Understanding the Information-Based Transformation of Strategy and Society

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ABSTRACT: The world economy is undergoing dramatic changes, largely driven by the new availability of fine-grained information. Innovative ways of using data—large and small—have also prompted a rethinking of the boundaries for the combination and use of knowledge. The strategic design of information flows in the economy has the upside of higher economic rents and competitive advantage, as well as the downsides of wealth inequality and abuse of power. This has brought a wide range of regulatory challenges. To understand the nature of these sweeping changes, it is important to examine the new ways information is used, and how information flows can be leveraged to create competitive advantage and dampen competition. The analysis in this article examines four economic entities that produce and consume value, as well as three determinants for the modes of their operations. The economic entities include *consumers, producers, markets*, and *society*, whose interactions are determined by *viability, networks*, and *agency*. In this framework, we paint a picture of the transformation of information-based strategy in the future and suggest promising research opportunities.

KEY WORDS AND PHRASES: consumers, economic theory, hyperdifferentiation, information flows, information politics, information strategy, intelligent assets, markets, producers, society transformation.

Information Abundance Leads to Active Information Design

Information is a key ingredient in most human activities, and its systematic collection and management is of strategic interest in all imaginable economic and social interactions [5]. The term *strategic* is used with respect to information typically to indicate some form of *payoff relevance* [106], especially when the information diminishes the uncertainty an *agent* (or an organizational decision maker) has about states of the world that matter for performance [94, 110]. Since information is generated, collected, processed, transmitted, and consumed over extended periods of time, the strategic design of an information source amounts to creating dynamic *flows of information* so as to influence the payoffs of those who set out to take advantage of them. Over the past 70 years, research on *information-based strategy* has focused on determining the impact information may have on decisions by individuals, teams, and organizations [78, 107], the *value of information* related to the observed outcomes [46], and how information asymmetries may affect decision makers' and organizations' abilities to interpret and respond to each other's perceived actions using appropriate mechanisms [139]. From the mosaic of past analyses, patterns have emerged that can be recognized and used as templates for effective strategy development and decision support [32, 37, 38].

By and large, the impact of information on managerial decisions is well-understood: symbolically speaking we therefore know $\partial(\mathit{Decision})/\partial(\mathit{Information})$, which represents the sensitivity of optimal decisions to information [18, 90]. However, when estimating the impact of information on optimal payoffs by computing the total derivative,

$$\begin{aligned}\frac{d(\mathit{Payoff})}{d(\mathit{Information})} &= \frac{\partial(\mathit{Payoff})}{\partial(\mathit{Decision})}\cdot\frac{\partial(\mathit{Decision})}{\partial(\mathit{Information})}+\frac{\partial(\mathit{Payoff})}{\partial(\mathit{Information})}\\ &= \frac{\partial(\mathit{Payoff})}{\partial(\mathit{Information})},\end{aligned} \tag{1}$$

it turns out that this sensitivity is (locally) irrelevant.[1] This is because $\partial(\mathit{Payoff})/\partial(\mathit{Decision})$ must be zero at an optimal decision due to Fermat's rule in optimization [10]. Moreover, rather than thinking of information as a parameter that changes decisions, one can think of it as a decision variable itself. The future of information-based strategy in an information-rich world will depend on the design of information. In other words, information flows can be actively used to attain a payoff maximum, at which the total derivative in Equation (1) vanishes. We believe that an abundance of data, in conjunction with changing boundary conditions in the economy, makes information a centrally important decision variable and thus the design of information flows is a major theme of future research in information-based strategy in organizations and society as a whole.

In what follows, we discuss how important trends are likely to affect four entities of action—*producers, consumers, markets*, and *society* [89]—whose interactions depend on the *viability* of all entities, the structure and capabilities of the multi-layered *network* of connections they belong to, and the attainable *agency*-based agreements they are able to forge for the allocation of tasks and resources among themselves. Figure 1 provides an overview. The three determinants respond to three

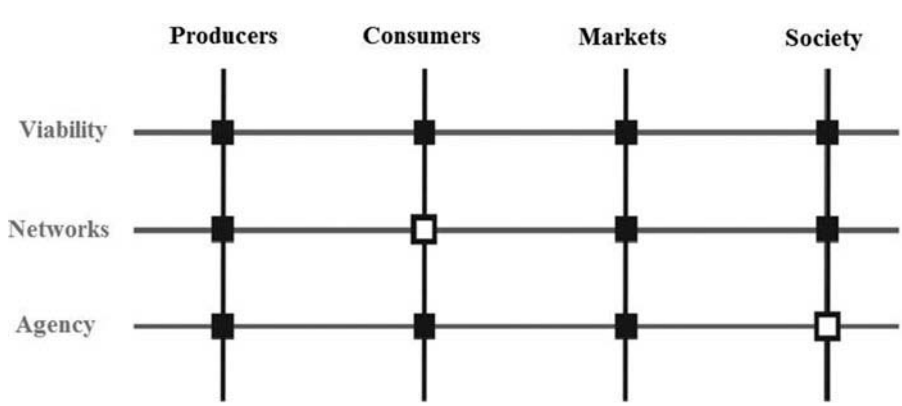

Figure 1. Entities of Economic Activity and the Determinants of Interaction

questions, namely, *why?* (viability), *how?* (network), and *what?* (agency) that define the entities' economic interactions. For each of the seven areas (consisting of four entities and three determinants), we identify important areas of investigation, and relate those to established research streams, recent cutting-edge work, as well as leading indicators and our own best judgment, as a way to gauge the transformation of information strategy in modern economies and society.

Producers: From Push Production to Large-Scale Customization

The Fourth Manufacturing Revolution

After the steam engine, Ford's mass production, and the first wave of automation in the 1970s, productivity increases have been decreasing rapidly in the new millennium.[2] The collective push production by globalized firms into large warehouses has led to excessive transportation and supply-chain rigidities. In addition, labor costs have increased, slowly eroding economic advantages from centralized global production. A fourth manufacturing revolution, sometimes called "Industry 4.0" [80, 85], driven by a combination of networked information technologies with intelligent manufacturing robots, will have a profound impact on productivity and on the economically feasible levels of product differentiation. The fourth manufacturing revolution is a result of the fusion of information technology and other real-world technologies in so-called cyberphysical systems. Besides implying a plethora of technical system-integration issues when adapting algorithms to take into account time delays, system heterogeneities, stability, and other hardware-related complexities [47], there are broader strategic implications. First, intelligent robots will increase the level of automation from currently less than 10 percent of all tasks to more than half of them, including many nonrepetitive ones [93, 105]. At this level of networked automation, differentiated and highly customized goods can be produced at close to the same cost as mass-produced widgets, thus providing a green light for the economic feasibility of mass customization in the domain of durable goods [84]. Second, the transformation of push production into pull manufacturing will make it efficient to relocate factories to where the demand is, transforming global into regional trade flows. This implies a new wave of reshoring and insourcing [62], at least partially reversing the global outsourcing trend of the past few decades.

