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Panos Constantinides, Ola Henfridsson, Geoffrey G. Parker

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Introduction

Platforms and Infrastructures in the Digital Age

Panos Constantinides,[a] Ola Henfridsson,[a] Geoffrey G. Parker[b]

[a] Warwick Business School, University of Warwick, Coventry CV4 7AL, United Kingdom; [b] Thayer School of Engineering, Dartmouth College, Hanover, New Hampshire 03755

Contact: panos.constantinides@wbs.ac.uk, http://orcid.org/0000-0003-2728-8975 (PC); ola.henfridsson@wbs.ac.uk, http://orcid.org/0000-0003-1605-5180 (OH); geoffrey.g.parker@dartmouth.edu, http://orcid.org/0000-0002-7160-6451 (GGP)

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Abstract. In the last few years, leading-edge research from information systems, strategic management, and economics have separately informed our understanding of platforms and infrastructures in the digital age. Our motivation for undertaking this special issue rests in the conviction that it is significant to discuss platforms and infrastructures concomitantly, while enabling knowledge from diverse disciplines to cross-pollinate to address critical, pressing policy challenges and inform strategic thinking across both social and business spheres. In this editorial, we review key insights from the literature on digital infrastructures and platforms, present emerging research themes, highlight the contributions developed from each of the six articles in this special issue, and conclude with suggestions for further research.

Keywords: digital platforms • digital infrastructure • architecture • governance • platform scale • platform policy

Introduction

In recent years, there has been mounting interest in digital platforms. Some of the most valued companies—including Alibaba, Amazon, Facebook, and Google—are platform businesses with surprisingly short histories. At the same time, many long-lived companies are considering how they can adopt platform thinking to improve performance. For instance, General Electric, the American multinational listed on the Dow Jones Industrial Average some 120 years ago, has made significant investments in platforms for the industrial Internet of things. Indeed, areas such as oil production, power generation, and heavy machinery are going through so-called platformization.

We define digital platforms as a set of digital resources—including services and content—that enable value-creating interactions between external producers and consumers (cf. Parker et al. 2016). We view such platforms as distinct from product platforms, such as those found in the automotive sector (Fisher et al. 1999). The digital platform itself does not necessarily hold physical assets in the form of infrastructure resources, nor generate value through product sales. In models such as Airbnb, the platform has little in common with previous linear value-chain models of product development. Rather, it fits a platform ecosystem model that emphasizes core interactions between platform participants, including consumers, producers, and third-party actors (Jacobides et al. 2018). In other cases, such as Apple's MacOS, iOS, watchOS, and tvOS, digital platforms enable the building of a powerful innovation ecosystem.[1] In both examples, platforms exhibit architectural and governance rules that seek to balance platform control with the necessary incentives for platform participants to engage with the platform and generate value for one another (de Reuver et al. 2017, Ghazawneh and Henfridsson 2013, Parker et al. 2016, Tiwana 2015).

Digital platforms are created and cultivated on top of digital infrastructures. We refer to digital infrastructure as the computing and network resources that allow multiple stakeholders to orchestrate their service and content needs. Examples of digital infrastructures are: The Internet (Hanseth and Lyytinen 2010, Monteiro 1998); data centers (Gandhi 2017); and open standards such as IEEE 802.11, and USB (Hanseth 2000), as well as consumer devices such as smartphones and tablets. While consumer devices can be considered "lightweight" infrastructures in comparison to the Internet, which is more "heavyweight" (cf. Bygstad 2017), it should be noted that smartphones are powerful computational and networking devices serving as infrastructures once they scale to a critical mass. For instance, consider the role of smartphones, the Internet, and geographical positioning technology in making Uber possible.

The wide availability of digital technology has hastened digital innovation to be built on top of digital infrastructures. Indeed, easy-to-access digital infrastructure is of vital importance to create and grow new digital ventures. Just as platforms facilitate the connection between supply and demand (Baldwin and Clark 2000, Gawer 2014), digital infrastructures provide the necessary computing and networking resources. Digital infrastructures, therefore, are distinct from other types of infrastructures because of their ability to collect, store, and make digital data available across a number of systems and devices.

Our motivation for undertaking this Special Issue rests in the conviction that it is significant to discuss platforms and infrastructures concomitantly while drawing from information systems, strategic management, and economics research. Most prior research has been developed in separate communities that rarely engage each other's work. Going forward, it would be beneficial to cross-pollinate separate bodies of knowledge to address critical, pressing policy challenges and inform strategic thinking across both social and business spheres. In the remainder of this paper, we set the stage for such cross-pollination.

In this Special Issue we first review key insights from the literature on digital infrastructures and platforms, which has provided a foundation for much research in this field. Then, we present new theoretical approaches and themes. We highlight the contributions developed in this Special issue and conclude with suggestions for further research.

The Architecture and Governance of Digital Infrastructures and Platforms

Digital technology architecture is of significant importance for platform businesses' use of digital infrastructure. Compared to a traditional product architecture (Ulrich 1995), digital technology invites a different business and organizing logic (Yoo et al. 2010). Specifically, the layered architecture of digital technology (Adomavicius et al. 2008) creates a powerful basis for building platforms that span industrial boundaries. So, while Volvo's new car SPA[2] platform offers scope within the confines of automaking, a digital infrastructure, such as TCP/IP, makes no distinction between the content transmitted.[3] In other words, a unified digital infrastructure offers broad platforms scope across industries, not merely within them.

The architecture of digital technology can also dictate new forms of platform governance. Boundary resources, such as APIs and metadata (Ghazawneh and Henfridsson 2013, Eaton et al. 2015), along with the decision rights of platform stakeholders (Tiwana et al. 2010) significantly influence the evolution of digital platforms. Emerging in the aftermath of the gradual decline of monopoly-driven infrastructures and their privatization (see Graham and Marvin 2001, Sassen 2001), platformization benefited from the decentralization of infrastructure governance and the unbundling of its use. In turn, this encouraged the distributed and collective innovation of new technologies and services (see, e.g., Ciborra et al. 2000, Constantinides and Barrett 2014, Tilson et al. 2010).

In this section, we first discuss digital architecture—specifically, the layered, modular architecture (Yoo et al. 2010), and its power to fuel platforms on top of digital infrastructures. We also discuss platform governance, not least in terms of providing appropriate structures and incentives for value-creation and balancing openness and control among different stakeholders (see, e.g., Tilson et al. 2010, Wareham et al. 2014).

Architecture

Platform architecture has certainly received increasing attention recently (see, e.g., Parker et al. 2016, Thomas et al. 2014). Tiwana et al. (2010, p. 677) define platform architecture as the "conceptual blueprint that describes how the ecosystem is partitioned into a relatively stable platform and a complementary set of modules that are encouraged to vary, and the design rules binding both." In this regard, the notion of a platform ecosystem rests firmly on the idea of modularity[4] (Baldwin and Clark 2000, Garud et al. 2003, Schilling 2000), making a distinction between the platform core—consisting of tightly coupled components—and loosely coupled peripheral components (cf. Baldwin and Woodard 2009). The design rules (Baldwin and Clark 2000)[5] then, serve as the means by which stakeholders in the platform ecosystem can govern their relations with other stakeholders.

In the digital age, however, viewing platform ecosystems as purely modular systems misses out on some unique properties of digital technology. While it is useful to conceptualize the peripheral components of the platform as complementary because they provide functionality, services, or contents not offered by the platform core itself, it is also important to remember that a digitally enabled complement is not like the accessory to a power drill. While diamond drill bits complement the drill with specific functionality for hard surfaces, digital complements, such as Google Maps, are more versatile in their potential functionality.

Additionally, digital complements are product-agnostic (Yoo et al. 2010). That is, their functionality is not predetermined. For example, when Google Maps is embedded in a physical product like a Samsung phone, it complements the platform core by making the phone more useful or attractive. However, Google Maps is also a stand-alone service. It can simultaneously be used in a variety of different ways; bundled with a host of heterogeneous devices such as desktop computers, mobile phones, and cars, and also in a variety of application settings such as Booking.com, Rightmove, and TripAdvisor. As such, digitization renders the components of an architecture product-agnostic (Yoo et al. 2010). Potentially, infinite opportunities exist for services and components to be added onto the architecture in a generative fashion (Lyytinen et al. 2018, Wareham et al. 2014, Zittrain 2006).

The modular architecture becomes layered once digital components are embedded into physical products, extending product boundaries and organizational structures. Consider how industries are converging—moving from independent, to mutually competitive, to overlapping structures (Messerschmitt and Szyperski 2003). This convergence creates unprecedented prospects for companies to envelop others by offering the incumbent firm's product functionality or service as part of their own. In the automotive industry, for example, original equipment manufacturers (OEMs) can consolidate the design and control of certain components with multiple digital capabilities that were formerly dispersed among suppliers (Lee and Berente 2012, Svahn et al. 2017).

