Business Horizons (2019) 62, 83—94

Available online at www.sciencedirect.com

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Competing in digital ecosystems

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KEYWORDS
Digital ecosystems;
Digital envelopes;
Product-in-use information;
Digital transformation

Abstract Digital technologies are revolutionizing traditional interdependencies among businesses. As a result, managers have begun to recognize their business environments as digital ecosystems. For firms accustomed to framing their business environments as industries, this represents a significant shift in perspective—one that requires an understanding of fresh strategic initiatives necessary to compete in the digital era. In this article, we highlight what is new and different about digital ecosystems for firm strategy. We offer frameworks that explain how digital ecosystems provide firms with new sources of value and new avenues for growth. Two sets of underlying concepts govern these frameworks: (1) production and consumption ecosystems and (2) digital envelopes and product-in-use information. We introduce and elaborate upon these foundational concepts and highlight new strategic options for firms to compete in digital ecosystems.

1. The power of digital transformation

Most managers now accept that firms compete within ecosystems. They view the modern business environment as interdependent networks of entities that connect with one another to create and capture value (Williamson & De Meyer, 2012). Managers have also begun to accept the analogy with biological ecosystems wherein multiple species and diverse life forms are interdependent (Moore, 1993). Digitization—especially through the pervasiveness of smartphones, cloud connectivity, the internet of things, 3-D printing, and other such related developments—has further compelled

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https://doi.org/10.1016/j.bushor.2018.08.013
0007-6813/

managers to focus on ecosystems not just as a means for improving efficiency, but also as a pathway for growth (Niden & Spriggs, 2016). The purpose of this article is to shed light on the distinctive features of digital ecosystems and the new opportunities they bring for firms.

Ecosystems signify interdependencies, networks, and partnerships (Kapoor & Lee, 2013; Zahra & Nambisan, 2012). These concepts are familiar to most companies as they play a role in managing interdependencies within the production process, supply chains, and distribution networks (Porter, 1985). Firms also recognize how their competitive actions and those of rivals are interdependent and appreciate the need to orchestrate them carefully to maintain industry structure attractiveness (Brandenburger & Nalebuff, 1995). They have rich experience in managing partnerships with suppliers—or alliances with rivals—and a robust comprehension of the networks that shape their value chains (Yu, Subramaniam, & Cannella, 2013).

Digital ecosystems, however, are powered by new digital technologies that have transformed the very nature and scope of traditional interdependencies. Digital ecosystems are far more expansive, with their reach and significance transcending traditional value chains and conventional industry structures. Today's music sector, for example, straddles computers, smartphones, social media platforms, and software. Digital ecosystems are also disrupting traditional industry structures on a grand scale and at an extraordinary pace (Gerth & Peppard, 2016). Apple, Google, and Samsung are rewriting the rules of delivering retail finance, a domain dominated for decades by Visa, MasterCard, and American Express. Healthcare's future appears to be at the intersection of traditional pharmaceuticals and technology titans such as Alphabet's Verily unit and IBM's Watson. In these new digital ecosystems, conventional products, services, and their underlying value chains are discovering unprecedented expansion in their scope and new opportunities to deliver value. Elevators, washing machines, and turbines can inform consumers in advance when they may break down; locomotives can inform drivers about optimum speeds for maximizing fuel efficiency; cars can find empty parking spots; and doorbells can do double duty as home security devices.

Some firms have already embraced these changes. Others, still accustomed to competing within traditional industry structures, need to adapt to new ecosystems driven by new digital technologies. This effort is commonly referred to as *digital transformation* (Westerman & Bonnet, 2015). While traditional firms must strive to retain their long-established strengths, they must also absorb new approaches to compete in a world of digital ecosystems. Our study focuses on this challenge and offers an analysis of how firms could manage their digital transformation journey. Our core framework is anchored by a set of interrelated concepts: (1) production and consumption ecosystems and (2) digital envelopes and product-in-use information.[1] Together, these concepts offer firms a fresh lens via which to identify new value opportunities offered by digitization and grasp novel approaches to compete in digital ecosystems (see Figure 1). We frame digital ecosystems as a combination of production and consumption ecosystems powered by digital envelopes and product-in-use information. Before we further clarify this definition and present the transformative potential of digital ecosystems, we expand on its foundational concepts.

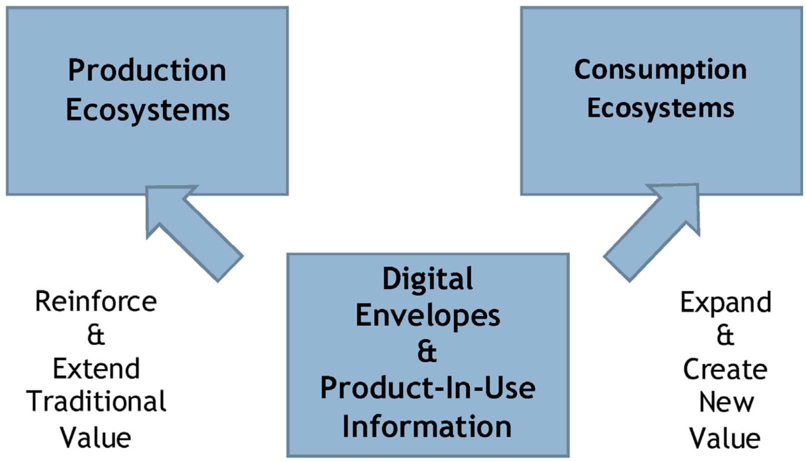
2. Production and consumption ecosystems

The contrast between traditional industry structure-related interdependencies and the new interdependencies driven by modern digital technologies can best be seen in the distinction between production and consumption ecosystems. Production ecosystems consist of interdependencies enmeshed in a value chain, such as producing and selling a product or delivering a service to a customer. Conversely, consumption ecosystems consist of interdependencies that evolve after a product is sold or a service is offered and as it is being consumed.