The fourth manufacturing revolution is just the tip of the iceberg: while especially high in manufacturing (60 percent), the automation potential is indeed very significant across the entire spectrum of economic activities, ranging from 27 percent in educational services to over 70 percent in accommodation and food services [105], pushing the cyberphysical frontier into most economic activities.

With the dissolving trade-off between cost efficiency and responsiveness, an undisputed tenet in current operations management textbooks (see, e.g., Chopra and Meindl [30]), interesting research topics will concern how to best translate articulated customer preferences into customized products, how to adapt product design in modular ways to the new mode of manufacturing,[3] and how to best generate value from the individualized product designs. An important feature is the close-to-real-time connection of demand to supply, with the *Internet of Things* (IoT) [66] being linked to the *Internet of Services*, making use of smart factories and smart products, among the many "newly intelligent assets" surrounding us—including smart buildings, smart grids, and smart mobility. At such a high level of sensing and processing, the design of the relevant flows of information becomes key.

Precise Consumer Tracking

New technologies, including mobile phones, IoT sensors, and the Internet make it possible now to track people in urban settings at many different levels [86]. These may include the *digital traces* of their social networks with personal profile and friends, geospatial and geotemporal data, their online site visits and purchase behavior, their IP-address connections, card-based spending habits, and so forth [48]. Companies need to understand how to combine various information sources to obtain a high-resolution image of their consumers' revealed preferences, which has hitherto been private information (e.g., their incomes and purchasing patterns)—with the result that information changes consumer behavior, and consumer behavior in turn changes corporate strategy [31]. Consumer-level data can be used to predict future purchase behavior and feed individualized hedonic valuation models to price new products. This big-data approach to design is set to create a better fit for customers with discoverable characteristics [29, 87]; yet the flip side of the coin is that firms also derive better and more precise levers for price discrimination, and thus can extract extra surplus from consumers, potentially more than offsetting the benefits of a better fit [16]. The regulation of such tracking is complicated because it is not easy to monitor the data processed inside a company, the effects of biases that may be inbuilt in algorithms, and the data that these algorithms are fed with.

Individualized Pricing

With hyperdifferentiated products in the market [35], enabled by intelligent manufacturing and precise consumer tracking, companies will try to approximate *first-degree price discrimination* by creating a "segment of one" [157], in other words: total customization [149]. We should thus expect to witness a transition from *second-degree price discrimination* (based on unobservable customer characteristics and self-selection) to *third-degree price discrimination* (based on observable or inferable customer characteristics) to an approximation of first-degree price discrimination. Because pricing does not happen in isolation, a firm's ability to extract a consumer's surplus is normally limited by the consumer's outside options [41, 128] and by its own ability to create meaningful and distinguishable versions of a product. As a countervailing trend to selling customized goods, there is a paradigm shift in consumers' minds away from owning goods to accessing them when they are needed to obtain value [14, 15]. And if goods are shared by many, they cannot be too customized. Hyperdifferentiation is therefore limited by a propensity for sharing, and firms will have to design this trade-off to their benefit.

Aftermarket Control

Manufacturers and sellers of technological goods have been trying to exert control on both the primary and secondary product markets, for example, by using compatibility and technological complements. Proprietary systems with limited interoperability serve as mechanisms to lock in consumers [2, 61]. Firms can also tie the sale of their products to consumers' buying of other products [27]. In this vein, sufficient sensing and networking intelligence embedded in devices enable firms to retain increasing levels of control over how exactly their devices are used after they have been sold. This will allow for the firm-consumer relationship to last and to adapt with unfolding use patterns, for instance, for the collaborative consumption of durables [153], including possibly the dynamic adjustment of product characteristics and add-on prices. The complex issue of how to economically design and exploit product control, subject to technological feasibility and available information, is an important direction for future study.

Consumers: From Ownership to Access

The Rise of the Sharing Economy

The past decade has seen the emergence of sharing markets in many domains. They allow consumers to adjust their consumption to their actual needs, and increase the economic usefulness of their assets [15, 143]. In addition, depending on their projected future needs for an item, they can forgo the purchase of a durable and gain future access via a sharing market, either from a peer or an intermediary that aggregates the demand and supply for currently unused products. Numerous research topics are related to this change in consumption behavior and its limits, as well as the implication this has for firms' product-design and pricing incentives [124, 152]. For example, with collaborative use in the aftermarket, the seller of a shareable good can increase the price by a sharing premium. In other words, the market value of shareable goods is set to rise, if the market imperfections, for example, through search and coordination in the peer-to-peer aftermarket, as well as the risk associated with sharing-related transactions, can be kept sufficiently low [151].

Shaping and Participating in Information Flows

Consumers now have access to many different sources of information. Just as easily as they can consume information, they can also become a source of information to which others can subscribe and the content of which others can collectively filter, authenticate, and verify. How do individuals cope with this extent of information overload? How can they effectively participate in a marketplace that is subject to such heavy information flow, such as a stream of product reviews with daily updates? The design of information flows is therefore multisided: as a source of information, an agent chooses the format of a message, within the design confines of a platform where the message will be visible; finally, a consumer of information sets filters and opts in and out of certain content, so as to design an individualized stream of information that warrants attention. As Herbert Simon [134, pp. 40–41] noted, "in an information-rich world, . . . a wealth of information creates a poverty of attention and a need to allocate that attention efficiently among the over-abundance of information sources that might consume it." Future research needs to take into account self-interested behavior, namely, that the wealth of (likely biased) information is likely to produce a "richness in filters," the quality of which modulates an individual's rational attention—a new form of *infomediation*, first described by Hagel and Rayport [77] at the beginning of the dot-com era. Regulatory challenges related to various targeted information streams such as advertising and fake news are discussed in the section on *society* below.

New Approach to Learning

With the increasing obsolescence of products in many contemporary domains (e.g., smartphones and their apps, video cameras, computer technology and peripherals, and many forms of online service offerings), consumers are likely to find themselves feeling increasingly like "newbies" and relatively unfamiliar with many if not most electronic products. The mounting system complexity and individuals' increasing scope of activities widen the impossibility of becoming an expert user. This, we argue, requires a new scalable approach to learning, rather than the traditional incremental acquisition of knowledge. It requires a mindset adapted for living with complex systems that involve heterogeneous technologies [129].