In contrast to non-digital infrastructures, digitization feeds into the ability of an infrastructure to remove any dependence on location for completing a process. As a result, it stimulates distribution of expertise across geographical and organizational boundaries (Dhanaraj and Parkhe 2006, Gupta et al. 2007). Such location-independence is creating a vast digital economy that is on a trajectory to outgrow the physical economy in a couple of decades (Brynjolfsson and McAfee 2014). Moreover, business processes that once occurred among human agents are now being executed among self-organizing, intelligent machine agents, constantly leaving and re-entering the physical world. The use of artificial intelligence and the industrial Internet of things is increasingly digitizing business processes. For example, Airbus is combining data on aircraft production with a self-learning algorithm that identifies patterns in production problems. The system matches about 70% of seemingly unrelated production disruptions to solutions used previously in almost real time (Ransbotham et al. 2017). By breaking free from geographical constraints, the digitization of a product or service also vastly expands its potential market by enabling entirely new business models.

All of these factors have generated an abundance of data streams on consumer behavior, orders, sales, business decisions, and location of physical and digital objects. The ability to access and share this data allows organizations to draw on in-depth, and often real-time, data analytics that lead to smarter decisions (McAfee et al. 2012). The unanticipated implication of such data ubiquity is that it allows loosely coupled networks of small firms to rival the production and service capabilities of large firms by better coordinating distributed resources and participants.

It is exactly on the basis of such increased digitization and openness that platforms emerge. As the layered, modular architecture of a digital infrastructure, a platform invites multiple external parties—such as consumers, producers, and providers of services and digital products, as well as third-party developers—to participate in interactions and the creation of new value. Consider, for example, how boundary resources, such as APIs, metadata, and software development kits (SDK) for Apple iOS, Ford Sync, and Google Maps platforms, facilitate the emergence of ecosystems based on principles of the layered, modular architecture.

As software developers create new applications and services to be traded on application marketplaces, they attract consumers and advertisers who generates both same-side and cross-side network effects (Parker et al. 2016). Such openness promotes ecosystems based on multiple and diverse value propositions, while also serving excess rents for the platform host or owner (Adner and Kapoor 2010, Boudreau 2010, Parker and Van Alstyne 2005).

Yet, digitization and openness also mean that components of the layered, modular architecture become easier to copy, reverse-engineer, or break. Such (sometimes) hostile strategies have manifested in varied forms including: building meta-platforms (Ghazawneh and Henfridsson 2013), jail-breaking devices (Eaton et al. 2015), and initiating proprietary platforms through open-source licensing (Pon et al. 2014). As explored by Karhu, Gustafsson, and Lyytinen's (2018) paper in this Special Issue, Amazon's proprietary Fire platform is an exploitation, or "platform forking," of the Android Open-Source project's core. Amazon not only copied the code of Android's technical core, but also exploits Android's suite of applications at the service and content layers in the form of complements.

These cases support the importance of new forms of governance that would let platforms control interactions between multiple stakeholders without jeopardizing their incentives for value-creation. We turn to governance next.

Governance

Tiwana (2013) broadly defines governance with regards to who decides what. This encompasses three facets: How decision rights are divided between the platform owner and third-party developers; what types of formal and informal control mechanisms are used by the platform owner (e.g., gatekeeping, performance metrics, processes that developers are expected to follow); and incentive structures. While the layered, modular "architecture can reduce structural complexity, governance can reduce behavioral complexity" (Tiwana 2013, p. 118).

A recognized challenge in developing platform governance, however, is how "to establish governance mechanisms that appropriately bound participant behavior without excessively constraining the desired level of generativity" (Wareham et al. 2014, pp. 1195–1196). Similarly, Yoo et al. (2012) note that "organizations must be designed to manage the delicate balance between generativity and control in the platform" (2012, p. 1400), a point also made by others (Eaton et al. 2015, Ghazawneh and Henfridsson 2013, Tilson et al. 2010). Implementing the controls necessary to achieve the dual goals of being simultaneously "stable and evolvable" (Wareham et al. 2014, p. 1196), is very much aligned to the layered, modular architecture of digital infrastructures. This is in contrast to centralized, command-and-control governance structures found in linear value chains and hierarchical organizations. It's important to reach the right balance because governance determines whether digital innovation made possible by the layered, modular architecture will be successfully leveraged (Boudreau 2010, Parker and Van Alstyne 2017, Rochet and Tirole 2003, Tiwana et al. 2010).

To start with, governance structures define the platform- and app-based decision-making rights of platform owners and app developers. These rights refer to the authority and responsibility for making decisions directly pertaining to the platform and/or the apps (Tiwana 2013). Second, governance relates to the various formal and informal control mechanisms that ensure platform owners that app developers are aligned with what is in the best interests of the platform.

In other words, control mechanisms let platform owners enforce rules that reward and punish behavior, and establish best practices on the platform (Evans and Schmalensee 2007). These controls can be informal or formal and may include tasks such as gatekeeping, process, metrics, and relational control (Tiwana 2013). A platform's boundary resources—such as SDKs and APIs—are formal control mechanisms, granting access to the platform hardware and operating system to write complementary applications or services (Ghazawneh and Henfridsson 2013). They form the foundation for a platform's technology-based governance over third-party developers.

Beyond technology-related issues, a platform's governance also includes incentive structures that influence the strategic behavior of stakeholders and the monetary profits of the platform. Digital platforms tend to engage in strategic actions and exert rules and regulations over participants, that are "distorted away from pure value creation in the ecosystem, and toward actions that lead to higher platform profits" (Boudreau and Hagiu 2009, p. 170). The platform owners' priorities, then, are to protect their own interests and secure their competitive positions while also securing the interests of producers and consumers who contribute to value-creation on the platform. To this end, a number of monetization strategies become important, including transaction fees, access fees, fees for enhanced access and enhanced curation, as well as strategies for subsidizing one side while charging the other (Parker et al. 2016). Clearly, conflict-of-interest risks can arise in this process.

Other platforms incentivize users to directly compete with developers (Gawer and Henderson 2007) or fold third-party innovation into the platform (Parker and Van Alstyne 2017) so that consumers obtain these functionalities at no additional cost. A platform owner can also restrict developers' access for quality-assurance purposes, an approach most commonly seen in the video game industry. Expanding the number of developers on a platform can result in congestion and crowding (Boudreau 2012), and consumers' search costs can increase due to information asymmetry between consumers and developers. To reduce these costs, platforms might engage in centralized, "quality certification" via developer pre-screening (Boudreau and Hagiu 2009, Evans and Schmalensee 2007). Platforms can choose to screen products and decide whether they are qualified for release, a practice carried out on the iOS App Store by Apple, Sony Playstation, and SAP. Not surprisingly, the inconsistency and lack of transparency of this process has attracted criticism from the developer community (Qiu et al. 2017).

Another practice is imposing restrictions on stakeholder interactions. Direct interactions between producers and consumers outside of the platform, can harm the platform's economic interests (Rochet and Tirole 2003, 2006), motivating platforms to control these forms of interactions. Restricted access is adopted mostly by platforms that also function as market-exchange owners. Boudreau and Hagiu (2009) show that TopCoder, a platform for tournament-based software outsourcing, prohibits interactions between producers and consumers to ensure that software development in the contest is a sequential and planned process.

The disincentive structures described above resemble behavioral-control mechanisms, where "specific rules and procedures are articulated, which, if followed, will lead to desired outcomes" (Kirsch 1997, p. 217). However, as Tiwana et al. (2010) suggest, digital platforms cannot be viewed through the lens of the classical principal-agent relationship as assumed in control theory. The "role of control mechanisms then, is one of coordination rather than mitigating agency hazards, as control theorists widely assume" (Tiwana et al. 2010, p. 680).

Additional research on collective action may be necessary to understand how governance and incentive structures can be best implemented to coordinate behavior across multiple platform stakeholders and their distinct interests (Constantinides and Barrett 2014). The main challenge is that given the openness and digitization of services and applications on platforms, as well as the competitive nature of interactions, it is difficult to collectively agree on common governance and incentive structures. This challenge may be addressed if governance is nested into a series of layers, in line with the layered, modular architecture. Such nesting would distribute responsibilities and incentives across stakeholders, with each layer dealing with similar types of issues but at a progressively larger scale, and lesser level of detail (cf. McGinnis 1999, Ostrom 1990).

