity evolves, new data types and sources will become increasingly important.

A third possibility is that ride-share companies become central to the automotive ecosystem (Figure 6).

Such a disruption of the OEMs would arise if ride-sharing platforms become the dominant way that users interact with motor vehicles. In such a scenario, ride-share companies become the primary connection between vehicles and riders, taking over from the OEMs and their dealers. Differentiation would shift from an OEM brand ("I want a Ford Expedition SUV") to the platform's brand ("I want to travel in a roomy vehicle provided by Uber"). Taken further, if a small number of powerful ride-share companies choose to acquire their own car fleets, they will be able to bargain directly with OEMs, driving down OEM margins, and reducing OEM influence and control. Such a scenario is like unlikely to fully develop overnight, but down the road, it could lead to commoditization of the OEM's business, thus reducing their margins, influence, and control.

4.3.3. Adjacent Entry: Complement Enters as Direct Rival. The commoditization scenarios previously described become more extreme if AV system suppliers or ride-sharing platform companies choose to enter directly into vehicle manufacturing, thereby taking over the OEM role. Direct entry by one or more of these complement providers (which could acquire an OEM or develop the required manufacturing capabilities internally) could further diminish OEM market share, influence, control, and bargaining power.

In a related scenario, ride-share companies or AV system suppliers could choose to contract with white-box contract assemblers to manufacture vehicles, thereby taking over that OEM role (see Figure 7). Such contract assemblers are now common in the electronics industry, where they enable firms with strong brands and design skills, such as Apple, to farm out manufacturing to a competitive sector of product-assembly specialists. These assemblers earn low margins compared with the branded firms.

Figure 6. (Color online) Disruption of OEMs by Ride-Share Companies

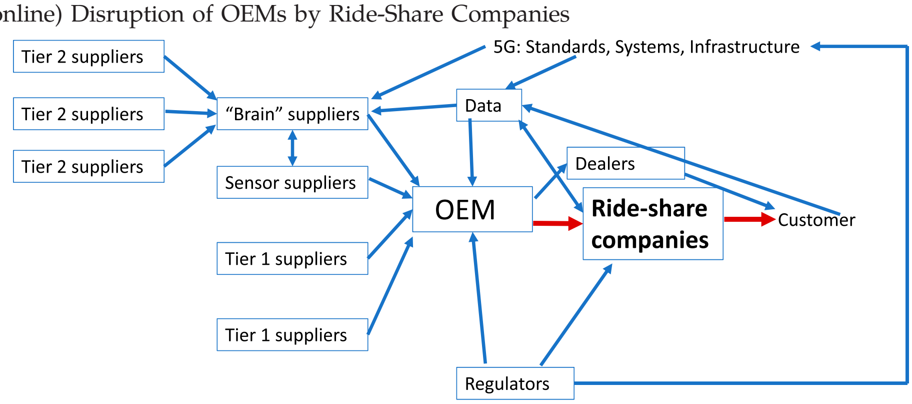
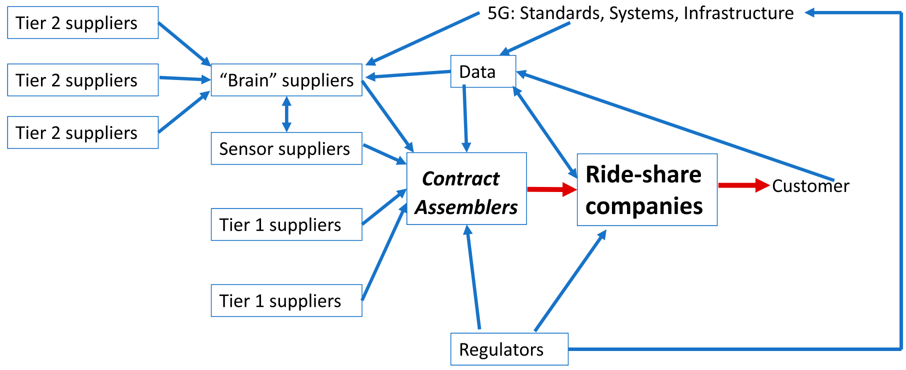


Figure 7. (Color online) Ride-Share Companies Replace OEMs with Contract Assemblers



To date, contract assemblers have not been a significant factor in the automotive industry, where the established OEMs have been protected by relatively high entry barriers (MacDuffie 2018). The massive scale and capital requirements to produce ICE vehicles at low unit cost have historically been major impediments to entry.