Network Embeddedness

Consumers are participants in multiple networks. While each of these may provide value and connectivity, the way they serve a consumer's interest is likely to vary widely, from social exchange, collaborative filtering (via recommendations of music, books, movies, etc.), brand loyalty and shopping, alumni contact, charitable volunteership, and political representation. How does this influence their ability to autonomously act and transact? What are the relevant privacy perspectives? And what does this mean for the trust consumers can place in others?

Network embeddedness will also bring new realizations to people about how to achieve a more appropriate use of the products that they either purchase or hope to have easy and cost-effective access to, or the on-demand services they need, which will change their purchase behavior. For example, when mobile phones are used to digitally share a passenger's pick-up location, the transaction cost for acquiring the service drop and the price for the on-demand transportation service (e.g., Uber or GrabTaxi) decrease. Furthermore, the penetration and availability of the service increase, together with the utilization of cars. In related research by an automotive analyst group at Deutsche Bank, it has been suggested that a move to transport-on-demand may diminish the number of vehicles in service at any time, while reducing the average service life of vehicles to about three years due to their greater service loading of miles driven and hours used each day, and demand-smoothing to diminish automobile sales cyclicality. As one may expect, not all observers agree with this forecast, pointing to the effects of sharing as diminishing the durability and lifetime distance for manufactured automobiles [130]—until automakers reassess their incentives in the presence of car sharing and change their build quality so as to provide more durability [124].

A further impact of network embeddedness and the resulting "thick" information flows is the prima facie increase of *customer informedness* about goods, services, and sellers, as well as an increase of *firm informedness* about consumers, customers, and competitors, in addition to *between-customer informedness* about individual preferences, opinions, and product/service recommendations [100]. As a second-order effect, the relationships between consumers and firms change, and both sides will use what they learn differently, as Clemons and Gao [34] noted a decade ago. The difference today is that the level of informedness for all entities of economic activity has led to faster markets, more responsive innovation on the supply-side, and greater speed of induced shifts in consumer tastes and market trends. While on the upside, more information tends to alleviate inefficient information asymmetries (e.g., about product lifetime or repair costs because users can post such information for all to see), it may also lead to a decrease in privacy [1, 136] and strategic manipulation of information [45]. Future research will tease out the balance of these countervailing effects for various product and service markets.

Markets: From Intermediated to Distributed Transactions

Endogenous Determinants for Intermediary Speed

While the analog world has not been able to exceed the speed of humans, a digital world allows for faster links and transactions, which are limited by physical constraints rather than bounds on rationality. A case in point is the emergence of *high-frequency trading* (HFT) practices in the equity markets in the 2000s [4], enabling trade on surprise developments communicated around the Internet and via social media, thus leading to rapid asset-price corrections [23]. Using dedicated telecommunication cables to communicate price and order information to and from an electronic exchange, delays could be cut down to a *very low latency* in telecom services terms [99]—resulting in what Steiner [138] has referred to as "Wall Street's speed war." Moallemi and Sağlam [113] estimate the cost of latency of trading on a human time scale in the presence of high-speed execution by others, deriving opportunity costs consistent with rents extracted by high-frequency traders. On the one hand, HFT improves price discovery, while on the other it tends to selectively remove liquidity from less attractive securities [22]. In the context of the adverse-selection effect on liquidity, HFT has been called "Insider Trading 2.0," with markets exhibiting increasing volatility since the mid-2000s. Indeed, some observers have pointed to a new irrationality and herding with overresponsiveness to mistaken signals of value changes, leading to undesirable price swings and market-wide impacts [21]. And yet the trading patterns of very active high-frequency traders did not change when prices fell during the Flash Crash in 2012 [91]. Similar to other "game-changing IT" that has captured firms' rent-seeking interest over the years, HFT has folded back into the "boring and unprofitable part of the basic infrastructure of markets" [158]. Future research needs to tease out whether beyond-human execution speed is indeed desirable or if markets could benefit from rules that inhibit technology races, such as the discretization of trading times (discussed, e.g., by Stiglitz [140] and Haas and Zoican [76]).

An area where a self-interested financial institution may have an interest in providing less than the greatest speed is electronic money transfer: banks have been offering (almost collusively) slow settlement speeds that are nowhere close to real time [75]. Indeed, a *faster payment settlement* has become a public policy goal in a variety of countries around the world (e.g., the UK, Denmark, Singapore, and Australia, among others) so as to achieve greater immediacy of transfers and enhanced fairness (e.g., among consumers, retailers, suppliers, and card intermediaries) under the watchful eye of financial regulators [145]. The European Central Bank, for example, has identified late 2017 and 2018 for the implementation of TIPS (TARGET Instant Payments Settlement) for its pan-European payment system, TARGET [59]. A possible alternative to bank-centered settlement systems, namely programmable cryptocurrencies, is discussed below.

The emerging technology-driven opportunities in the financial sector (e.g., in payments, wealth management, credit cards, trade finance, remittances, investing, and financial research [150]) are often referred to as being in the *fintech domain of technological innovation*. Fintech leads to revised expectations for the performance of customer acquisition, data-driven analytics, customer segmentation, and harmonization for possibly shared infrastructure investments [49]. It also implies new research directions to better design information flows and ingeniously derive information-based strategy.

Programmable Cryptocurrencies and Blockchain Technology

Historically, transaction costs imposed by banks are a result of their seeking rents [146], and the same holds true for intermediaries' commissions. Both are instances of endogenous inefficiencies created by middlemen. In a programmable world where currencies need not be guaranteed by institutions but are rather based on collectively accepted cryptographic protocols, a middleman's speed limit need no longer affect the transacting parties. When cryptography can ensure payments conditional on the parties' agreements, then the need for intermediaries (as guarantors and aggregators of trust) subsides. There are many research topics in a new world of direct peer-to-peer transactions, and intermediaries' creative reactions to maintain a regime that provides for their economic viability.

A spate of recent research on applications and their economic feasibility in this area came as a result of digital cryptography innovations associated with Bitcoin [116]. The underlying technology, *blockchain*, is a technical approach to prohibit the replication of digital tokens, so digital money derived from these tokens cannot be spent more than once. The essence of the solution, a *distributed ledger system*, was described in a recent article published in *Communications of the ACM*, as follows: "When a user wants to add a transaction to the ledger, the transaction data is encrypted and verified by other computers on the network using cryptographic algorithms. If there is consensus among the majority of computers that the transaction is valid, a new block of data is added to the chain and shared by all on the network. Transactions are secure, trusted, auditable, and immutable. They also avoid the need for copious, often duplicate, documentation, third-party intervention, and remediation" [147, p. 15]. This approach has made it possible to encode a dramatic amount of new information using blockchain: for payments and foreign exchange transactions, smart contracts, general ledger updates, and securities settlement [79]. There are also many applications that go beyond financial services, such as automobile registration histories [44], the provenance of fine art [25], and electronic travel services [70].