The value of nesting can be seen in the horizontal and vertical assurance problems that arise from technological interdependence. In these cases (cf. Adner and Kapoor 2010), governance is polycentric and multi-layered—they may govern consumer-consumer interactions versus producer-producer interactions versus consumer-producer interactions versus platform-producer, and so on. Each layer of interactions is governed independently from others, as long as its self-governance does not affect other layers. In this way, governance is nested to higher layers until a layer is reached where all stakeholders with a substantive interest in a collective-action problem are represented adequately.

A number of value-based principles have been proposed to achieve such polycentric governance (Constantinides 2012), however, these still need to be adapted to the layered, modular architecture on which each platform operates. For example, the iOS platform will require a significantly higher level of nesting than the Uber platform. In fact, it has been argued that governance principles and incentive structures, along with relevant decision rights, must mirror the technical architecture of the platform (Tiwana 2013). We discuss the challenge of mirroring, as well as other themes emerging from this Special Issue, in the next section.

Themes Emerging in the Special Issue and Opportunities for New Research

We now describe five themes that emerged in the Special Issue and place these into a broader context of areas where further research might be productively pursued. We refer to these themes as: the new mirroring hypothesis; platformization and infrastructuring; competition and scaling of digital platforms; blockchain as a new infrastructure and platform; and online labor platforms.

Table 1 summarizes these themes with reference to the phenomenon, relevance, existing work, and possible research questions.

The New Mirroring Hypothesis

In the 1960s, both computer science and organizational theory posited a hypothesis that the structure of a product development organization must "mirror" the architecture of the product it develops (Conway 1968, Lawrence and Lorsch 1967, Thompson 1967). The explanation is that a specific architecture is thought to imply a certain partitioning of product development tasks. Therefore, it should also determine the optimal structure of the corresponding product-development organization. The previously cited concept of modularity offers a better understanding of the mirroring hypothesis. Modularity aims to capture the degree to which the elements in a system (whether a software system or an organization) are partitioned into functionally specialized modules, or business units. These modules operate nearly independently and can be easily removed or replaced because they interact through simple, standardized interfaces, in the case of software systems (Baldwin and Clark 2000). Organizations, on the other hand, interact through standardized exchanges (Schilling and Steensma 2001).

More recently, Colfer and Baldwin (2016) reviewed 142 empirical studies and found strong evidence of the mirroring of technical architecture to organizational tasks. However, they also found that in "open, collaborative projects" supported by new digital technologies, the mirroring hypothesis does not hold true. This is because contributors work interdependently for limited periods of time without the need to coordinate (e.g., crowdsourcing contests). Although, Colfer and Baldwin (2016) primarily focus on open-source software development projects, other types of "open" interactions—similar to those found on digital platforms—show even stronger evidence that the mirroring hypothesis does not hold true. Without such mirroring, the long-held interdependence between technology and organization tasks (Thompson 1967) is put into question; coordination is now achieved in different ways.

Within organizations, the mirroring of technical dependencies and organizational ties is an important approach to organizational problem-solving that conserves scarce cognitive resources. People charged with implementing complex projects or processes must arrive at solutions that account for the technical constraints; that is, they must communicate with one another and cooperate to solve problems where and when they arise (Puranam et al. 2012). Across organizations, the absence of technical and organizational ties might determine, or predict, the location of firm

Table 1. Themes and Opportunities for Further Research

Theme	Relevance	Possible research questions
New mirroring hypothesis The seminal mirroring hypothesis is challenged by platform-enabled, open interactions. Scholars can investigate new forms of relationships between organizational structures and technology architecture.	The mirroring of technical dependencies and organizational ties is an important approach to organizational problem-solving that conserves scarce, cognitive resources. This is also important for determining loose versus tight coupling between system components.	• How can new, value-creating interactions be supported without being constrained by existing organizational structures and technical architectures? • How can constantly changing boundaries be governed? • How does coordination happen on digital platforms?
Platformization and infrastructuring Infrastructures are undergoing a process of *platformization* as architectural and governance control points are opened through digitization. Platforms, meanwhile, are undergoing a process of *infrastructuring* by expanding their reach and scope into supply chain management.	This dual process of platformization and infrastructuring builds on vast networks of installed, existing infrastructures and platforms, respectively. As such, they avoid the "bootstrap problem," or the "chicken-and-egg problem," achieving greater and faster scaling. There are important policy implications regarding competition and data ownership.	• How do platforms and infrastructures scale on each other? • How does such scaling affect innovation and competition? • What are the policy implications for the network effects generated through platformization and infrastructuring?
Competition and scaling of digital platforms The nature of competitive strategy is changing as businesses adopt platform thinking. Scaling is a particular area where platforms lead to new ways of competing.	With the increasing number of platform businesses and traditional businesses seeking to adopt platform thinking, it is vital to understand the competitive dynamics of the digital era. This applies to platform owners as well as complementors, such as third-party developers, seeking competitive ways to advance their business.	• What is the strategic interplay between platform owners and ecosystem actors over time? • What are the competitive moves that platform owners can use to design boundaries to surrounding ecosystem actors? • How can third-party developers advance their businesses across multiple platforms?
Blockchain as a new infrastructure and platform Blockchains are capable of performing trusted operations in a decentralized infrastructure. Through a consensus mechanism, parties with the right to validate new transactions can update the blockchain and interact directly with each other, anonymously, and without the need for central coordination.	Blockchain infrastructure holds the promise of increased speed of exchange, a reduced number of intermediaries and associated costs, improved security, digitized assets, wider access to disadvantaged groups (especially in emerging economies), and improved regulatory compliance.	• How can blockchain technology overcome existing architectural and governance challenges in digital platforms and infrastructures? • How can blockchain-based digital platforms transform existing value-creating interactions? • How does blockchain technology address the misaligned incentive structures and trust currently faced by digital platforms? • What are the policy implications for developing "smart" blockchain contracts?
Online labor platforms The shift from permanent employment to need-based outsourcing, and from local labor markets to global online labor platforms.	Online labor platforms have implications for the sourcing and delivery of services and products, but also for capital decisions and for the degree of labor specialization needed.	• How does pricing for work done on an online labor platform impact repeat engagements? • How do value uncertainties about a task affect employers and freelancers on online labor platforms? • How does online monitoring affect successful matching of employers and freelancers on online labor platforms? • What are the training and development effects of online labor platforms for unemployed workers?

boundaries. It means that technical systems made up of many discrete modules can be implemented by loosely coupled organizations, i.e., separate firms, while systems with many interdependencies require tighter coupling, such as those found in a single firm (Baldwin and Clark 2000).

Previous research on system integration (Brusoni and Prencipe 2001, Ceci and Prencipe 2008, Davies et al. 2007) also has challenged the mirroring hypothesis. This research, which observed the design and construction of complex technical systems involving many firms, found that while the systems were modular (and mirrored) with respect to technical dependencies and most tasks, the systems integrator had to interactively coordinate and manage the entire network of component suppliers. To fulfil this coordination role, systems integrators needed capabilities that spanned a wide range of technical fields (Parker and Anderson 2002). As a result, their knowledge extended well beyond what was directly relevant to the tasks they performed in-house.

This view also has been explored in academic research on the strategic manipulation of firm boundaries by the surrounding "industry architecture" (Jacobides 2006, Jacobides et al. 2006). Interestingly, it was found that technologically dynamic industries constantly change their technical dependencies and organizational ties to create new institutional arrangements (Amaral et al. 2011, Pisano and Teece 2007). Technical architectures and organizational structures, therefore, should be approached as a source of strategic opportunity, and should be dynamically changed over time.

Although research presented in this Special Issue has not explicitly discussed the mirroring hypothesis, there is evidence to show that value-creating interactions between different platform participants renew opportunities for dynamically changing both organizational structures and the technical architecture that supports the former.

For instance, the research conducted by Lee, Ba, Li, and Stallaert (2018) in this issue examines the performance of crowdsourcing contests on Kaggle. The authors show that despite the well-reported merits of using open contests for research and development tasks previously performed within internal business units (Boudreau and Lakhani 2013), the performance of these contests is very much dependent on in-progress feedback to the contestants. Such feedback may lead to "salience bias" among contestants—i.e., "to over-emphasize the feedback while overlooking other important information that may be helpful for them to achieve desirable outcomes."

What is revealing about these findings is that although open contests of the type found on crowdsourcing platforms allow an organization to break free from existing organizational structures and technical architectures, platform owners need to implement appropriate control mechanisms to align the behavior of the online community with the platform's objectives. Although digital platforms enable an opening of their structural boundaries—both organizationally and technically—to support new value-creating interactions, such boundary openings, need to be met with appropriate governance structures.