For a conventional light bulb, for instance, production ecosystems entail interdependencies across various suppliers, manufacturing and assembly plants, research and development (R&D), distributors, and retailers. In contrast, its consumption ecosystems entail interdependencies that come into play after the bulb is sold, such as the availability of sockets, wiring, and electricity. Traditionally, most firms were designed to focus primarily on their production ecosystems, as consumption ecosystems were rarely relevant to their business models. For example, established bulb manufacturers such as GE and Philips have long been proficient at coordinating hundreds of suppliers, scores of integrated or outsourced plants, and various distributors and

[1] The term "product" refers to both products and services in this article.

Figure 1. Framework for digital ecosystems



mass retailers such as Sears, Walmart, or Home Depot. Engaging in the domains of sockets, wiring, or electricity understandably never made much business sense for them.

With modern digital technologies, however, the conventional bulb has evolved into a smart bulb. Equipped with sensors and Internet of Things (IoT) connectivity with a variety of other objects, the smart bulb encounters a host of new interdependencies when consumed; it connects to an expanding set of objects such as Amazon's Echo, Google's Nest, smartphones, smart doorbells, and smart blinds. These new interdependencies generate significant new value to both consumers and producers that goes far beyond a bulb's conventional role in lighting. In homes, for instance, it can be part of security systems helping capture motion sensing or aiding live camera feeds. In warehouses, it can analyze the movement of inventory, improving storage and logistical efficiency. On city streets, it can sense gunshots, alert police, and switch on camera feeds for evidence in subsequent crime investigations. Such new domains for value opportunities arise from the smart bulb's expanding consumption ecosystem, as more and more objects, assets, systems, and people become digitally connected. If bulb producers choose to engage in these emerging-consumption ecosystems, they can create new revenue-generating services from bulbs.

The concept of consumption ecosystems can be traced to the well-known notion of complementarities (Lee, Venkatraman, Tanriverdi, & Iyer, 2010). Complementarities exist when any set of products or services needs to be used in tandem and has little value on its own (Dhebar, 2016). Toothbrushes and toothpaste, DVDs and DVD players, or paper and printers are classic examples. Consumers usually buy such products separately and combine them for their own use. Traditionally, firms have provided different kinds of options for consumers to make those combinations. Some companies offer open standards such as light bulbs and sockets; others offer proprietary standards such as razors and cartridges (e.g., Gillette) or modular designs that enable adding different complements at later times (such as printer ports on personal computers). Some manufacturers co-own or co-brand the complements such as toothbrushes and toothpaste (e.g., Colgate), while others like bulbs and sockets do not. Given the cumbersomeness and tangible limitations of combining physical objects beyond a manageable number, the scope of such complementarities in the past was understandably small.

But with the rise of software, sensors, and connectivity, the scope and significance of such complementarities significantly expanded because of the ease with which consumers can connect different digital products (Gao & Iyer, 2006). For instance, the software driving the operating system of a smartphone enables consumers to add all kinds of software-driven apps. Thousands of third-party developers can also complement a smartphone's operating system software. Technologies such as application program interfaces (APIs), which enable software programs to communicate with one another, have further expanded this scope exponentially (Iyer & Subramaniam, 2015a). The wide-scale possibility of connecting a growing range of complementary products—and the options for countless third-party entities to provide the complements—has given rise to what we describe as consumption ecosystems (Iyer & Subramaniam, 2015b). And with software becoming an integral part of a growing number of products and other physical assets, the significance of consumption ecosystems for industrial-age firms is also steadily growing. The software operating system Sync in Ford's new connected cars, for instance, is open to an estimated 18 million developers (Ranger, 2013); this unlocks a formidable consumption ecosystem for auto manufacturers and enables them to offer a vast range of apps and services consumers can mix and match to customize their cars after purchase.

Consumption ecosystems personify what is new about business interdependencies; they either did not exist or had narrow and insignificant scope before the modern developments in digital technologies. Interdependencies in consumption ecosystems can allow for significantly more plug-and-play options. In contrast, production ecosystems represent traditional industry structure-based interdependencies. These interdependencies among supplier, R&D, manufacturing, or distribution operations tend to get hardwired into routines and are not easy to reconfigure. Indeed, traditional reengineering efforts to make changes in production ecosystems are notoriously time-consuming, expensive, and risky (Dixon, Arnold, Heineke, Kim, & Mulligan, 1994).

That said, production ecosystems are also being transformed because of modern digital technologies. Digitally embellished production ecosystems can help firms significantly enhance the features of traditional products and services. These enhancements, which we will subsequently elaborate on, largely reinforce their traditional market positions. Industrial-age firms must embrace new trends in digitization to reinforce their traditional interdependencies in the production ecosystem. More significantly, they must add to their focus new interdependencies in the consumption ecosystem that will open new areas and opportunities for growth.