At present, Bitcoin and blockchain are both regarded with a blend of skepticism and anticipation by large commercial banks and regulators [81, 112]. Some describe it as an inevitable pathway for innovation in payments and related financial services. For example, Arthur Levitt Jr., ex-chairman of the U.S. Securities and Exchange Commission, argued that Bitcoin can enhance global financial inclusion, alleviate the network scaling, computational speed, and "last mile" cost concerns of Bitcoin FX conversion, and provide increasing resilience in the face of past Bitcoin exchange failures such as Mt. Gox [97, 98]. Research will envisage and analyze a world without intermediaries and explore what shifts this may imply for financial intermediaries' rent-seeking opportunities and the future of middlemen more generally, across electronic markets.

Trust Protocols

As a by-product of the cryptographic advances that enable programmable currencies, it is possible to ameliorate informational asymmetries via digital protocols. Evidence of information availability can be given without transmitting any part of the information using zero-knowledge proofs, thus breaking Arrow's *paradox of information* *value* [9], which highlighted a fundamental problem of charging for information without disclosing it, thus possibly ruling out a market-based solution to patent protection. At issue is whether there can be appropriate incentives for producers of innovation that becomes a public good (as is usually the case with new technologies) to allocate a socially optimal amount of resources to pursue innovation in the first place. Livak [101] argues against all patent-related technological information being treated as exclusive, and questions whether instead some of it can be commoditized for widespread use, similar to Volvo's decision in the late 1950s to give away its patent on the three-point automobile safety belt. With new technologies such as blockchain, it now may be possible to go beyond the patent system by encoding instances of technology innovation-related patent information for which commoditized versions can be shared, including instructions for implementation that can be tracked as a basis for identifying market transactions. Thus, in contrast to the widely held view that patents create incentives that tend to protect technological information, blockchain offers a countervailing basis for their commoditization and metering of the related transactions.

The extension and design of new protocols for the release of information in business, government, and social settings will be a fruitful area of research that has immediate economic relevance. Many observers, including the tech-savvy market research firm International Data Corporation (IDC), have pointed to the importance of the *digital platform transformation* in business and government organizations. They recognize a progression from mainframes and centralized computing (the *first platform*, via less centralized client-server computing (the *second platform*), to the cloud of Internet computing capabilities combined with wireless devices, smart products, IoT sensors (the *third platform*) [144]. It is here that we expect to observe substantial contributions and intersection of research activity involving information systems, computer science, and economics.

Micropayments

The ability to monetize small transactions can have a profound impact in the aggregate. For example, by charging very small amounts for e-mail transmissions, untargeted spam messages may be curtailed [6, 148]. Similarly, micropayments could incentivize aggregate behavior such as for energy savings, thus helping with matching demand for electricity with its intermittent supply. For example, the Swiss Ethereum Foundation's (www.ethereum.org) blockchain-encoded unit of exchange (Elethron) involves transferrable digital credit tokens for the sale of energy from a power company to the electricity grid used by consumers and organizations, or for the end users to sell power back to the grid [52].

And yet, it has long been recognized that micropayments may not be the best instrument for payment when the good or service is one for which usage-based fees are not appropriate [115]. For example, is a monthly flat connection fee for the opportunity to do as many searches on the Internet as desired, at zero marginal cost, or a per-search fee more appropriate? The answer may be a matter of degree: for a sufficiently small per-search fee, marginal cost is inconsequential enough to almost disappear from consideration, yet still perhaps tends to reduce procrastination (see, e.g., Andreou and White [7] for an overview). These issues, including a crossover to behavioral economics, suggest interesting avenues for research on electronic markets for durables and commodities such as energy or advertising that transcend disciplinary boundaries.

Trading of Externalities

Information flows about individuals' activities can provide important feedback about actions (*externalities*) that influence the payoffs of others. For example, air and water pollution, and other damage to the environment may be perceived as a consequence of ineffective management of negative externalities such as excess carbon dioxide. Prices for such externalities can help, for example, in the form of a carbon tax or the cost of emissions permits in a cap-and-trade market. The design of such markets can even include secondary objectives such as providing incentives for investing in innovation [154]. Beyond environmental externalities, there are other equally pervasive payoff interconnections, for example, related to congestion. But would it make sense to use peak-load pricing for train tickets to manage congestion? Can we use micropayments and real-time bidding to improve social welfare by switching traffic lights to favor the queue with the highest bids? The underlying logic is provided by the seminal *Coase theorem* [39], which ensures the attainability of Pareto-optimal (i.e., economically efficient) outcomes in situations without information asymmetry as long as property rights are allocated.[4] Future research will focus on how to use our information-rich environment and intelligent regulation to ensure clearly defined property rights, together with a smart dynamic market design so as to implement efficient outcomes in real time.

Society: From Allocative Efficiency to Fair Sustainability

Social Context

Modern IT is dramatically changing business and society. While in aggregate these changes tend to be positive, the benefits of technology applications tend to be distributed unevenly. And, as with any disruption, there are likely to be winners and losers.

As with previous technologies associated with mass production of textiles and heavy industry, there have been both a great creation of wealth and a substantial surge in unemployed or underemployed workers. Recent technological innovations have intensified income inequality [120], in part due to the *winner-take-all* [63] character of many online business models [24]. There may be additional unforeseen impacts, where wealth disparity and income inequality are further exacerbated, and although society might benefit as a whole, some sectors of the labor market and some segments of the production economy can be significantly worse off, perhaps for extended periods of time.

There also may be unforeseen risks associated with the winner-take-all nature of some businesses, reinforced by economies of scale and network effects, where the first established player may have the power to eliminate competition and stifle innovation. And there may be unforeseen risks associated with firms that gain dominance in one industry or one market segment, and then use that power to dominate other areas, again potentially limiting competition and stifling innovation [33]. There may even be areas in which many users gain, but some participants are hurt due to externalities, possibly outweighing the gains [104]. Some of the key questions include:

- What are robust objectives for social welfare? What are appropriate metrics?
- How should social and regulatory policies be designed? More specifically, how would one describe the greatest good that could be produced by a transformative innovation and how would one know if it had been achieved?
- How would one regulate innovative emerging businesses to achieve the greatest good? How would one measure behavioral improvement? What regulation is likely to yield improvements in the chosen social-welfare objectives?
- How would one regulate so as to not increase the harm or limit the benefits from innovation? This could happen through premature or inappropriate regulation that reduces competition or stifles innovation, for example.

To address those questions effectively, a mix of qualitative and quantitative methods is appropriate, from both an empirical and a theoretical viewpoint, as the answers will contain descriptive, normative, as well as prescriptive elements.