Beyond the openness of interactions, the digitization of platforms also challenges the mirroring hypothesis. The research conducted by Rolland, Mathiassen, and Rai (2018) in this Special Issue explores the digital options, including "the transformative capabilities afforded by digital platforms' generative characteristics." They examine how a Swedish media organization leverages those capabilities to further develop its use of a platform. The digital options' concept underscores that organizations must continuously identify options worthy of exploration and selectively realize those that generate new value (Sandberg et al. 2014, Svahn et al. 2015).

Rolland, Mathiassen, and Rai also explore digital debt; "an organization's cumulative buildup of technical and informational obligations related to maintenance and evolvability of its platform and infrastructure" (Kruchten et al. 2012, Ramasubbu and Kemerer 2016). Their research shows that the Swedish media organization was constrained by this technical build-up as it tried to align its organizational structures with a new digital platform. In the end, the media organization leveraged a number of digital options and broke free from its existing "digital debt." For instance, in addition to integrating previously dispersed work systems, the platform encouraged new application development, while encouraging the extraction, tagging, and transferring of unstructured data among journalists and producers.

These findings are significant because they provide evidence that the mirroring hypothesis becomes increasingly less relevant as the digital platform evolves to provide more digital functions that transcend existing organizational structures. Rolland, Mathiassen, and Rai pay particular attention to the role of the layered, modular architecture of platforms, as well as their "digitality" in enabling organizations to leverage digital options and manage digital debt for new value-creation opportunities, without becoming locked into legacy systems.

Further research can more explicitly examine how digital infrastructures and platforms challenge the mirroring hypothesis. Some relevant research questions include: *How can new value-creating interactions be supported without being constrained by existing organizational structures and technical architectures*? *How can constantly changing boundaries be governed*? *How does coordination happen on digital platforms*?

Platformization and Infrastructuring

We have already discussed how infrastructures are undergoing a process of platformization by opening their architectural and governance control points through digitization, as described in the study by Rolland, Mathiassen, and Rai. At the same time, we are also beginning to see the opposite happening: The infrastructuring of digital platforms by making them more physical, while expanding their reach and scope.

Amazon is a good example of this countereffect. Amazon started off as an online retailer but gradually moved toward a multi-sided platform model that allows different actors—buyers, sellers, and other third parties, including advertisers, software developers, cloud providers, and so on—to interact on its platform and create value for one another. Over time, it has grown so much that it has increasingly taken over a number of businesses with physical assets, while getting involved in more traditional supply chains or "pipeline businesses" (Parker et al. 2016). For example, Amazon recently bought Whole Foods, a supermarket chain. Together with its Amazon Prime service and AmazonFresh unit, and a logistics network to rival those of FedEx and UPS,[6] Amazon has developed capabilities to deliver multiple items in the same order, on the same day. A clear strategy is underway to move into supply-chain management and distribution, while expanding the company's digital platform strategy.

The dual process of platformization and infrastructuring builds on the existing installed base of infrastructures and platforms, respectively, avoiding the "bootstrap problem" faced by early infrastructures (Hanseth and Aanestad 2003, Hanseth and Lyytinen 2010), as well as the "chicken-and-egg problem" of early digital platforms (Hagiu and Eisenmann 2007, Parker et al. 2016). Instead, by taking advantage of network effects on the existing installed base, these new infrastructures and platforms achieve greater and faster scaling. There are also important policy implications around competition and data ownership given the scale of these infrastructure-platforms (see Implications for Policy).

Fundamentally, platformization can be viewed as a strategy for operating multisided platforms and connecting buyers and sellers without controlling or owning the products or services being sold, as in the examples of eBay, Airbnb, and others. In contrast, infrastructuring can be viewed as a strategy for operating as a supermarket supply chain, acquiring and then reselling products and services. Multisided platforms have become very popular in recent years because they are financially more attractive and less complex than supply chains. Multisided platforms also have low operating costs and high percentage margins because they usually take a cut from each transaction, which goes straight to the bottom line. On the other hand, supply chains typically have higher revenue, but also high capital investment in infrastructure—such as data and product warehouses, and distribution—as well as greater operating costs and lower percentage margins.

The two strategies can be viewed along a continuum, as companies strive to acquire more control, while at the same time pushing for more innovation. Scale and aggregation effects become very important in this continuum (Hagiu and Wright 2013), as they help platform owners determine when to engage in infrastructuring. For example, high-demand products like supermarket items are known to sell more efficiently by one large reseller than by many small sellers. Also, some products and services have much higher value to buyers when bought together than when purchased separately from independent sellers. In these cases, a platform owner such as Amazon, may choose to become a reseller to capitalize on economies of scale in infrastructure investments, while feeding into more innovative products and services (Hagiu and Wright 2013). Scale and aggregation effects are also important for building innovative complementarities between products and services.

For example, Apple engaged in both platformization and infrastructuring in its iTunes-iPod combination when it used a typical razors-and-blades pricing strategy given the scale and aggregation effects. In contrast, when it comes to the Apple App store, Apple does not engage in infrastructuring because gaining control over thousands of developers, their pricing strategies, end-user licensing, and customer support would mean increasing costs for Apple. Instead, the company kept to its multi-sided platform strategy.

Recent research has conceptualized the differences between multisided platforms and reseller supply chains in terms of "the allocation of control rights between independent suppliers and the intermediary over non-contractible decisions (prices, advertising, customer service, responsibility for order fulfilment, etc.) pertaining to the products being sold" (Hagiu and Wright 2015, p. 3). In the case of multisided platforms, all of these residual control rights rest with independent suppliers (e.g., partner shops on Amazon and eBay). In the case of reseller supply chains, all residual control rights rest with the supply-chain coordinator, such as Walmart.

Other literature streams have also contributed to a better understanding of control and its relationship to innovation. For example, research on vertical integration and the theory of the firm (Grossman and Hart 1986, Hart and Moore 1990) has focused on "make-or-buy" decisions, with implications as to the level of control a firm retains while seeking to build in-house capabilities versus sourcing those from third parties. These decisions may be relevant to infrastructure investments, however, for multisided platforms the focal firm (platform owner) does not act as a contractor, but merely as an enabler and facilitator. Consequently, the trade-offs for innovation are different.

Research also has looked more broadly at decisions around an organization's design (Alonso et al. 2008, 2015), and the design of infrastructures (Hanseth and Lyytinen 2010, Henfridsson and Bygstad 2013).

This research captures the relationship between control and innovation, and change as implicated in different governance modes and architectural configurations. Broadly speaking, centralized governance with tightly coupled components may lead to more control, but that comes at the risk of impeding innovative efforts. In contrast, decentralized governance and loosely coupled components may lead to more innovation but less control and eventually, chaotic environments (Hanseth and Ciborra 2007).

All these streams have provided great insights on how control can be achieved while accommodating innovation, but there is currently no research examining what happens when a company engages in *both* platformization and infrastructuring, and has to control both demand-driven innovation (platforms), and supply-driven innovation (infrastructures).

As discussed, and as noted elsewhere (Tilson et al. 2010, de Reuver et al. 2017), digital infrastructures and platforms are now far less limited in the ways their components can be recombined; one digital infrastructure can form a service foundation for other infrastructures, and even platforms. This digitization, coupled with the powerful democratization of innovation (Chesbrough 2006, Von Hippel 2005, Zittrain 2006), has had a disruptive effect of redistributing control across online participants and the applications they use to interact and co-create value.

At the same time, however, as the examples of Amazon and Alibaba show, a few companies now dominate the construction and maintenance of global digital infrastructures requiring prohibitive amounts of financial and technological resources for market entry (Eaton et al. 2015, Tilson et al. 2010). Smaller companies cannot effectively participate in innovative programs without such infrastructure being controlled by a few powerful companies. Therefore, further research needs to theoretically grapple with the paradoxical tension of the generative and democratizing force of digital platforms and the monopolistic and controlling force of digital infrastructures. That's why they should be studied concomitantly.

Some relevant research questions include: *How do platforms and infrastructures scale on each other*? *How does such scaling affect innovation and competition*? *What are the policy implications for the network effects generated through platformization and infrastructuring*?

Competition and Scaling of Digital Platforms

The idea of winner-take-all markets has dominated the discussion on competitive strategy in the platform context. This concept implies a sense of urgency to scale quickly. Such urgency is grounded in the benefits of positive network effects, that is, the increased platform value for all existing users generated by each new user added (Katz and Shapiro 1986, Parker and Van Alstyne 2005). In markets where network effects are strong, there is simply little competitive space for more than a few players. In addition, velocity in the early stages of a technology's life is fundamental for its future path (Schilling 2002). Even with superior technology or performance, it is difficult to catch up to any platform provider with early advantage. In nascent markets, this creates strong incentives to grow the user base quickly (Huang et al. 2017).