In ignoring consumption ecosystems, traditional firms not only miss out on potential growth opportunities but also open themselves to threats of disruption from digital players that thrive in these ecosystems. Google, Facebook, Apple, Amazon, and Uber have already begun influencing several consumer products' consumption ecosystems through their different software platforms. For instance, Google Home or Alexa may already be better positioned to control the light bulb's consumption ecosystem in smart homes, connecting the bulb to other devices such as alarm systems or thermostats. As value shifts from the physical bulb to new services within the consumption ecosystems of smart homes—such as home security or energy conservation—traditional bulb producers focused only on production ecosystems may face erosion in their traditional value. It is in the interest of firms to find ways to not only revitalize their production ecosystems but also engage in new consumption ecosystems. To understand how firms can do so, it is important to recognize the second set of concepts we highlighted earlier: digital envelopes and product-in-use information.

3. Digital envelopes and product-in-use information

A digital envelope is a digital representation of a physical product and its use. The digital representation comes through the collection, analysis, and deployment of real-time, product-in-use information on both the product's operation and the environment in which it is used. Product-in-use information is collected via sensors that can observe the operation of every individual or group of assets. It is analyzed and deployed through software platforms and analytical tools.

The more sophisticated and intricately positioned the sensors are on any asset, the more refined and powerful the collected information. A digital envelope of a car, such as a Tesla or Chevy Bolt, senses detailed information on the car's operations such as how its components like engine, exhaust, or brakes are working; it also gains real-time information on the car's environment. This information is both *contextive* (e.g., information on roads, maps, traffic or weather conditions)and *contextual* as to specific location, how far any other car is behind or in front, or in a side lane helping the driver decide on how much to accelerate or when to change lanes (Pitt, Berthon, & Robson, 2011). This has allowed Tesla to collect detailed product-in-use information on 5 billion miles (Lambert, 2017), 1.3 billion of which are when cars are switched to self-driving mode (Hull, 2016). GE has 66,000 individual jet engines (Powers, 2017), locomotive, and turbine assets, each of which has a unique digital envelope operating on its software platform Predix. An analytical model draws various inferences from the data using advanced techniques, big data, and self-learning artificial intelligence. The software platform feeds these inferences back into the asset to repeat the cycle. With repeated cycles, the physical asset itself becomes smarter, providing even more nuanced data to its digital envelope. With every additional mile driven in each specific trip of GE's locomotives, for example, its digital envelopes can better optimize fuel costs and emissions by processing the total weight of the train, the car configuration, the topography of the route, and the environmental conditions along the route. This enables GE to offer new services in its locomotive business to help drivers maintain optimal speeds that minimize fuel consumption.

With the proliferation of sensors along with advances in an array of analytical tools and artificial intelligence, digital envelopes are applicable to nearly every physical asset today. A digital envelope of an Oral-B toothbrush being used by a consumer streams product-in-use information on how the brush operates, including the speed of rotors and the interaction of its bristles with gums and tooth enamel. The toothbrush uses Bluetooth connectivity and smartphone apps to stream the information. Digital envelopes of mattresses can capture data on individual consumers' sleep patterns through heart rates, breathing rhythms, tossing and turning, and even snoring. This information has the potential to dynamically adjust the contours of the mattress to enable better sleep. The information is already being connected to lamps for lighting adjustments or to thermostats for optimal temperatures while sleeping. New prototypes are being developed to connect this information to pulmonologists or sleep specialists to detect sleep apnea and intervene medically if so required. Similarly, with the help of nanotechnology, liquid detergent digital envelopes may soon enable manufacturers of washing machines and detergents to sense the exact process of how the detergent cleans clothes in real time. Today there are digital envelopes of pills (e.g., Abilify Mycite, a drug for bipolar disease) that can inform doctors whether their patients take their medicines (Belluck, 2017). Such digital envelopes are made possible by sensors both within each pill and on wearable patches, communication between which is managed by smartphone apps.

Each digital envelope operates on a software platform very much like how an individual operates on Google's search engine or Facebook's social media platform. And just as Google or Facebook can over time get an understanding of an individual user based on the person's interactions with the platforms, so can the digital envelope of every individual asset gain information on that asset based on its real-time operations. While sensors extract and offer raw information, software platforms convert it into interpretable meanings for different goals. For example, light bulb sensors can offer raw data on the motion of objects. Depending on whether the motion-sensing is in homes, warehouses, or city streets, software platforms channel the information for different goals such as energy conservation or security in homes, efficient logistics in warehouses, or city safety in streets.

Product-in-use information is different from the kinds of business information firms have traditionally generated since the advent of information technology (IT) over the last few decades (Dedrick & Kraemer, 2005). Conventional IT services collect information through databases or customer relationship management (CRM) systems that largely focus on improving prevailing workflow efficiencies in the production and selling of products. For example, clothing retailer Zara's database of customers and in-store transactions can help the company forecast fashion trends or sales and accordingly adjust its manufacturing and retailing capabilities. Product-in-use information generated by digital envelopes entails understanding what happens to those products after they are sold by tracking the interactions of the products with other objects in customers' environments as they are being used. This difference is important, as product-in-use information can not only offer unprecedented insights into how products are used but also how they connect with other products, which expands networks and generates new opportunities for value.