Democratization by Access

What once took a professional audio studio to master, anybody can now record at home. The radical change in affordable recording technology and the possibility for self-publishing music is symptomatic of the democratization that follows from access to hitherto unaffordable assets and technological progress [19]. A professional film camera can be rented, access to a sports car obtained on a sharing market, and a yacht consumed collaboratively while the owner is on vacation. The effects of income inequalities, for example, to curtail consumption for some, are attenuated by the possibility of temporary access to products, creating a win-win for the effective use of available resources. This implies a thicker tail for the scope of consumers' demand interests and product offerings in the market. Research will explore the effects of access democratization and resulting new pricing and differentiation of products that may restore partial inequalities if it is possible to effectively segment the market so consumers with a higher ability to pay also pay more.

Widening Human Reach and Newly-Binding Constraints

The changes in human abilities due to augmented reality, advanced materials, genetic manipulation, and self-healing abilities will have a profound impact on society. All of these dimensions of transformation depend heavily on information-processing capabilities. And the (perhaps merely virtual) gains need to be matched to the allocative realities of a finite globe.

Since the earth's steady-state carrying capacity [40] is being overconsumed by a large multiple, it is inevitable that natural-resource constraints will become binding at many levels in the not so distant future [67]. This imposes a closed-loop perspective on the use of resources, including durables, consumables, and services, resulting in numerous new flows of material, information, and income [156]. Intelligence embedded in assets can help provide information feedback for producers and consumers [53].

Regulatory Challenges

Our intuition suggests that it would be quite surprising if the rapid domination of the market by a dozen fairly young companies did not create unanticipated side effects, much as the domination of a few railroads, a single oil company, a single steel company, and a single telecommunications company did a century ago. Ubiquitous information flows have side effects, which in turn create regulatory challenges, the heterogeneity of which is illustrated by the following three examples.

Targeted advertising, differential pricing, and "free" services. Why would services subsidized by targeted advertising be a problem? Why should targeted advertising be any different from standard broadcast advertising? Why should value-adding strategies based on providing free services, funded by cross-subsidies from advertising revenues, be any different from one-stop shopping at a really good supermarket, mega-market, or hypermarché? Moreover, nothing in existing regulation appears to deal with the delayed and hidden harm from privacy violations. Our online activities allow service providers to create a detailed and accurate profile of our preferences, our habits, our desires, our willingness to pay for goods and services, the risks we face, and the costs to serve us. The current benefits from our activities are clear. The future downsides are both uncertain and not yet visible. The most extreme may be first-degree price discrimination in essential services [133], or in health care if the Affordable Care Act of 2010 is repealed in the United States.

Reallocation of scarce resources and society's perceptions of fairness. Uber and Airbnb are simply the harbingers of sharing platforms that may lead to the *marketization* of everything, with a market-clearing price that allocates everything to the individuals most willing to pay for it. This may be socially acceptable for taxis at rush hour under *surge pricing*. Yet this may not be acceptable for organ transplants. Many other goods and services are in a gray zone, and in need of a societal vision of fairness against which to measure the need for allocative efficiency. For instance, Airbnb provides clear benefits both to people who want to earn a little extra money by offering their homes as accommodations to renters, and to short-term renters who want to obtain housing but do not want to stay in traditional hotels. Without platforms such as Airbnb though, the sharing economy would be impossible. Other cities are concerned that long-term tenants might be forced out of their apartments and entire regions of the city might become de facto hotels, reducing the available residential housing market while providing unfair competition to existing hotels. Some tenants are concerned that mixing short-term renters with long-term residents may significantly alter the character of their homes. How should these concerns be balanced? Markets alone do not address the problems created by externalities; by definition, they are outside the scope of market forces.

Manipulation of public opinion via search and fake news. Nothing in existing regulation appears to address the problems of *intentional search bias* and the potential for *manipulation of public opinion*. Recent studies have demonstrated that search-engine bias can be used to manipulate public opinion before elections and referenda occur [56, 57]. There is no Federal Search Commission to ensure fairness, much the way the Federal Communications Commission used to ensure fairness when there were a small number of TV stations, and bias could indeed affect the electorate's access to information. With search now far more concentrated than media, and with search bias much harder to detect than media bias, is it necessary to enforce some form of fairness in search? How could that be defined or implemented? Could that indeed include a Federal Search Commission [20]? Even more directly affecting public opinion than biased search results is the surge of unverified, so-called fake news, which appears to not be addressed at all in existing regulation. First Amendment rights allow for freedom of speech, subject to few restrictions. But fake news on social media can reach millions very quickly and is therefore materially different from private speech. For instance, the impact of fake news on the Brexit Referendum is becoming clear [72, 135]. And yet the impact of fake news on the 2016 U.S. presidential election may never be fully revealed [118]. Moreover, fake news is emerging as a potential issue in upcoming elections throughout the European Union.

Toward Closed-Loop Public Policy

Public policy can set important boundary conditions for individuals' decisions. For example, investment decisions in low-emissions technologies are driven by expectations of a sufficiently high price of emissions, which can be imposed by a regulator using various instruments such as taxes or emissions permits. The information for defining such policies and making them effective is often not available at the point when the policies are defined. They therefore need to be made conditional on relevant indicators in the future. For example, an emissions tax may be made contingent on economic activity or on the results of controlled pollution measurements. Generally speaking, policymakers need to think in terms of closed-loop information-based policies. The path of the policies will then depend on the realizations of the contingencies specified in the public plan.

Viability: Ensuring Economic Survival of the Self

Survival Principles

Viability concerns the successful survival of an economic entity. Because of increasing resource scarcity, existing consumer demands, and mounting competitive pressures between firms and market operators, concerns for economic viability will only go up. And if the survival of an entity is at stake, there may be little room for error, so that the objective of surviving is fundamentally different from simply maximizing expected payoffs in a regime of going concern. To deal with the existential aspects of survival, there are two extreme perspectives. First, there is a *robust approach*, relevant for consumers and small firms for whom the loss of viability is difficult to recover from. By maximizing value when a worst-case situation occurs, it may be possible to guarantee survival independent of the payoff distribution.[5] Yet the resulting strategy is likely to be rather conservative, leading to a loss of competitive edge, and further damaging viability in a society where others act less cautiously. The second approach concerns jointly held economic entities such as firms or other organizations that are protected by *limited liability*. The latter implies convex payoffs near bankruptcy and therefore a risk-seeking attitude, as investor-owned firms are usually gambling with other people's money [60].[6] Between these two extreme approaches, each operating in isolation, evolutionary principles may serve as a guide for the behavioral and strategic maxims that would increase the chance of successful economic survival in a hyperconnected world [125, 126]. We specialize these to *redundancy, modularity*, and *adaptation*, which—although not exactly orthogonal—provide three useful axes for discussion.