While traditional strategy models, like the five-forces model, still make sense in the platforms context (Porter and Heppelmann 2014), it is fair to say that platforms invite new forms of strategic thinking. The significance of the platform's core interaction (Parker et al. 2016), and the related network effects as it connects supply and demand, changes some of the strategy fundamentals. Consider how the size of the user base in the early life of a digital venture has become as important as traditional measures such as revenue, market share, and number of employees.

In view of the increasing number of platform businesses and those adopting platform thinking, it is vital to better understand the competitive dynamics of platforms. Much of the existing research deals with competitive strategy for platform owners (see, e.g., Ghazawneh and Henfridsson 2013, Tiwana et al. 2010). Equally important, but less-often covered in the literature, is how complementors—such as third-party developers—find ways to develop their businesses. This might involve multi-homing, that is, participation across several platforms to extend the size of a potential market. It might also encompass competitive moves at the boundary between the platform core and its complements.

Some of the strategic moves of platform owners involve redrawing boundaries. Such boundary redefinition often takes place in competition with other platforms, but can also require redefining the boundary for ecosystem actors, such as third-party developers. Platform envelopment is an example of a strategy whereby a platform uses its overlapping user base to overcome entry barriers and expand its reach. Eisenmann et al. (2011) describe platform envelopment as "entry by one platform provider into another's market by bundling its own platform's functionality with that of the target's so as to leverage shared user relationships and common components" (p. 1271).

Envelopment involves increasing the scope of the platform and the platform owner can make similar moves in relation to its ecosystem actors. For instance, the paper by Foerderer, Kude, Mithas, and Heinzl (2018) in this Special Issue, deals with the consequences of platform entry for third-party developers in the same market category. Studying Google Photos and its entry on the Android platform, it deals with the problem of entering complementary markets and the consequences for innovation, including the rents of the complementors (see, e.g., Eaton et al. 2015, Tiwana 2015). Clearly, Google's unanticipated decision to enter the photography app market was challenging to established third-party photography app developers in the Android ecosystem. Should they increase innovation as a response to the entry? Interestingly, the research suggests that the spillover of consumer attention in the photo-app category helped build a larger market, compensating for the negative effect of the platform entry and supporting further innovation in the area.

However, platform complements also help in strategizing. One of the most well-known strategies for platform complements to expand their market is to multi-home (see, e.g., Eisenmann et al. 2006). Multi-homing refers to a platform complement's participation in multiple platforms at the same time. In addition to increasing the potential market, multi-homing is also pursued to lower the risk associated with being dependent on one platform ecosystem. The paper by Cennamo, Ozalp, and Kretschmer (2018) adds to our understanding of multi-homing. It highlights that complement providers face trade-offs when they seek to grow their potential market through multi-homing. In particular, complementors have to decide the extent to which the complement should be specialized to each technical platform. In a study of the U.S. video game industry, the authors find that the quality of games released on a focal platform drop on subsequent platform releases.

Forking is another example of a strategic move that non-focal actors of a platform can make. Examining forking in the context of the Android platform, Karhu, Gustafsson, and Lyytinen's Special Issue paper investigates five cases of strategic exploitation where the hostile firm exploits the shared-platform resources without engaging with the platform owner's controlling boundary resources. They analyze a number of forking strategies and the related platform responses involving modification of the boundary resources (Ghazawneh and Henfridsson 2013, Eaton et al. 2015) to mitigate the exploitation.

Finally, the Special Issue paper by Niculescu, Wu, and Xu (2018) deals with the strategic decision to open a proprietary technology platform by analyzing the interplay between same-side openness, the intensity of the network effects, and the absorptive capacity of the entrant. Using a game-theoretic model, the study documents some interesting strategic outcomes. In particular, it shows the conditions under which the incumbent would either close the technology or open it to entrants possessing enough absorptive capacity.

There is a growing body of knowledge in the area of platform competition and strategy, but there are clearly many unanswered questions for future research to address. Indicative research questions include: *What is the strategic interplay between platform owners and ecosystem actors over time*? *What are the competitive moves that platform owners can use to design boundaries to surrounding ecosystem actors*? *How can third-party developers advance their businesses across multiple platforms*?

Blockchain as a New Infrastructure and Platform

Blockchain, which first emerged as the technology underpinning cryptocurrency trading, "is a distributed ledger technology in the form of a distributed transactional database, secured by cryptography, and governed by a consensus mechanism" (Beck et al. 2017, p. 381). A blockchain can also include so-called "smart contracts," or modular components (similar to apps), added onto the blockchain and run without any risk of downtime, censorship, or fraud (Buterin 2014). Briefly, when two parties begin an interaction, such as a request for data or a financial exchange, "the ledger automatically creates a new transaction record composed of blocks of data, each encrypted by altering (or "hashing") part of the previous block. The cryptographic connection between each block and the next forms one link of the chain" (Plansky et al. 2016). This process means that committing a successful fraud becomes almost impossible, because blocks of transactions are continuously validated. "Records cannot be tampered with, because altering them would require coordinating many separate computers" (Plansky et al. 2016).

In contrast to a centralized infrastructure controlled by a single party (e.g., a bank, an electricity provider, a logistics provider, etc.), distributed ledgers enabled with smart contracts can perform trusted operations in a decentralized infrastructure. Through a consensus mechanism, parties with the right to validate new transactions can update the blockchain and interact directly with each other, anonymously, and without the need for central coordination.

Blockchain infrastructure holds out great promise, to increase the speed of exchange, reduce the number of intermediaries and associated costs, improve security, digitize assets, give wider access to disadvantaged groups (especially in emerging economies), and improve regulatory compliance (Tapscott and Tapscott 2016). It is also very disruptive. "Conventional digital tools may improve the way things work, but they don't fundamentally alter the structure of infrastructure. Blockchain, on the other hand, offers infrastructure leaders the opportunity to not only increase efficiency and reduce costs, but evolve how physical commodities are distributed and consumed" (Talton and Tonar 2018).

Many companies are beginning to explore the development of new payment and trading platforms for energy, finance and banking, health, logistics and transportation, and others. For instance, Grid+ (Consensys 2017) is developing a blockchain-based infrastructure and platform that would allow users to buy and sell electricity from different energy producers using cryptocurrencies, while intelligently managing smart loads (e.g., Tesla Powerwall, or Nest thermostat). Blockchain technology has also been noticed by a consortium of energy companies, including BP, Royal Dutch Shell, Statoil; trading houses Gunvor, Koch Supply & Trading, and Mercuria; and banks, such as ABN Amro, ING, and Societe Generale. This multi-sector consortium wants to develop a blockchain-based digital platform for energy commodities trading.[7]

Examples from other sectors include a joint venture between IBM and Maersk to provide "more efficient and secure methods" for global trade using blockchain technology,[8] and the Blockchain in Transport Alliance,[9] that involves shipping giants UPS and FedEx, and aims at setting industry standards for using blockchain to track shipments, manage logistics, and replace freight brokers.

Blockchain infrastructures and platforms are usually complemented with cryptocurrencies. "Cryptocurrencies are digital assets designed to work as a medium of exchange using cryptography to secure the transactions, to control the creation of additional units, and to verify the transfer of assets" (Montemayor et al. 2018, p. 4). The currencies enable a blockchain infrastructure to be truly peer-to-peer, while creating vast opportunities to disrupt established transaction networks.

Although the above examples indicate increasing, large-scale developments in blockchain technologies in recent years, there has been "less academic research . . . [on] the implications of blockchain for how we organize contemporary economies, society or organizations" (Beck et al. 2017, p. 381). Extant research focuses primarily on the technical design of blockchain technology, informed largely by theoretical papers on cryptocurrencies (Tschorsch and Scheuermann 2016). This has led to a neglect of research on the managerial, organizational, and economic impact of blockchain in areas other than finance, including many of the topics covered in this Special Issue.

A recent systematic review of the literature on blockchain technology, its applications, design, use, and implications across various disciplines, identified three themes for further research (Risius and Spohrer 2017). The themes include:

- "Design and features," which focuses on "decentralized control and immutability of event logs, and the applicability and potential of the technology" (Risius and Spohrer 2017, p. 390);
- "Measurement and value," which "addresses the added value that blockchain produces for users and industries under consideration of platforms and applications" (ibid., p. 394);
- "Management and organization," which concerns "questions surrounding the governance, use, effects, and overall organization of blockchain-based information systems" (ibid., p. 396).

The authors provide a compelling read and identify a number of research questions across these themes and perspectives that future IS research could take on. Regarding blockchain platforms, the authors raise questions around the scalability, decentralization, modularity and interoperability, and governance challenges faced by different stakeholders, as well as new types of value creation.