A recent debate in the literature addresses the feasibility of new, large-scale entry into the EV market. Using data on Tesla, Perkins and Murmann (2018) estimated the cost of entry into the industry. They found the cost of designing and producing an EV to be within easy reach of large tech companies in the United States and China that have been positioning for potential entry. However, MacDuffie (2018) argued that entry requires mastering sophisticated manufacturing, something in which these firms lack experience. He saw as more likely a scenario of collaboration with the established OEMs that are strong in manufacturing but less experienced in software and machine learning. Thus, it is not clear that direct entry into vehicle manufacturing by the ride-share companies or AV system suppliers (or their contract assembler proxies) will prove technically and economically feasible in the near future. Partnerships with OEMs may yield higher profits. Even so, a credible threat of entry may be sufficient to strengthen the bargaining position of ride-share companies and AV system suppliers within the ecosystem. In any event, the possibility of such an entry serves to illustrate the *complement enters as direct rival* form of disruption.

4.3.4. Complement Becomes Substitute (Displacement).

Initially, ride-sharing platforms were complementary with the OEMs' main business of selling cars. Their rise stimulated demand for new cars, as ride-share drivers were required to own cars of relatively new vintage. In the longer term, though, shared-use platforms could reduce total vehicle sales, given that ride sharing allows vehicles to be used more intensively. Thus, ride sharing has served initially as a complement to the OEMs' business, but over time, it may play more of a substitution role, diminishing the overall volume of vehicle sales.

Furthermore, shared-use platforms seem likely to evolve beyond the current business model, in which ride-sharing drivers use their own cars. The potential for fleets of autonomous vehicles owned by the ride-sharing companies could lead to further displacement of the OEMs. Such vehicles could be based on mechanically simpler, lower-performance designs, given that the vehicle's appeal to the driver is no longer relevant. Passengers in these vehicles may prefer vastly different features from those that OEMs emphasize today. For example, passengers may not want high-performance acceleration, instead favoring vehicles with entertainment systems or greater internet connectivity. This means that cheaper vehicles may be adequate (aside from the cost of the AV technology), and ride-sharing companies may be able to go beyond existing OEMs to find suppliers of such vehicles. A shift to simpler vehicles equipped with modular systems for autonomous driving would allow midlevel-quality contract manufacturers to enter and compete directly with the OEMs.

Such combined effects of ride-sharing technology and autonomous vehicles would lead to a smaller, more competitive automotive market than what the OEMs face today. Conceivably, the market could bifurcate into low-end, relatively simple vehicles (albeit with sophisticated AV technology) for ride sharing and high-end recreational vehicles that are driven for personal enjoyment. Some OEMs might be able to retreat successfully to the high end, whereas others might fail or be transformed into commodity producers.

In this example, progress made by the complement technology (ride-sharing platforms) reduces the size of the incumbents' market, but that market does not go away entirely. Although some OEMs would likely be forced out by the market shrinkage, other players in the automotive ecosystem, such as insurance companies, could be even more severely displaced by complements.

4.4. Complementors Disrupting Complementors

Disruptive dynamics can unfold not only between a core position and a complementary position but also across any two positions in the ecosystem. We have been looking at OEMs as the core actor, but they are just one type of firm in the vast automotive industry facing disruption through complements. Consider auto insurance, which today serves as a complement to motor vehicles. In most countries, it is legally required, given the harm and damage that can be caused by driver error. Moreover, most drivers also get value from insurance, which protects them from large financial loss.

However, once full AV is achieved, drivers will no longer need to be insured. Rather, errors will arise from defects and limitations of the vehicle (or the AV system within it). Auto insurance as we know it today will disappear; the insurance function will likely be taken over by vehicle manufacturers. Ultimately, we could see a full disruption of the incumbent insurance companies' automotive business (except for insuring recreational drivers, which will remain an important niche).

This disruption is likely to unfold incrementally, with complete displacement still many years off. Nevertheless, some effects on the insurance market have already begun. Since the mid-2000s, insurers have tried to convince their customers to accept monitoring in exchange for lower rates. By installing "black-box" devices in their vehicles, which would monitor driving habits by, for example, using a count of hard stops as indicator of aggressive driving, insurers hoped to reward safer drivers. Tesla's real-time data collection on vehicle behavior—pursued to improve its AV algorithms—can also be applied to judge driver safety. By virtue of its preinstalled sensors, Tesla has visibility into every aspect of driving behavior. If allowed by regulators, it could offer perfectly tailored insurance offers to each one its drivers in a way that no third-party auto insurer ever could.

Efforts to improve car safety, historically beneficial to insurers, can thus lead to displacement through value inversion, eliminating the basis of insurers' value creation. This example shows that disruption by complements is a two-way street. In an ecosystem where all firms are partners in value creation, core and complementor are a matter of perspective, rather than absolute.