An economic entity's *resilience* is implied by the confidence it has in its management of unforeseen contingencies and risks [132]. It is in part created by redundancy and the flexibility from modularity, but it does have additional aspects. For example, a resilient firm not only must have the ability to withstand shocks but also must adapt to changing circumstances.

Redundancy

By maintaining relationships with more than one company for the redundant supply of a key part or the provision of outsourced software (SaaS), infrastructure (IaaS), or process-as-a-service (PaaS), a firm can ensure supply of business resources that are critical in the production of its own goods. Services can be maintained even if the counterparties they typically work with fail. Clemons et al. [36] pointed out that beneficial *redundancy* can arise from a "move to the middle," away from single-source suppliers in procurement, as suggested by selection of the lowest-price suppliers of requisite quality, as opposed to maintaining many costly relationships to coordinate when fewer will do. In a similar vein, Kauffman and Mohtadi [88] apply transaction-cost theory to procurement with digital intermediation via platforms that are proprietary or open. Inherent risks are due to the possibility of supply failure including failure of a platform and the operating intermediaries. The authors consider risks as part of transaction costs and explain the sensitivity of open versus proprietary platforms to random performance shocks. It turns out that open supply platforms tend to exhibit some degree of *antifragility* [141] as a result of the payoff convexity created by the options embedded in the diversity of platform participants.

Modularity

By separating components, companies can facilitate the customization of products. A modular design creates real-option value for future design modifications [11]. Modularity also simplifies aftermarket control and monetization. Such design can be used as a basis for tracking asset components by firms, consumers, or the regulator. Prior to the emergence of IoT solutions, and new ways to go beyond the limitations of radio frequency identification (RFID), asset tracking was possible in the factory, along the supply chain, and at the retailer's or wholesaler's premises [43]. Beyond the pre-sale business process, however, there were few substantive technical solutions available for automated tracking (with the exception of serial numbers, part identifiers, and point-of-purchase information). Yet today, we see the emergence of IoT sensors, digital proximity beacons, and embedded devices that support smart tracking of products [108]. These capabilities create new ways for organizations to achieve economic viability in their aftermarket business. Combined with analytics from aftermarket service data, it may be possible for them to create new revenue streams and enhance profitability.

Adaptation

The ability to adapt is a prerequisite for organizations to achieve and maintain economic success. Effective adaptation can be attained using dynamic information-based strategies. Naturally any opportunity to gain a supranormal profit in an economy disappears over time, due to imitation, technological innovation, and the drift of consumer preferences—be it natural or induced. The *red-queen effect* connects evolutionary biology to the economic rat race [127]: an organism needs to continually change so as to stay at the same relative level of competitiveness regarding other species, because the other organisms in its ecological niche are similarly evolving. The same holds true for competitive advantage; it disappears if not continuously built and rebuilt in a Schumpeterian process of creative destruction [131]. By contrast, the *court-jester hypothesis* suggests that other abiotic forces, rather than competition between autonomous entities, may be responsible for driving adaptation. In our context, it is safe to say that a combination of the two holds true, in the sense that innovation—even from noncompetitors or as a result of cultural change—can destroy profit opportunities, and thus drive the adaptation of economic entities as a matter of their survival. Consider, for example, the digital convergence of technologies [160], which is not the direct product of competition but rather a product of technological breakthroughs in different industries, together with a demand pull by consumer tastes that ask for smaller devices with more functionality, as well as for interoperable technologies.

Information Systems Applications

The emergence of natural-resource constraints and new levels of competitive pressure, as initially posited, requires a rethinking of effective strategies that provide good chances of survival for economic entities. Research in information systems needs to tackle informational requirements for the implementation of such strategies in dynamic environments with significant uncertainties (e.g., about technologies, constraints, or agents' preferences). It also needs to build a convincing ensemble of cases, be they analytical or qualitative, which allow us to extract patterns of *viable* information-based strategy, evaluated in terms of providing sufficient redundancy, modularity, and adaptation.

Multilayered Networks: Topology of Business and Social Interactions

Connectedness

Network nodes often belong to multiple networks, both physical and informational. A better understanding of this multilayered connectedness is needed, together with an empirically tested theory of how decisions are made in such a collectivized environment. For example, networks may have a social layer, a physical transaction layer, and a financial transaction layer. In addition, there may be cooperative or competitive relations among different agents and different modes of interactions. Representations and analysis tools for such multiplex networks have become available only recently. To make good predictions about the behavior of real heterogeneous networks, researchers in information systems may adapt some of these techniques, including representation, centrality measures, and spectral properties; see Garas [64] for an overview. Related to the inherent multilayered complexity of network structure, it is necessary to understand how interventions, and more generally diffusion processes, percolate through a network. This can help identify network nodes where intervention would prove especially fruitful, in terms of the expected results per expended effort.

For almost half a century, the Bass diffusion model [12] has been the gold standard for explaining technological adoption processes in terms of simple logistic growth curves, with excellent predictive performance [13]. Due to its aggregated formulation, the Bass diffusion model does not tend to capture well the interesting diffusion dynamics that arise in the presence of systematic differences among node types in a network – such as consumers vs. firms, or in different regions, such as city vs. rural locations. Some progress has been made in implementing a Bass-type diffusion model on networks [17], or in deriving Bass-type diffusion results in a setting with market frictions and strategic interactions, for example, in the context of sharing markets [123]. It is important to note that diffusion phenomena in networks tend to exhibit sharp phase transitions (in terms of the link-formation probability) [102], which are similar in spirit to the required presence of a critical consumer mass in fulfilled-expectations product-diffusion models with network externalities [51]. Estimating the required critical mass for the diffusion of key technologies is important for proper conditioning of regulatory incentives [117].

Privacy

Connectedness and distributed sensing create a significant challenge for privacy. The latter can be valued and perhaps protected using the micropayments and encryption protocols discussed earlier under "Network Embeddedness" and "Micropayments." A secondary effect will be countermeasures by the concerned parties (e.g., consumers) to disguise their identities and actions, in an effort to secure their transactions and limit the outside's awareness of their personal choices. Interesting future research topics involve the balance between the preservation of privacy, the legitimate collection and use of information by self-interested organizations about others, and the robust welfare objectives in a free society.