In recognizing the digital envelope as a digital representation of a physical entity and use, it is helpful to appreciate its strategic significance beyond just an amalgam of sensors and the sense-making of product-in-use information through operating systems. It is a construct that helps firms choose the unit of analysis to collate, analyze, and deploy product-in-use information. For locomotives, jet engines, mattresses, cars, or pills, each individual product is often the chosen unit of analysis. For search engines, it is an individual user. Yet all digital envelopes need not be at the level of individuals or individual products. In manufacturing plants, digital envelopes are options not just for each individual machine, but for a section of a plant or even an entire plant. In the first case, digital envelopes help monitor the performance of individual machines such as robots; in the latter two cases, the digital envelopes help monitor performance of an entire production system. What a firm intends to do with its digital envelope and its product-in-use information drives these choices. These choices, in turn, help anchor its objectives for its sensors, analytics, and operating systems. Envisaging digital envelopes is an important precursor to a firm's digital strategy. Indeed, as we elaborate below, how firms frame their digital envelopes and use them to channel product-in-use information into production and consumption ecosystems drives how they compete in digital ecosystems.

4. Leveraging new opportunities from digital ecosystems: Strategic options

Building on the concepts in the earlier sections, we see digital ecosystems as a combination of complex production and consumption ecosystems that need to be managed as a system of interdependencies. Digital envelopes and the product-in-use information they generate are the prime movers to do so, injecting new value into both production and consumption ecosystems. This is because a firm can intensify the value of product-in-use information as it gets channeled into production and consumption ecosystems in different ways (Glazer, 1991). A firm's strategic options can be framed as how it chooses to channel its digital replicas: toward production ecosystems, consumption ecosystems, or both (see Figure 2). The four quadrants in Figure 2 represent distinct strategic choices about how/where firms compete in digital ecosystems. The lower-left quadrant is about getting ready for digital transformation and setting up the underpinnings to generate advantage. The upper-right quadrant is about dominant orchestration of digital ecosystems, signifying the nature of emerging new digital monopolies. The other two quadrants represent players that have segment-level advantages in ecosystems and are seeking to expand their presence via various hybrid approaches. These firms start with certain positions in the digital ecosystem network because of their history and heritage and subsequently seek new connections (see Table 1 for a comparison of the quadrants). We expand below on this logic of digital ecosystems and offer a roadmap for firms on how they can compete and partner with others in digital ecosystems.

4.1. The digital foundation

Every firm begins somewhere in its digital transformation journey; the digital foundation is its first stage. Here, a firm is on the periphery of the modern digital revolution and testing the waters of digitization while maintaining the status quo on prevailing business models and market positions. A company may introduce smartphone apps for certain services or experiment with big data to better predict market trends and improve its prevailing workflow efficiencies. Most banks, for example, have smartphone apps that provide new features such as check deposits. Similarly, Domino's customers can order pizza with their smartphones, Twitter, smart TVs, or smart watches. Such efforts embrace new digital platforms but merely to extend prevailing supply chain strategies and traditional IT capabilities that reinforce prevailing market positions. Firms exercising this option have not yet initiated digital envelopes or leveraged product-in-use information in a significant way. Yet, they may be building a foundation to do so.

4.2. Primary focus on production ecosystems

In this option, a firm channels the digital envelope and product-in-use information primarily into its production ecosystem. In so doing, it intensifies the value of product-in-use information through

Figure 2. Strategic options in digital ecosystems

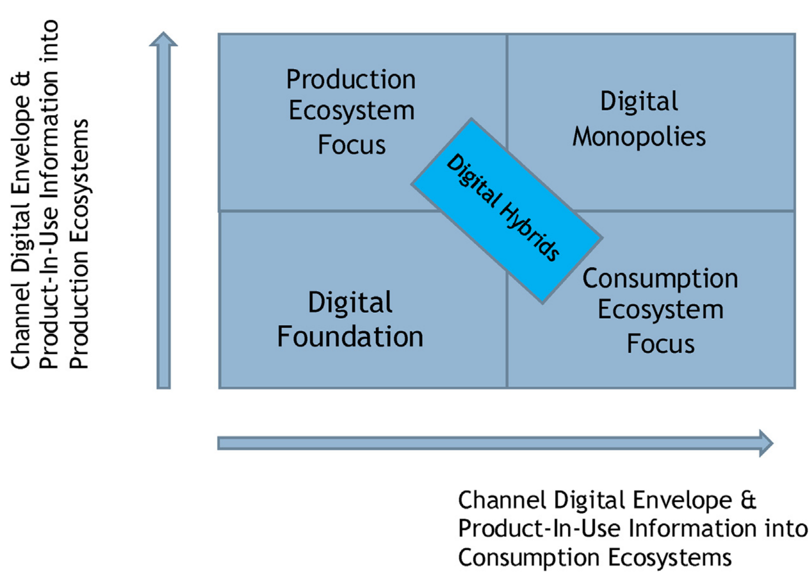


Table 1. Digital ecosystem quadrant comparison

	Digital foundations	Production ecosystems	Consumption ecosystems	Digital monopolies
Core strategic action	Embrace new digital technologies to make incremental changes to traditional business processes	Channel product-in-use information from the digital envelope onto production ecosystems	Channel product-in-use information from the digital envelope onto consumption ecosystems	Aggregate multiple sources of product-in-use information
Key characteristics of product-in-use information	• Not yet operational	• Extends a firm's prevailing product features and service options • Protected in-house with tight control over APIs • Scope restricted to product and user • Useful for product features and services customization • Useful for predictive maintenance	• Expands the firm's scope into new domains because complementary entities find new value • Shared with open APIs • Scope expands serendipitously; encourages unstructured growth • Versatility of product-in-use information for complementary products/services	• Propensity to control the hub of the digital ecosystem network • Relevance in many overlapping ecosystems
Basis for strategic advantage	• None	• Continuous customization of features and service offerings due to learning over time	• Network effects through interactions among complementary entities	• Domination of ecosystem through control over multiple sources of product-in-use information