4.5. A Structure for the Debate on the Evolving Automotive Industry

Given the capabilities of the existing OEMs in dealing with the coordinative complexity of motor vehicle production, it is conceivable that many, perhaps even most, of the current OEMs could survive in the mainstream of the automotive market, thereby avoiding disruption. Historically, the coordinative skills of the OEMs have served as a key bottleneck asset supporting the centrality of the OEMs in the ecosystem. If the brain of the AV of the future turns out to be commodity-like, with multiple competing vendors, the OEMs have a superior chance of retaining their importance. Even the insurance companies, whose existing automotive business seems threatened in the long term, may thrive in the short run as perceived risks rise during the transition to AVs. In general, the time frame of disruption, if it occurs at all, depends on the coevolution of CASE technologies (filling in elements that are currently lagging, such as 5G connectivity and sensors that operate in all weather conditions) as well as strategic actions taken by the ecosystem players.

Our goal in this section has been to show how our typology can be used to organize thinking in an emerging setting rather than to stake out claims to specific outcomes. Our discussion of the automotive industry is thus, explicitly, illustrative rather than predictive. We have sketched out multiple possible evolutionary paths of the automotive ecosystem that illustrate the forms of disruption by substitutes and complements described earlier in this paper. Although all the paths are plausible, some are more likely than others. The value of our framework is in offering a structure with which to make clearer arguments and pose more pointed rebuttals.

The framework we have proposed helps to better understand an entrant such as Tesla, which has leveraged itself along multiple disruptive pathways in the evolving ecosystem. If Tesla were merely an EV producer, it would pose only a limited threat to the established OEMs. Tesla's powerful positioning comes from the fact that it has developed strong capabilities not only in EV but also increasingly in AV and big data—and potentially in other parts of the ecosystem once the company adds its proposed "robotaxi" or ride-sharing service. Tesla has exhibited remarkable dynamic capabilities in adapting to opportunities not only in the automotive arena but also in related domains such as home battery storage. It is the confluence of these activities—covering virtually all the disruptive pathways we have discussed—that makes Tesla such a threat and likely contributes to its massive market valuation relative to the OEMs, despite Tesla's still-small vehicle sales in 2020. Unlike the latent threat to the OEMs posed by complementors such as Waymo and Uber, or the substitution threat posed by EV, Tesla has grown to rival the OEMs, beating them to the future by integrating its set of capabilities to encompass all key parts of tomorrow's automotive ecosystem.

Tesla's collection of massive data on its cars and drivers gives it a key advantage in the evolving automotive ecosystem. In general, disruption by complementors seems likely to increase with the rise of big data. Data become a critical asset, characterized by fungibility (data created for and by one use can be employed in another use) and approximation (correlated data can be captured at multiple points within an ecosystem). Data also present a problem of ownership and exclusion. As data ownership becomes more important, the potential for complementors to affect the competitiveness of focal firms—positively *and* negatively—will increase.

5. Conclusions and Implications

We have described three pathways of disruption through complements: commoditization, adjacent entry, and value inversion. Along with disruption through substitutes and well-known processes of competitive rivalry, these three pathways represent major threats to the continued success of incumbent firms in many industries. Disruption through complements is distinctive in that the threat arises not from outside entrants or existing rivals but rather from complementors—actors that are already contributing to value creation and therefore have resources, capabilities, relationships, and learning opportunities that differ from those that characterize other potential threats.

Much prior work has focused on the role of complements in interfirm relationships. Our novel contribution is to flesh out the dynamic processes that turn “friends” into “foes” within business ecosystems. The pathways we have described in this article convert initially positive relationships between complementors into something more adversarial. Commoditization comprises a shift in power, influence, and/or value away from a focal firm and toward an ecosystem partner. Adjacent entry converts a partner into a direct rival. Value inversion, the most subtle of the pathways, gradually transforms a complement into a substitute. In general, recognition of the three pathways of disruption through complements is important for a more complete understanding of how and why many successful firms lose power, profitability, and market share.

We have shown how actors with central roles in the ecosystem can find themselves diminished or displaced by other players in that system. In some of our examples, the displacement is complete; we have clear disruption in such cases. In other examples, the displacement is partial or merely in the form of a credible threat, where the outcome may depend on the response of the threatened player. In these situations, which have the potential for disruption through complements, the threat of disruption must be taken seriously by incumbents, even if the initial movement is only a small departure from the status quo.

Beyond affecting the profitability of incumbents, disruption through complementors can also alter the direction of industry evolution. Commoditization, adjacent entry, and value inversion have distinct implications for the direction of longer-term profitable growth for industry actors. These processes affect the investment and innovation efforts of the actors, as well as the external selection environment that governs their access to resources. Disruption through complements is also likely to leave a different empirically observable fingerprint on the target industry compared with disruption by substitutes. The pace of change, shifts in business models and profit drivers, the locus of differentiation, and the guarantee of quality—all of these will be affected by the differential starting point and motivation of complementors.