Social Networks

Managers in firms and consumers operate in social networks where their choices are influenced by those to whom they are connected. As many social networks now have an online presence, whether on social media networks such as Facebook or Twitter, online forums such as Stack Overflow for programmers, or e-mail list servers, researchers now have easy access to social networking information that was extremely hard to come by before. This has allowed us to gain a much better understanding of the role of social networks in marketing [159], adoption of new technology [119], diffusion of innovation, performance of teams [58], production of open source software [142], finance [122], and other economic activities. As pointed out earlier, the social-network layer is set to become an integral part of business transactions. This creates room for interesting theoretical and empirical case studies. For example, Gunarathne et al. [74] consider customer-complaint management on a social network and find, in the case of an airline, that intervention and self-reported satisfaction varied significantly with its customers' relative influence in the network.

Network Structure

Ever since Granovetter [71] pointed out the importance of the whole network, including the parts that are distant and close to any one node, researchers have been looking not just at local node properties such as degree but at overall network connectedness and centrality [83]. To actively make use of social-network properties for economic analysis is not without its own challenges. An important example is a possible endogenous connection between connectedness and homophily [95], making it difficult to disentangle the effects of social-network connectivity from the direct effects of similar demographics [8, 96]. As noted earlier, many of the challenges for future research will stem from the necessity to take into account the multilayered heterogeneous nature of the networks surrounding us, and from the difficult questions about where to intervene or how to tailor the network topology to achieve specific objectives.

Nonlocality of Intervention

To solve the "wickedly connected" problems in a networked world, borrowing the words of John Seely Brown in his concluding keynote at the fiftieth anniversary of the Hawaii International Conference on System Sciences (HICSS), it is necessary to think of global rather than local approaches. Problems are connected and they generally change when people and organizations start to actively work on them. So again, a much better understanding is needed of diffusion and percolation across networks and networked feedback effects, so that we can begin to comprehend how forward-looking and effective intervention in multilayered networks may be designed.

Agency: Designing Nodal Interactions

Sourcing from a Networked Crowd

Peer pressure across networks may be used to motivate nodes to contribute to a task or to comply with certain behavioral norms (e.g., paying back a crowd-financed loan [65]). There are many interesting topics associated with trying to get a group of people to generate an aggregate product or record, which may on the one hand improve the efficiency of discovery and problem-solving [3] and on the other hand also lead to more novel (although perhaps less feasible) ideas than those of traditional professionals [121]. From a more abstract viewpoint, the performance of a network in aggregating information, for example, depends on its structure [69]. More generally, the observability of actions across social networks changes the behavior of individuals. Research may contribute to a better understanding of these issues, in particular it could inform how information technology can help (e.g., via protocols) to create a regime of trust and thus become an at least imperfect substitute for costly social interactions.[7]

Transparency and Obfuscation

While prima facie interconnectedness would tend to promote transparency and mutual awareness, it also provokes deliberate obfuscation activities. For example, when assessing creditworthiness in a network, other nodes and reputation may be helpful, but an individual may take countermeasures to obfuscate his or her financial history. Beyond the simple evasion or hiding of disadvantageous information, such *endogenous obfuscation* appears also in situations where it is perhaps much less anticipated: on the part of firms and intermediaries. For example, search intermediaries face a trade-off between revenue generated by displaying sponsored links (which tend to reduce the usefulness of the search and thus decrease participation), and providing transparent results to drive up participation. Weber and Zheng [155] consider an intermediary that uses a weighted average of bid amount and product quality as its ranking mechanism for sponsored links, and reveal that revenue is generally highest when a positive (but never the full) weight is placed on quality. Ellison and Ellison [54] show that retailers engage in practices of obfuscation, making the search of consumers more difficult, thus decreasing consumers' price sensitivity (see also Ellison and Wolitzky [55]). The underlying motivation for obfuscation is rent-seeking, of course [146]: an intermediary's reason to exist is usually because it alleviates a market imperfection, for example, by reducing search cost, improving matching, or resolving moral hazard [137]. Yet, the intermediary also tries to appropriate as much of the efficiency gain as possible, so that society tends to benefit much less than it might seem at first.[8] Future research needs to tease out the boundary conditions under which endogenous obfuscation is limited or even eliminated. This relates to the "world without intermediaries" that may be achievable using programmable cryptocurrencies, discussed in the section on *markets*.

Connecting the Digital to the Physical

The analog and digital worlds are orthogonal to each other. A "narrative" often serves a useful purpose to bring them together.[9] For example, the gamification of an augmented-reality view of a supermarket or a shopping street promotes the users' willingness to explore and follow sponsored cues [111]. To be useful for a real-time decision market, the available designed flows of information need to be able to seamlessly fit into the decision maker's reality and familiar heuristics. Human–computer interaction [26] has evolved over the past 40 years so as to narrow the gap between the machine environment and the human task environment. To be usable, information-based strategy needs to be simple enough for human decision makers, and it needs to be adapted to human heuristics, correcting systematic decision biases in a prescriptive way. In other words, information-systems research—however useful it may be at the theoretical level—should strive for integration into human decision processes. (For an overview of the latter, see Kleindorfer et al. [92].)

Conclusions

Strategic Design of Information Flows

Information is the glue that binds economic activities together. It is increasingly embedded in products, transaction protocols, and social interactions, which can be both a blessing and a curse. Designing information flows is payoff-relevant and therefore of strategic importance. Understanding this is critical as we shift from the "Internet Economy" to the "Sharing Economy" and the "New Age of Smart Machines." Our central argument is that information flows are being designed by every economic entity: *consumers* are both sources and sinks of multisided information flows and can use filters to help them concentrate on subjectively relevant pieces from an abundance of signals; *producers* collect large amounts of transaction-based and third-party information about consumers that can be used for mass customization, taking advantage of the next level of automatization in factories; *markets* tend to aggregate information through price discovery [73]; and a networked *society* acts as a moderating force because peer-to-peer information percolation is difficult to control by self-interested parties, even the government. It is imperative for a new generation of senior decision makers to reflect more deeply about the role of active informational design in encouraging actions that ensure long-term organizational viability, fairness, and societal improvement.

Managerial Implications

As we have argued throughout, an active management of information flows may be important, but what exactly does this mean? What can decision makers do? And how can research help? We discuss managerial implications for each of the three determinants of interaction in our simple discussion framework (see Figure 1).

Viability. In the information-rich markets we envision, businesses without profound design thinking applied to the information flows of concern in their marketspaces are strategically vulnerable to competitors who engineer information for competitive advantage and market power. Uncertainties and shocks in the economy are so significant that substantial value fluctuations are affecting even a majority of the top ten multinationals (in terms of market capitalization).[10] Although a general resurgence in the global economy likely played some role, each of these firms experienced 12-month variations in equity value in excess of 25 percent between mid-2016 and today. Firms need to have robust management practices, with sufficient redundancy, adaptation, and modularity in their supply chains, so that they can protect their balance sheets from operational risks, with negative realizations such as Samsung's recent battery failures in flagship consumer products or Volkswagen's 2015 emissions mismeasurement scandal in some of its diesel vehicles. Acquiring and reacting to customer feedback systematically can help to quickly fix issues before they become major concerns, especially if the company disposes of redundant suppliers and a modular product design. To adapt well to changing demands, the information collected from consumers needs to be effectively translated to design- and production-relevant specifications.