exchanges within its production ecosystem (Glazer, 1991), with outcomes that largely reinforce and extend traditional sources of value creation. The action is depicted on the left-hand side of Figure 1. Here, a firm also chooses to contain the scope of its product-in-use information from digital envelopes to interactions between its own products and users through tightly controlled APIs that restrict information sharing to within its own production ecosystem.

Caterpillar's excavator, for example, may be digging soil in a construction site anywhere in the world, but its digital envelope can provide information on the precise conditions the excavator is working in and the wear and tear to its parts because of sensors in components that can detect the attributes of the soil and developing fault lines within components. Caterpillar uses this information to embellish what its prevailing production ecosystems were designed for: providing reliable products and efficient service to its customers. Traditionally, Caterpillar strived to design reliable excavators capable of working in all kinds of terrains; now, by observing more accurate wear and tear during actual use, it can allow its customers (construction companies) to price their rentals more accurately. Caterpillar routinely standardized many of its products and components to make it convenient for its dealers to optimize spare part inventory for quick service response. Digital envelopes channeled into production ecosystems make these traditional capabilities even stronger. With predictive information on likely failure of components, Caterpillar can alert dealers to replace parts in advance, saving them costly downtimes. Furthermore, the company is working on using digital envelopes to enable 3-D printing, allowing for components' availability at the construction site before predicted failures occur.

Two primary value-generating opportunities are of note here. One is through customization of product features and services that can be microtargeted for specific users in ways that were not possible without digital envelopes. Digital envelopes of sleep mattresses as mentioned earlier can customize each individual mattress based on ongoing product-in-use information of each user's sleep patterns. Before digital envelopes, attempts at customization included features such as sleep numbers that adjusted the inclines of headrests based on the numbers the users chose. New designs being prototyped are based on much more intricate product-in-use information of sleep patterns. They aim to adapt and customize the very contours of the mattress, so that the mattress material adjusts its shape and firmness to provide the best possible sleep depending on each sleep pattern. Likewise, Procter and Gamble's liquid detergents injected with nanotechnology sensors may soon customize each wash cycle based on specific attributes of soiled clothes. Oral-B can refine technologies behind brush motors and develop varying shapes, speeds, and rotation contours of the brush heads customized for each user. Hotels can customize their room features and airline companies their seat settings for each customer. These types of customization can generate new revenue streams. Also, ongoing accumulation of product-in-use information generated by digital envelopes provides new sources of competitive advantage, as over time products will become increasingly differentiated, unique, and difficult for competitors to replicate, which will create formidable switching costs.

The second value-generating opportunity is from predictive maintenance. As digital envelopes can monitor each component as it is being used, it can sense and alert breakdowns before they happen. Predictive maintenance services are particularly valuable when the cost of unexpected breakdowns is nontrivial. For consumer durables like dishwashers, refrigerators, or cars, unforeseen breakdowns can be annoying. For many industrial products such as turbines or construction equipment, downtimes can be costly. In the health sector, hospitals can incur significant costs due to unplanned downtime of medical equipment such as CT scanners and MRI equipment. A 1% improvement in uptime in such machines can reportedly save the industry $63 billion (Evans & Annunziata, 2012). Digital envelopes of GE's machines in its healthcare sector help track, diagnose, and preemptively maintain them to reduce such downtime and earn a share of these savings. GE calls such new forays of revenue generation *outcome-based business models*.

4.3. Primary focus on consumption ecosystems

In this option, a firm channels its product-in-use information from digital envelopes to initiate, engage, and orchestrate new consumption ecosystems. In so doing, it intensifies the value of product-in-use information through exchanges within its consumption ecosystem, or an array of third-party consumers of that information who connect it with other complementary information (Glazer, 1991). A firm consequently expands its value-creating opportunities from new sources. The action here is on the right-hand side of Figure 1. The Nest thermostat, for instance, has a digital envelope for each of its units installed in a home and constantly updates product-in-use information based on the interactions of its users with its products. This information, however, is used beyond just adapting or customizing temperatures in a home or reinforcing its traditional functional attributes. With its Works with Nest program, Nest invites and connects with scores of external entities and IoT enabled products to offer services far beyond what traditional thermostats offer. Nest thermostats connect with smartphones, cars, and traffic information to sense time of arrival accurately and to operate garage door openers, coffee machines, or light bulbs. They connect to energy providers to sense the most optimal times to operate various appliances such as washing machines or dishwashers. The objective is to initiate a mushrooming consumption ecosystem, where thousands of external entities can connect with Nest and offer an expanding set of services based on the product-in-use information generated by Nest's digital replicas.