Understanding the shifting positions and power of firms within an ecosystem is becoming increasingly relevant given the rise of digital technologies, for which complementarities are often paramount. Many of the examples we have provided involve such technologies. Once primarily a characteristic of the computer industry, digital technologies are now ubiquitous.

In the automotive industry, digital technologies are converting conventional supply chains into ecosystems. The established automotive OEMs, which have dominated their complex global supply chains for decades, now face challenges in dealing with new partners as the industry moves to an ecosystem structure. We have discussed how AV technology and ride-sharing platforms have the greatest potential for disruption through complements. It will be fascinating to see which, if any, of the possible pathways of disruption come to be realized in the automotive sector.

From a managerial perspective, our framework lays out a broad road map of potential threats and actions for ecosystem players to consider. We formalize for managers what some have understood intuitively, as many firms have carried out strategies for disruption through complements without guidance from our study. Microsoft (in the 1980s and 1990s) and Tesla (today) are prominent examples of companies that have masterfully pursued disruption through complements. Although Bill Gates and Elon Musk seem to have understood the pathways we have laid out, we hope that most managers will find value in categorizing and assessing potential threats from evolving technological substitutes and complements along the lines we have proposed. Such assessments can provide insights for competitive defense as well as for attack.

Our framework provides a unified view on a range of threats to incumbents that have been noted in prior studies. Our contribution is a taxonomy of mechanisms and a broad perspective on the process of disruption. The framework we propose has potential implications for research on industry evolution, strategic positioning, platform strategy, and ecosystem strategy. We invite others to build on and extend the framework.

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Endnotes

[1] Whereas other, more standard forms of product substitution can displace incumbents (see Porter (1980)), such forms, which can be driven by factor price changes and differential rates of technical change, are well understood.

[2] From a customer perspective, we use *value* to refer to the difference between the customer's willingness to pay and the price of the product or service. We assume that a customer faced with two competing products will choose the one that delivers higher value (i.e., net of price paid). The value proposition of disruptive entrants improves over time as their product or service gets better, cheaper, or both. Customer switching occurs when the value from the entrant's product exceeds the value from the incumbent's product. From an *ecosystem* perspective, a firm's *added value* is the total customer value that would be lost if the firm were removed from the ecosystem. In situations of disruption (through substitutes or complements), the added value of the focal incumbents diminishes over time, even though the total value to the customer increases.

[3] Prior work has shown how, beyond appropriation of immediate rents, control over complementary assets can affect firms' abilities to enter new markets (e.g., Mitchell 1989 and Wu 2013) and survive transitions brought about by substitute technologies (e.g., Tripsas 1997). Our focus, by contrast, is about how the complement itself can drive the upheaval in the market.

[4] Recognizing that complements are qualitatively different from substitutes, Porter explicitly excludes them from his famous framework because, unlike the other forces, their impact is variable: "[L]ike government policy, complements are not a sixth force determining industry profitability since the presence of strong complements is not necessarily bad (or good) for industry profitability. Complements affect profitability through the way they influence the five forces" (Porter 2008, p. 34).

[5] The addition of complements to catch up to the offer of a competing platform is more akin to imitation than to disruption. Even before IBM added Lotus 1-2-3 to the IBM platform, its PC was a clearly recognized rival to the Apple. There is a great deal of competitive rivalry among platforms and ecosystems that does not qualify as disruption. We thank an anonymous reviewer for this observation.

[6] Multiple factors contributed to the broad decline in differentiability—large among them were modularity (Baldwin and Clark 2000) and a lack of ex ante strategizing regarding the locus of differentiation on the part of assemblers (Jacobides and MacDuffie 2013, Jacobides et al. 2016). No less important was the limited trajectory available to BIOS as a position in the system—the potential for continued, robust innovation regarding input–output was far lower than in other components, especially the microprocessor and the operating system.

[7] Although the Microsoft–Intel collaboration is often referred to as the Wintel standard, Intel always faced competition from AMD in a way that Microsoft did not.

[8] This is an interesting variant of the DMU from performance improvements identified in Adner (2002) and Adner and Zemsky (2005) as the fundamental driver of classic disruption. In those studies, DMU arose as increases in the performance of the focal technology yielded ever smaller increases in customer utility. In the present case, the absolute utility (i.e., not marginal) that customers derive from the performance of the focal technology is being eroded through improvement in the performance of the complementor.

[9] Honda, for example, is not a leader in AV, but it offers a "Sensing" package with the following features: lane departure warning, lane-keeping assist system, forward collision warning, collision-mitigation braking system, road-departure mitigation system, and adaptive cruise control with low-speed follow.)

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