Networks. The connectedness of consumers in multilayered networks with physical, informational, and financial flows makes it important for organizations to understand how the effectiveness of their actions depends on the network structure, and how influencing the structure can therefore change monetary payoffs and other performance criteria, such as the environmental sustainability of its closed-loop supply chain. An important aspect is that the Internet of Things can add products —provided they are sufficiently smart—as nodes to the network, visible to the firm and others. Products can be updated and monitored remotely, and their current use status or failure likelihood may be known dynamically. Firms need to learn how to use such information to their advantage and how to make consumers agree to let their appliances transmit the information. In other words, subject to the prevailing privacy regulation, information transfers from and to products need to be incentive-compatible for consumers. That is, companies must design information flows and the payoffs surrounding them so as to ensure a win-win scenario for themselves *and* their consumers.

Agency. As noted in the main text, cryptographic protocols may have the power to reduce the need for intermediaries as guarantors of trust. In the absence of complete and instant verifiability, the transmission of information remains fundamentally strategic, in the spirit of Crawford and Sobel's [42] seminal contribution. As such we have noted that endogenous obfuscation is part of any firm's DNA in networked markets; they may try to obfuscate their prices to change consumers' price elasticity and—in the case of intermediaries—they can withhold valuable information they possess in order to appropriate the surplus their transactional innovation stands to generate. Indeed, as Sophocles pointed out: "Truly, to tell lies is not honorable. But when the truth entails tremendous ruin, to speak dishonorably is pardonable" (Creusa).

Where Does the Future of Information-Based Strategy and Society Begin?

The future of information-based strategy begins in the present, when firms can make commitments to reconceptualize their information-based capabilities, related to customer and product data, their business partnerships, their markets (and after-markets), and the industries within which they operate. When it comes to the design of information flows by organizations for their own benefit and the market's, it is important that some aspects of the designs must be immediately able to gain traction for supporting solutions. For some of the companies we noted above,[10] they have done well to enhance people's mobility, transform their ability to acquire and share information and content with one another, gain access to cloud computing solutions while transforming the infrastructure of computing itself, go beyond physical stores to identify the online sources of the best value for purchases, support global access to financial markets and innovative financial services, and to do so in any region of the world, in any language, and under any market conditions. Beyond design for the present markets, of even greater importance relative to the long-term value of firm activities is the ability of senior executives who create strategy to "project themselves and their organization[s] into the future, creating a path from where they are now to where they want to be some years in the future" [103, p. 87]. So then, information design for future competition must be viewed in terms of real options [50]: adding to the information infrastructure of the present will create value for future innovation, connectivity, execution, and—finally—for value creation itself. We advocate *experimenting with experimentation*!

Changes at the societal level result from the aggregation of many different kinds of efforts that underlie the primary changes that we observe. Very often such changes result from the application of new venture capital, along with the redirected efforts of large and long-standing competitors that, in aggregate, make changes in the way that processes are architected, markets are operated, and rents are charged. This leads to differences that sometimes require oversight, as some of the new technology-based capabilities result in perceived unfairness and a shifting balance of individual rights to privacy. This has been the case, for example, with the haphazard disclosure of personally-identifying information, unsuspected uses of private information, and many forms of network penetration by hackers with nefarious motives for profit from identity theft. The perceived transformation, expectations of future gains, and the emergence of unexpected (or expected) problems are also likely to attract the interest of entrepreneurs, citizen groups, regulators, governments and journalists. The economic changes will become real when they show up in the performance statistics of urban areas, regional economies, corporate sectors, real estate values, and financial markets.

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Notes

1. This is the content of the well-known *envelope theorem* in economics (see, e.g., Mas-Colell et al. [109, pp. 964–966]).
2. A decrease in productivity growth obtains also after adjustments to take into account output reductions associated with the Great Economic Recession between 2007 and 2009 [28].
3. *Additive manufacturing* will reduce the number of parts (perhaps by a factor of 20), simplifying and inherently modularizing product design.

4. By contrast, in a situation with bilateral or multilateral asymmetric information, the Myerson–Satterthwaite theorem [114] guarantees a generic *ex post inefficiency* of any possible transaction mechanism.

5. Maximizing the worst-case outcome is not the only approach to robustness. For example, Goel et al. [68] introduce a robust approach to fairness using a competitive ratio (termed *relative fairness*, there), which could be viewed as a possible social goal for the allocation of resources that leads to outcomes that are reasonable with respect to a large class of reasonable social welfare function; see also our discussion on *society*.

6. The payoff convexity near bankruptcy in the presence of limited liability can be seen as follows. Let $\pi(X)$ be a firm's profit, where $\pi(\cdot)$ is an increasing function of the real-valued realizations x of the random variable X. Then $\max\{0, \pi(x)\}$ is a convex function in the neighborhood of the point x_0 where $\pi(x_0) = 0$. For example, if $\pi(x) = \log(1 + x)$ for x in (–1, 1), then $\max\{0, \pi(x)\}$ is equal to 0 for x in (–1, 0) and equal to $\log(1 + x)$ for x in [0,1). Even though the firm is risk-averse for $x > 0$ because of its concave payoffs there, it is risk-seeking for lotteries that take significant advantage of its limited liability. For example, a 50–50 lottery with the possible outcomes of $x_1 = -0.5$ and $x_2 = 0.5$ yields an expected profit of log(1.5) that is larger than the firm's profit of the expected value of the lottery: $\pi(0)$ (as $0 = (0.5)\, x_1 + (0.5)\, x_2$); so the firm would be happy to take on the lottery rather than the expected value of $x_0 = 0$ for sure because it is protected by limited liability and is therefore exposed only to upside risk.

7. Using evidence from the New York City taxi industry, Jackson and Schneider [82] find that social connections (e.g., within ethnic communities) may significantly reduce moral hazard.

8. For example, because a sharing intermediary charges a commission to the users, the diffusion of sharing markets is slowed down, thus decreasing the attainable surplus in the economy [123].

9. See, for example, Todd Richmond's ideas on "emulsional worlds" at http://emulsionalworld.com.

10. The companies are: Apple ($797.8 billion), Alphabet ($663.2 billion), Microsoft ($532.8 billion), Amazon.com ($453.6 billion), Facebook ($437.8 billion), J.P. Morgan ($309.4 billion), and Alibaba ($290.4 billion); based on data from May 8, 2017 in major United States stock exchanges.

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