Focus on consumption ecosystems generates value that is different from a focus on production ecosystems. When focusing on production ecosystems, prevailing products are embellished to perform better within their traditional domains. A smart toothbrush that adapts to each individual application becomes a better toothbrush and a jet engine that informs the right altitude for a flight is a better jet engine; in so doing, digital envelopes essentially enhance the firm's own traditional strengths and competencies. Focus on consumption ecosystems, in contrast, draws on strengths from external entities. For example, the Nest thermostat's value is enhanced because of how external entities add new functional attributes to the basic product and leverage its product-in-use information for more customized services. That also allows firms to expand into domains not necessarily connected to their prevailing value chains or core capabilities (such as sensing temperature). The scope of customization through configuring consumption ecosystems is also broader because of the flexibility digital connectivity offers to add various complements as options even after the product is sold. A smart light bulb, for instance, could be customized to track inventory within smart warehouses, to manage security within smart homes, or any other creative use, depending on which complementary objects it connects to or which consumption ecosystem it chooses to harness.

To do so, however, a firm needs to open its product-in-use information from digital envelopes to external entities. The APIs are managed to encourage interaction among complementing entities and generate new value beyond the traditional scope of the product. Firms can then forge competitive advantage from network effects (McIntyre & Subramaniam, 2009) or the value from the size and variety of the external network of entities willing to participate and contribute to the core product. This approach also opens possibilities to leverage new ideas from the creative imagination of any entity that could connect with the firm, even years after products are sold. New opportunities are usually unscripted, serendipitous, and arise from sharing product-in-use information with all kinds of likely or unlikely complementing entities.

4.4. Digital hybrids

Firms with a strong heritage in managing value chains may first focus on production ecosystems. GE and Caterpillar, for example, commenced their digital transformation journey with a focus on production ecosystems with predictive maintenance and outcome-based services. In contrast, firms with a software technology heritage like Uber have first focused on consumption ecosystems in autos. In either case, firms that perceive benefits in both production and consumption ecosystems tend to expand across those ecosystems, which we describe as digital hybrids. They may expand on their own or form partnerships with entities possessing complementary strengths in the alternate ecosystem.

If the firms focused on production ecosystems find their product-in-use information to have intrinsic versatility or the potential to be of value to external entities outside the scope of their traditional value chains (Kude, Dibbern, & Heinzl, 2012), they will tend to expand into consumption ecosystems. Versatility, of course, can vary across different products. In the consumer sector, product-in-use information for dishwashers or microwave ovens may be less versatile than for light bulbs or thermostats. In many industrial sectors, product-in-use information from any one asset is of value to other assets that jointly contribute to the overall sector such as in power stations, manufacturing plants, robotics, or construction projects. In power stations, an orchestrated coordination of GE's turbines with other assets can improve overall efficiency of power generation, creating incentives for GE to channel its digital replicas for its turbines toward a consumption ecosystem beyond its production ecosystems. Similarly, construction project sites have many intricate interdependencies among hundreds of other construction assets being used. It is estimated that 5% of project costs (often running into billions) are wasted in rework because of a lack of coordination among various vendors (Hwang, Thomas, Haas, & Caldas, 2009). With connectivity and information sharing across these assets, both the equipment providers and their customers can benefit from better coordination and reduced rework by being part of a common consumption ecosystem. Caterpillar is aiming to benefit from participating in such a consumption ecosystem in addition to its current focus on production ecosystems.

In the automobile sector, firms are beginning to unlock new value from cars' product-in-use information, which appears to be versatile. For instance, Ford has expanded its focus on production ecosystems and predictive maintenance services for engines, brakes, and powertrains to sharing its cars' product-in-use information with external entities to create a new consumption ecosystem. Through its SYNC 3 voice-activated technology, some Ford models allow drivers to order coffee while driving by using Amazon's Alexa. Relying on its location while on the road, and connectivity with weather and traffic information, the car could predict exactly how long it would take for the user to get to Starbucks and prompt its employees to start preparing the coffee. Starbucks could have people deliver coffee at the right temperature to the car. Because Ford's MyPass app can contain mobile payment information, a user could complete the transaction without having to leave the car. Parking lots equipped with sensors (offered by city administrators) are also soon expected to be part of the car's consumption ecosystem, allowing drivers to find empty parking spaces efficiently.

Digital hybrids coming from the other direction, or from consumption to production ecosystems, do so for better control over product-in-use information. The premise is to control the physical assets that generate product-in-use information in the first place, which would allow firms to better orchestrate their consumption ecosystem. Not surprisingly, technology titans (e.g., Google, Apple, and Uber) with strong capabilities in managing consumption ecosystems are now venturing into the production of automobiles through partnerships and joint ventures. They are betting on a scenario in which driverless cars may be able to compete primarily on services derived from personalized information on users, including:

- Enabling cars to predict and arrive when needed;
- Directing the ride based on the user's itinerary;
- Offering stops at favorite coffee shops or stores; and
- Streaming customized news, videos, or music.

Designing and controlling their own digital replicas of their own fleet of driverless cars may enable greater control over product-in-use information and greater effectiveness in managing their transportation-as-service platforms.

To evolve into digital hybrids, firms often use partnerships and acquisitions. Caterpillar recently acquired Yard Club, a startup it had initially funded to develop a shared platform for various construction site contributors to coordinate their work and venture into consumption ecosystems. Uber, which had no prior experience in car manufacturing, has partnered with Mercedes-Benz for a driverless car project. Ford purchased on-demand shuttle service company Chariot for $65 million to gain insights into managing transportation as a service in cities like New York and San Francisco.