Beyond cryptocurrencies and the exchange of financial value, research questions are raised as to whether blockchain can begin to support other types of value creation including verification and enforcement of contract agreements, validation of electoral votes, secure transfer of private information and data, shipping and logistics information, and much more. Many of these questions rest on the assumption that blockchain is a "trust machine" (*The Economist* 2015). Yet, some have cautioned that trust cannot be replaced by algorithms instead of institutions and market authorities (Lustig and Nardi 2015) as well as the communities that govern blockchain agents' interactions (Maurer et al. 2013). To ensure a trust-less infrastructure in financial transactions would require all financial agreements to be cash-collateralized at 100%, which is very challenging from a cost-of-capital perspective (Roubini and Byrne 2018). Still, the possibilities created by blockchain should drive a re-examination of existing research on trust on virtual teams and online digital transactions, whether it is knowledge-based or swift trust (Crisp and Jarvenpaa 2013, Robert et al. 2009).

Another important point concerns the ability of a blockchain infrastructure and platform to scale. Blockchains require that all transactions be verified cryptographically, which slows them down because they require a huge amount of energy. One recent report has argued that Bitcoin "mining" operations in Iceland consume more energy than all Icelandic households combined (see Roubini and Byrne 2018). In a platform context, since not all users have the same hardware, Bitcoin transactions may get slower and more expensive in energy consumption. At the moment, Bitcoin Core, the Bitcoin software client, processes only five to seven transactions per second, compared to Visa, which processes 25,000 transactions per second. Scaling blockchain infrastructures and platforms appears to be seriously challenged.

Further research into blockchain will need to consider both the underlying digital infrastructure and the emerging digital platforms. Some relevant research questions include: *How can blockchain technology overcome existing architectural and governance challenges in digital platforms and infrastructures? How can blockchain-based digital platforms transform existing value-creating interactions? How does blockchain technology address misaligned incentive structures and trust currently faced by digital platforms? What are the policy implications for developing "smart" blockchain contracts?*

Online Labor Platforms

In recent years, new digital technologies have facilitated the shift from permanent employment to need-based outsourcing, and from local labor markets to global, online labor platforms (Chen and Horton 2016). The online labor industry, dominated by three major platforms—Upwork, Freelancer, and Zhubajie/Witmart—was estimated to account for $1.9 billion in gross service revenue in 2013, with 48 million registered workers (Kuek et al. 2015). Beyond their size, online labor platforms are worthy of research attention because of the ease with which research can be conducted (see Horton et al. 2011), but also because they can serve as a testing ground for new applications of human and machine intelligence (e.g., the case of Amazon's Mechanical Turk) (Chen and Horton 2016).

Online labor platforms also challenge the role of geography, matching workers and employers across borders (Agrawal et al. 2016, Hong and Pavlou 2017, Gefen and Carmel 2008). This borderless labor source has implications "not only for what is made where and by whom, but also [for] the human capital decisions made by individuals, and even the degree of specialization of workers" (Chen and Horton 2016, p. 407). Indeed, online labor platforms have the ability to act as standalone markets, disrupting traditional labor markets and the organizations that depend on them. A recent study by Burtch et al. (2018) even shows that entrepreneurs may choose to work on online labor platforms as freelancers rather than try to pursue entrepreneurial projects of relatively low quality. In that way, there is initial evidence that online labor platform jobs "may, on average, substitute for lower-quality entrepreneurial activity rather than act as a complement to higher-quality entrepreneurial activity" (Burtch et al. 2018, p. 4). Online labor platforms also exhibit new forms of leadership, offering a type of faceless management sometimes referred to as algorithmic management (Möhlmann and Zalmanson 2017).

The shift from traditional to online labor platforms can be explained by both the demand- and the supply-side of the market. New global digital infrastructures and new legal and regulatory incentives (Befort 2002) have pushed employers to turn to flexible work. Concurrently responsibility for worker protection and social costs have shifted back to freelancers creating an arms-length, or mediated relationship between workers and employers (recent developments with Uber illustrate the point). Nevertheless, there has been a significant increase in demand for this work, especially toward achieving work-family balance, supplementing stagnant wages, compensating for unemployment, and coping with "just-in-time" work (Collier et al. 2017).

The key challenge from a digital platform perspective is that platform owners struggle to keep repeat engagements on the system. This is a classic problem that arises when the platform pricing extracts more value from the interaction than it adds (Rochet and Tirole 2003). In the case of Uber, drivers earn fares by providing rides on a flexible basis. Given this flexibility, a central question is the extent to which the Uber platform can influence the supply of drivers on their platforms without hurting demand. Dynamic, or surge pricing, as it is sometimes called, can help establish such a supply/demand balance by paying attention to labor-supply elasticities, that is, "the responsiveness of supply hours to changes in the prevailing price of services" (Chen and Sheldon 2016, p. 2). Determining exactly "the magnitude of high-frequency, labor supply elasticities is fundamental to the economic justification of not just Uber's dynamic pricing system, but any firm employing a dynamic pricing system to incentivize the supply of services" (Chen and Sheldon 2016, p. 3).

A related challenge is how to price a task when there are uncertainties. In such situations, there may be bid-price dispersions on a task, which may create value uncertainties between both freelancers and employers (Hong et al. 2016). Although there has been substantial research from either the employer's (e.g., Horton 2017) or the freelancer's perspective (e.g., Agrawal et al. 2015), there has been very little research assessing both parties' choices and the implications for their successful matching on online labor platforms (see Zheng et al. 2016).

Another challenge that emerges is adverse selection due to asymmetric information between employers and freelance workers (Hong et al. 2016). Opportunistic freelancers may misrepresent or over-report their effort, leaving employers unable to separate high-quality contractors from low-quality ones (Lin et al. 2018). Such information uncertainties can be mitigated by implementing robust reputation systems that serve as a sanctioning device against freelancers' misrepresentation of their capabilities (Moreno and Terwiesch 2014). One unintended consequence of reputation systems, however, is that they create an entry barrier for qualified freelancers who have not yet established a reputation (Pallais 2014). A separate mechanism for addressing information asymmetry is online monitoring of freelancer task-based activities through new digital technologies (Agrawal et al. 2015). While a significant amount of research effort has been placed on the design, evaluation, and optimization of reputation systems, few studies have considered the role of online monitoring and the implications such monitoring may have for the successful matching of employers and freelancers on online labor platforms (see Liang et al. 2016).

Despite these challenges, online labor platforms can achieve some positive outcomes for participants. For example, some platforms might offer training to help their affiliates tackle more complex work. Companies such as uTest (testing software), MicroTask (quality assurance for data entry), CloudCrowd (proofreading and translation), and LiveOps (call centers), already recruit and train workers for their standardized tasks and set prices for both sides of the market. However, there is little research examining the effects of training and development on online labor platforms for workers seeking employment. There are a number of sectors where this would be highly beneficial, especially for "new-collar jobs"[10] in developing countries.

Further research into online labor markets and the future of work will need to consider both the employers, or buyers, as well as the freelancers, or sellers, of services, while also accounting for the digital capabilities of platforms. Some relevant research questions include: *How does pricing for work done on an online labor platform impact repeat engagements*? *How do value uncertainties about a task affect employers and freelancers on online labor platforms*? *How does online monitoring affect successful matching of employers and freelancers on online labor platforms*? *What are the training and development effects of online labor platforms for unemployed workers*?

Implications for Policy

The largest platform firms have multi-trillion U.S. dollar market valuations, and touch the everyday life of the world's Internet-connected citizens (Parker et al. 2016). The infrastructures and platforms of these firms present new challenges related to data ownership, privacy, the influence of social media on democracy, disruption of existing business models and of full-time work, and the swelling concentration of wealth. Although a comprehensive review of the policy implications spawned by platforms and infrastructures is well beyond the scope of this editorial, we will discuss some of the most straightforward ones. We conclude with suggestions for research that can inform better regulation.

Data Ownership

Related to the content and device layers, a battle is looming over the ownership of data that is generated by everyday physical devices such as power-generation equipment, jet turbines, and street lamps. As an example, the OEM, John Deere, has seen conflict with farmers over who has rights to access the software and data generated by tractors (Naughton 2017). Once simple farm equipment, tractors have evolved into sophisticated information-gathering machines—more like the Mars Rover—that can capture precise data such as seed and fertilizer inputs, soil composition, and atmospheric conditions. In a study sponsored by the American Soybean Association, farmers reported a 15% cost reduction from using data-driven technology; a difference large enough to impact profits and loss (Johnson 2012). What is important is that, the data that farmers provide to manufacturers have applications far beyond improving the basic productivity of farms. Uses range from powering seasonal labor markets, to selling insurance, and even informing commodities trading decisions (Wolfert et al. 2017).