4.5. Digital monopolies

With digital ecosystems upending traditional industries, they also bring new drivers of monopoly power. Monopoly power has long been considered the bedrock of competitive advantage for firms (Porter, 1979). Traditionally, attractive industry structures drove monopoly power for industry incumbents, which was earned through commitments and investments in production capacities, know-how, or brands (Demsetz, 1973). These firms assessed monopoly power through observable metrics such as concentration ratios, and dominance through relative market shares. Digital ecosystems, however, do not follow the contours of conventional industry structures. Dominance may not be necessarily tied to or even noticed through market shares within well-circumscribed boundaries. Instead, dominance may stem from the right to control product-in-use information from digital envelopes; monopoly influence may be won by controlling the flow of product-in-use information across several interconnected ecosystems.

Such new jockeying for digital monopoly can be best observed in the tactics of technology titans Amazon and Google in their contest to control the digital envelopes of most individuals (Iyer, Subramaniam, & Rangan, 2017). Ever since Google developed its search engine, or Amazon its online retail platform, they started constructing individual digital envelopes for each of their users. Every search made on their platforms enabled them to aggregate select facets of user persona. Similarly, with every Netflix movie watched, every Alexa or Siri query, and every interaction with friends on Facebook, individuals impart different slices of their persona and steadily contribute to a full digital envelope of themselves that is controlled by a technology titan. This trend is compounded by the ubiquity of e-commerce platforms, social media, IoT devices, and smartphone apps and the internet, which encourages more and more individuals to leave digital traces of their preferences, behavior, and persona. This has provided the technology titans an unprecedented opportunity to construct as complete a digital envelope as possible for every individual that most closely predicts user behavior. The more such insight possessed by a titan on individuals, the greater their influence over a host of different consumption ecosystems.

Consider the automobile sector where every car ride can provide a treasure trove of information about the user. Yet, any single automaker like Ford or Toyota has access only to that information generated by its own assets' digital envelopes. The technology titans, in contrast, have access to the digital envelopes of millions of individuals; armed with stronger insights on individual user persona, they are better equipped to offer services users may prefer from their cars. For instance, through Alexa or Google Home, Amazon or Google may have better insights on a user's day-to-day itinerary, the errands that individual may run, his or her preferences for shopping, or his or her choices for music and news sources. This gives them an advantage in managing such services in future automobiles compared to any single traditional automaker.

In homes, we may soon see appliances managed as a network (e.g., a washing machine is connected to other gadgets). In such a consumption ecosystem, it is possible among other things to monitor the electrical load being drawn by each appliance and thereby avoid an overload or take advantage of shifting electrical costs when there is intraday dynamic pricing. Amazon through Alexa or Google through Google Home are better positioned to coordinate such ecosystems as compared to any individual appliance maker. In other words, these technology titans are occupying important hubs (Iansiti & Lakhani, 2017) in several overlapping consumption ecosystems of a vast array of consumer products, giving them special insights and influence on each. Traditional appliance manufacturers may persist to compete in concentrated industry structures, yet, if value shifts to new services in their consumption ecosystems, they may cede monopoly power to the technology titans.

Barring a few exceptions, the technology titans have yet to focus on nonconsumer industrial products. In these domains, consumption ecosystems are relatively more circumscribed and independent of one another. That is, the consumption ecosystems in power generation may not overlap with those of aircraft manufacturing in any significant way. Nor do they necessarily overlap with the consumption ecosystems of other consumer products dominated by the technology titans. However, these consumption ecosystems within industrial sectors remain underdeveloped, yet to be envisioned and initiated. There may be substantial first-mover advantages in initiating them and establishing early influence. But it requires a focused effort to entice all complementary entities to be part of a common interoperable platform. Some of these entities may be small contractors without adequate resources to create a digital front. Bigger players may need to invest in them to incentivize their transformation. Other complementary entities may be competitors with their own plans to dominate the consumption ecosystem. For instance, GE may have to find ways to collaborate with Siemens or Asea Brown Boveri to establish an effective consumption ecosystem that allows power plants to pick seamless plug-and-play options to enhance overall power-generating efficiencies. This looming battle over who gets preferential rights to control the flow of information from most digital replicas in the digital ecosystem may shape the nature of new digital monopolies.

5. Rewire and reshape for digital transformation

New digital technologies have rewired how firms and consumers are connected. It has created new interdependencies that are not only reshaping the roles of conventional value chains but also bringing fresh complementary inputs at an unprecedented scale. It has enabled the collection and sharing of intricate product-in-use information that can be significant drivers of value. The frameworks we offer in this article, based on the concepts of production and consumption ecosystems powered by digital envelopes and product-in-use information, can help traditional firms better understand these changes and empower them to engage in digital transformation.

Acknowledgment

We would like to thank Prakash Iyer and Rajneesh Gupta for their helpful suggestions on earlier drafts of this article.

References

Belluck, P. (2017, November 15). F.D.A. approves first pill that reports back. *The New York Times*, p. A16.

Brandenburger, A., & Nalebuff, B. (1995). Right game: Use game theory to shape strategy. *Harvard Business Review, 73*(4), 57–71.

Dedrick, J., & Kraemer, L. K. (2005). The impacts of IT on firm and industry structure: The personal computer industry. *California Management Review, 47*(3), 122–142.

Demsetz, H. (1973). Industry structure, market rivalry, and public policy. *Journal of Law and Economics, 16*(1), 1–9.