The metaphor of tractor as data-gathering machine extends to many other domains, too. For example, city street lights can serve as hosts for a multitude of sensors, from sound to atmospheric. They can also extend communications network equipment by taking advantage of pre-existing connections to power, and relative ease of connection to broadband backhaul to connect radio equipment to networks. In other settings, warehouses that use forklifts and other handling equipment might become platform nodes to collect data on the movement of goods through a distribution system.

The question farmers, as well as everyone else, might reasonably ask is, how much value is being created from their data, and is there some way they can benefit as well? The amount of value created from tractor data can be significant. More challenging is how to share the value created from high quantities of data—such as traffic or pedestrian flow data in cities—or user data from wearable devices, or even from location data from mobile devices and apps such as Google Maps or Waze, and home assistants such as Amazon Home and Google Echo. Scholars have grappled with what frameworks might govern personal data, and Schwartz (1994) laid out five principles that a market design would need to cover, as follows:

- *Limitations on an individual's right to alienate personal information*;
- *Default rules that force disclosure of the terms of trade*;
- *A right of exit for participants in the market*;
- *The establishment of damages to deter market abuses*;
- *Institutions to police the personal information market and punish privacy violation*

In practice, the principles that Schwartz (1994) laid out have been difficult to implement primarily because of regulations, although there are also significant technical issues to overcome. Spiekermann et al. (2015) note that in many countries, privacy protection regulations "leave little room for market negotiations between the data subject and the data controller, let alone between third parties." Koutroumpis et al. (2017) lay out some of the challenges of implementing data markets and suggest that blockchain technology may provide a way to create markets with enforceable contracts (for a review, see Catalini and Gans 2016).

A summary of the U.S. efforts on network policy can be found on the U.S. Commerce Department's website:[11,12]

On November 9, 2015, the Secretary of Commerce unveiled the Department of Commerce's new Digital Economy Agenda, which will help businesses and consumers realize the potential of the digital economy to advance growth and *opportunity. The Agenda focuses on four key objectives*: *promoting a free and open Internet worldwide*; *promoting trust online*; *ensuring access for workers, families, and companies*; *and promoting innovation.*

Even more directly related to the topic of platforms and infrastructure is the focus report on the Internet of Things (IoT), which lays out four focus areas:[13] Enabling Infrastructure Availability and Access; Crafting Balanced Policy and Building Coalitions; Promoting Standards and Technology Advancement, and Encouraging Markets. Of particular relevance to IoT data trading, Koutroumpis et al. (2017) detail a number of multilateral data trading platform market designs. In particular, they note the tradeoff between control and quality on one hand and transaction costs on the other. A centralized model has a market intermediary that can keep transaction costs low but might offer lower quality and control. A decentralized market uses encryption technologies such as blockchains to provide a publicly verifiable ownership and source for data.

Privacy Protection and Democracy Concerns

The European Union and the United States have long had different approaches to privacy. Whitman (2004) argues that the difference is rooted in cultural norms. To quote Whitman, *"Why is it that French people won't talk about their salaries, but will take off their bikini tops*? *Why is it that Americans comply with court discovery orders that open essentially all of their documents for inspection, but refuse to carry identity cards*?*"* Whitman (2004) argues that Continental protections are rooted in the protection of a right to respect and dignity. In contrast, Americans seek to protect their liberty, especially in their own homes. This difference in values has found its way into policy, especially with respect to data collection.

The Safe Harbor agreement, replaced in 2016 by the EU-US Privacy Shield Framework, provided a way forward for a time.[14] However, increasingly, data are collected and aggregated from across the globe. It is not always possible for the cloud service firms to say exactly where a particular piece of data is stored because there are constant optimizations in the shift information across the globe to balance the load on the various infrastructure services. The challenge comes when one authority tries to claim jurisdiction. For example, in a recent case before the U.S. Supreme Court, Microsoft argued that it could not produce e-mail evidence in a drug trafficking investigation because the data in question was stored in Ireland instead of the U.S. (Matsakis 2018). Microsoft's position was that U.S. authorities should work through Irish authorities to gain access. The U.S. Justice Department argued that the search warrant is valid because it could take action in the U.S. to produce the evidence. As it turns out, the U.S. omnibus budget bill signed into law in March 2018 settled the case by statute.[15, 16]

More generally, the EU has taken the lead in the area of consumer protection as it prepares to implement the General Data Protection Regulation (GDPR) in May 2018 (Blackmer 2016). The regulation includes the following features.

- Expanded scope: GDPR regulation includes "processors" and "controllers" of data; institutions must own their compliance as well as third-party companies.
- Significant fines: non-compliance can incur a fine of either 4% of a company's annual global revenue or €120 million, whichever is greater.
- Increased consumer rights: GDPR has expanded the scope of rights for data subjects, including data portability and access.
- Data breach reporting: notification of a data breach is now required within 72 hours.
- Data protection officers: institutions may be required to appoint data protection officers to monitor compliance with GDPR regulation.

The case for such regulation and the challenge of controlling data use after collection has played out in a very public way, as Cambridge Analytica's use of Facebook data has dramatically shown (Seetharaman and Bindley 2018). Although social media systems can control who has initial access to their users' data, it is much more difficult to audit use after the fact, since data can be combined from multiple sources making it difficult to trace the exact origin without having internal access to data sources. As a result, locking down data access at this point is somewhat like "closing the barn door after the horses have left." If the data that was released improperly ages quickly, then new privacy policies can have a significant impact. However, if the released data is more permanent, such as the list of "friends" in a social network, then improper releases will have a longer-term impact. The GDPR's affirmation of a "right to be forgotten" stands in direct contrast to this potential longer term impact.

The challenge for both platform operators and government representatives charged with protecting citizens' interests is to balance what people *say* they want, against what their actions imply about their preferences. The idea of a property interest in personal data can help users better understand the value of what they are giving away versus the goods and services that systems provide. The EU's proposed tax on pure data platforms, such as Google search, suggests that regulators are exploring such structures.[17]

In addition to issues of data ownership and privacy protection, there are increasing concerns about the impact of social media platforms on democracy. The Russian attempts to interfere with and influence the 2016 U.S. presidential election using social media has been well-documented. Less well-known is that at least 17 countries experienced election manipulation in the following year as a report documenting election influence showed in November 2017 (Kelly et al. 2017). Despite the efforts of Russia to influence elections in other countries, the authors note that the majority of interference was deployed by incumbent governments to suppress democracy within their own countries.

A recent study of social media and "fake news" using a detailed database supplied by Twitter showed that false information spreads significantly farther and faster than fact-based news (Vosoughi et al. 2018). One possible reason given for this finding is that false news can be more novel, and thus generate more interest, even if it is untrue. The broader issue is that social media systems are subject to "information cascades" that can cause information to spread quickly, whether accurate or not. This phenomenon might be partially explained by the rapid deployment of machine learning algorithms that can quickly sift through mountains of data to identify patterns (Athey 2018).

A solution might be to put intentional brakes into social media systems to slow the copying of messages. But such brakes run counter to the goal of algorithms that reinforce consumer preferences by delivering "more of the same" when they demonstrate interest in a topic. Braking cascades might be possible through self-governance, but if that fails, then some kind of government regulation might be necessary. A major challenge, however, would be making regulation compatible with the U.S. Constitution's First Amendment.

Net Neutrality

On December 15, 2017, the Federal Communications Commission (FCC) voted to scrap net neutrality regulations that previously prohibited broadband providers from blocking websites or charging for higher-quality service or certain content. The U.S. federal government will also no longer regulate high-speed Internet delivery as if it were a utility. The vote reverses the FCC's 2015 decision during the Obama administration, to have stronger oversight over broadband providers.

There are arguments for and against net neutrality. On one hand, the Internet Association, the trade group that represents big tech firms such as Google and Facebook, are for net neutrality because, as they argue, the Internet was built as a public good, free for all to use, without restrictions. According to the "best-effort principle," each data packet is transmitted in a content-blind manner without any discrimination ("a bit is a bit is a bit," Faulhaber 2011, p. 18). On the other hand, however, Internet Service Providers (ISP) like AT&T and Comcast argue that, given that some 70% of Internet traffic during peak hours comes from digital platforms like Netflix and YouTube, they need to charge fees for the growing traffic to be able to maintain and improve the digital infrastructure. They argue that, if control points are not implemented, we will end up with some powerful platforms free-riding and crowding-out competition from smaller platforms. This may also lead to a dying digital infrastructure—at least for poor, remote areas—as we have seen in the case of transportation and electricity infrastructures (Graham and Marvin 2001).