Dhebar, A. (2016). Razor-and-blades pricing revisited. *Business Horizons, 59*(3), 303–310.

Dixon, J. R., Arnold, P., Heineke, J., Kim, J. S., & Mulligan, P. (1994). Business process reengineering: Improving in new strategic directions. *California Management Review, 36*(4), 93–108.

Evans, P. C., & Annunziata, M. (2012, November 26). Industrial internet: Pushing the boundaries of minds and machines. *GE Reports*. Available at http://files.gereports.com/wp-content/uploads/2012/11/ge-industrial-internet-vision-paper.pdf

Gao, L. S., & Iyer, B. (2006). Analyzing complementarities using software stacks for software industry acquisitions. *Journal of Management Information Systems, 23*(2), 119–147.

Gerth, A. B., & Peppard, J. (2016). The dynamics of CIO derailment: How CIOs come undone and how to avoid it. *Business Horizons, 59*(1), 61–70.

Glazer, R. (1991). Marketing in an information-intensive environment: Strategic implications of knowledge as an asset. *The Journal of Marketing, 55*(4), 1–19.

Hull, D. (2016, December 20). The Tesla advantage: 1.3 billion miles of data. *Bloomberg*. Available at https://www.bloomberg.com/news/articles/2016-12-20/the-tesla-advantage-1-3-billion-miles-of-data

Hwang, B.-G., Thomas, S. R., Hass, C. T., & Caldas, C. H. (2009). Measuring the impact of rework on construction cost performance. *Journal of Construction Engineering and Management, 135*(3), 187–198.

Iansiti, M., & Lakhani, K. R. (2017). Managing our hub economy: Strategy, ethics, and network competition in the age of digital superpowers. *Harvard Business Review, 95*(5), 84–92.

Iyer, B., & Subramaniam, M. (2015a, April 13). Are you using APIs to gain competitive advantage? *Harvard Business Review*. Available at https://hbr.org/2015/04/are-you-using-apis-to-gain-competitive-advantage

Iyer, B., & Subramaniam, M. (2015b, June 8). Corporate alliances matter less thanks to APIs. *Harvard Business Review*. Available at https://hbr.org/2015/06/corporate-alliances-matter-less-thanks-to-apis

Iyer, B., Subramaniam, M., & Rangan, S. U. (2017, July 6). The next battle in antitrust will be about whether one company knows everything about you. *Harvard Business Review*. Available at https://hbr.org/2017/07/the-next-battle-in-antitrust-will-be-about-whether-one-company-knows-everything-about-you

Kapoor, R., & Lee, J. M. (2013). Coordinating and competing in ecosystems: How organizational forms shape new technology investments. *Strategic Management Journal, 34*(3), 274–296.

Kude, T., Dibbern, J., & Heinzl, A. (2012). Why do complementors participate? An analysis of partnership networks in the enterprise software industry. *IEEE Transactions on Engineering Management, 59*(2), 250–265.

Lambert, F. (2017). Tesla global fleet reaches over 5 billion electric miles driven ahead of Model 3 launch. *Electrek*. Available at https://electrek.co/2017/07/12/tesla-global-fleet-electric-miles-model-3-launch/

Lee, C.-H., Venkatraman, N., Tanriverdi, H., & Iyer, B. (2010). Complementarity-based hypercompetition in the software industry: Theory and empirical test, 1990–2002. *Strategic Management Journal, 31*(13), 1431–1456.

McIntyre, D. P., & Subramaniam, M. (2009). Strategy in network industries: A review and research agenda. *Journal of Management, 35*(6), 1494–1517.

Moore, J. F. (1993). Predators and prey: A new ecology of competition. *Harvard Business Review, 71*(3), 75–86.

Niden, H. L., & Spriggs, T. G. (2016). How smart, connected products are transforming companies: Interaction. *Harvard Business Review, 94*(1), 18–24.

Pitt, L., Berthon, P., & Robson, K. (2011). Deciding when to use tablets for business applications. *MIS Quarterly Executive, 10*(3), 133–139.

Porter, M. E. (1979). The structure within industries and companies' performance. *Review of Economics and Statistics, 61*(2), 214–227.

Porter, M. E. (1985). *Competitive advantage: Creating and sustaining competitive advantage*. New York, NY: The Free Press.

Powers, C. (2017). GE Power's effort to digitize itself and utilities industry with IOT data. *ASUG*. Available at https://www.asug.com/news/utilities-ge-internet-of-things-analytics

Ranger, S. (2013, December 18). There are 18.5 million software developers in the world — but which country has the most? *Tech Republic*. Available at https://www.techrepublic.com/blog/european-technology/there-are-185-million-software-developers-in-the-world-but-which-country-has-the-most/

Westerman, G., & Bonnet, D. (2015). Revamping your business through digital transformation. *MIT Sloan Management Review, 56*(3), 10–13.

Williamson, J., & De Meyer, P. A. (2012). Ecosystem advantage: How to successfully harness the power of partners. *California Management Review, 55*(1), 24–46.

Yu, T., Subramaniam, M., & Cannella, A. A., Jr. (2013). Competing globally, allying locally: Alliances between global rivals and host country factors. *Journal of International Business Studies, 44*(2), 117–137.

Zahra, S., & Nambisan, S. (2012). Entrepreneurship and strategic thinking in business ecosystems. *Business Horizons, 55*(3), 219–229.