New platforms and infrastructures in the digital age are built on a layered modular architecture, which, as we have discussed so far, has far-reaching implications on net-neutrality and its prevailing principles. Data now flow between devices and service applications, as we discussed above, that exceed pure capacity needs. This imposes new requirements regarding the quality, reliability, and efficiency of the data transfer, and gives rise to new questions regarding net neutrality, beyond ISP (Statovci-Halimi and Franzl 2013). For example, some have called for "device neutrality" (Krämer et al. 2013) to argue that neither device manufacturers nor software developers (e.g., Apple iOS, Google Android) should have influence on what content or which services can be accessed by the devices (e.g., Apple does not support Flash on its iOS devices). Thus, there is a call for new regulation on net neutrality, one that takes into account the increasing digital convergence of platforms and infrastructures (see Sedlmeir et al. 2017).

Industry Level Challenges

Beyond the above challenges observed at the four layers of the layered modular architecture, there are also disruptive challenges at the industry level. Disruption has been observed in media, lodging, transportation, and more. The concern is especially keen when platforms have ignored existing regulatory frameworks, as in the cases of Airbnb and Uber. Entrants claim that incumbents have engaged in regulatory capture, while incumbents argue that everyone needs to play by the same rules (Edelman 2015, Parker et al. 2016). One conceptual framework might come from the impact that globalization had on manufacturing industries in OECD countries in the 1990s and 2000s. Autor (2015) demonstrated that globalization had an unambiguously negative impact on the specific industries and towns where the associated infrastructure was located. At the same time, the broader benefits of global trade have also been demonstrated. The challenge is how to deal with and potentially alleviate the major consequences that small groups experience, while still allowing for the broader benefits.

The challenge that regulators face as they try to craft a response to disruption is to avoid capture by the incumbent firms that would prefer to use government authority to avoid competition. The upcoming implementation of Payment Services Directive 2 (PSD2) highlights some of the contradictions of using regulation in quickly changing industries. The goals of PSD2 are as follows (European Commission 2018).

- *Contribute to a more integrated and efficient European payments market*
- *Improve the level playing field for payment service providers (including new players)*
- *Make payments safer and more secure*
- *Protect consumers*

The implementation of PSD2 requires financial institutions to provide API access to customer accounts. The goal is to facilitate the entry of entrepreneurial "fintech" firms to innovate and provide new solutions such as robotic portfolio advisory services and single portal access to accounts held in multiple institutions. This goal can be partly viewed in the context of EU concern about the relative lack of "tech" start-ups, described as "Platform Anxiety" by Evans and Gawer (2016). The concern that incumbent financial services firms express is that, although the goal is to facilitate entrepreneurship, the practical impact might be to create openings for the incumbent technology firms (Amazon, Google, etc.) to enter financial services markets with the possible unintended consequence of crowding out start-ups.[18] Regulators are likely to view such concerns with scepticism given the obvious interests incumbents have in protecting their markets.

Another industry level challenge is the potential for anti-competitive behavior by platform firms that enjoy large market shares protected by network effects and switching costs (Eisenmann et al. 2006, 2011). Search markets, for example, have drawn scrutiny from both EU and U.S. regulators. The concern in search is that results will be manipulated to favor platform partners. On the other hand, markets that are linked by network effects often have unique prices where certain user segments can see prices at or below marginal cost. Although this might look like predatory pricing, in reality, the firms involved are often engaging in optimal price setting behavior. Evans (2013) argues that legal briefs that do not cite and incorporate the two-sided network literature be subject to Daubert motions of dismissal. Nonetheless, as large technology and social media platforms continue to grow, the possibility for abuse grows as well and will need a vigilant set of regulators to ensure a level playing field.

Recommendations

There are a number of fruitful avenues for further research to support the resolution of the regulatory issues described above. These include but are not limited to the following.

- Clarify intellectual property rights to establish ownership. Potentially secure those rights using technologies such as blockchains.
- Foster the debate to balance the goals of privacy against the desire for economic growth.
- Examine whether social media should be viewed as "critical infrastructure" given their ability to influence critical societal functions such as elections. If so, what are the appropriate regulatory regimes?
- Examine an appropriate role for government intervention into how platforms operate. Specifically, is there a role for a "platform tax" to help ease the transition of disrupted workers into new industries?
- Assess whether platforms can regulate themselves. Is the threat of negative publicity and lost users enough of an enforcement mechanism or is government regulation inevitable? Platform owners need to invest in research to better understand their broader impact. How might social media platforms make design changes that might reduce/prevent information cascades?

Conclusion and Acknowledgments

The submission response to this Special Issue attests to the importance of the topic of digital infrastructure and platforms. Our goal was to bring forward leading-edge research from the information systems, strategic management, and economics literatures to inform our understanding of platforms and infrastructures in the digital age. We began by outlining the rich tradition of research on platforms and infrastructures based on multiple disciplines. We presented our own understanding of this research by paying attention to the architecture and governance of infrastructures and platforms. We then highlighted themes emerging from this Special Issue and discussed opportunities for further research. We are thankful for the contributions made and are confident that the issue provides a solid ground for future studies that draw on both infrastructure and platform research to address new business and social problems.

We received 54 submissions covering a range of sub-themes. Some otherwise promising papers were screened for their fit with the objectives of the Special Issue. A total of 35 submissions went through a full review process by a community of 28 associate editors and nearly 100 reviewers, drawn from multiple disciplines and with a wide range of theoretical and methodological skills to handle both empirical and theoretical papers. The six papers published in this issue were shaped and refined by their authors with the assistance of this community. As Guest Senior Editors, we would like to extend our heartfelt thanks to this community of scholars who dedicated their time and expertise to the process.

We would like to acknowledge, in particular, the associate editors–many of whom hold editorial positions at *Information Systems Research* and other top journals in the IS, management science, and economics fields. They have contributed substantial effort to the editorial process of the Special Issue. We would also like to thank the Editors-in-Chief of *Information Systems Research*, Ritu Agarwal, who was brave enough to support our concept in the early stages, and Alok Gupta, who has supported its completion. A special thanks to Frances Moskwa, who assisted us, the Guest Senior Editors, and the large pool of associate editors and reviewers who demonstrated great patience and understanding through the administrative processes. Thanks are also due to Paula Klein for language editing. Finally, we greatly appreciate the work of Sandor Roberts in finalizing the publication process for this article and the entire Special Issue.

Endnotes

[1] However, most of Apple's revenue and profit is, admittedly, realized through product sales.

[2] The Scalable Product Architecture serves as a platform for the latest generations of Volvo's XC60, XC90, and S/V90 models.

[3] Yoo et al. (2010) refer to this as the separation between network and content (p. 726).

[4] Modularity refers to the degree to which a product can be decomposed into components that can be recombined (Schilling 2000). A modular architecture offers an effective way to reduce complexity and to increase flexibility by decomposing a product design into loosely coupled components interconnected through prespecified interfaces (Baldwin and Clark 2000).

[5] Baldwin and Clark (2000) refers to design rules as a way to prevent cycling in the design of interdependent objects.

[6] See http://uk.businessinsider.com/r-amazon-to-spend-149-bln-on-air-cargo-hub-fans-talk-of-bigger-ambitions-2017-2?r =US&IR=T.

[7] See https://www.reuters.com/article/us-energy-blockchain/bp-shell-lead-plan-for-blockchain-based-platform-for-energy-trading-idUSKBN1D612I.

[8] See https://www.forbes.com/sites/rogeraitken/2018/01/16/ibm-forges-global-joint-venture-with-maersk-applying-blockchain-to-digitize-global-trade/#1b376389547e.

[9] See https://bita.studio/.

[10] See https://www.nbcnews.com/business/business-news/companies-colleges-unite-train-new-collar-students-n802251.

[11] https://www.commerce.gov/tags/digital-economy (accessed March 18, 2018).

[12] https://www.commerce.gov/news/blog/2015/11/commerce-departments-digital-economy-agenda.

[13] https://www.commerce.gov/news/press-releases/2017/01/us-department-commerce-releases-green-paper-proposing-approach-advancing (accessed March 18, 2018).

[14] https://www.ftc.gov/tips-advice/business-center/privacy-and-security/u.s.-eu-safe-harbor-framework (accessed March 22, 2018).

[15] https://www.nytimes.com/aponline/2018/03/22/us/politics/ap-us-budget-battle-email-searches.html.

[16] https://www.wsj.com/articles/u-s-authorities-get-access-to-data-stored-on-overseas-cloud-servers-1521827685.

[17] https://www.reuters.com/article/us-eu-tax-digital/eu-proposes-online-turnover-tax-for-big-tech-firms-idUSKBN1GX00J (accessed March 25, 2018).

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