Upgrading Strategies for the Digital Economy

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Research summary: *Although computerization has been enabling changes in the structure and economic geography of industries for decades, recent public discourse has become focused on a set of "new" advanced digital technologies and technology applications that appear poised to dramatically reduce demand for routine tasks and transform the organization and content of work. How are these changes shaping the strategic options for companies and policy-makers in less-developed economies? This paper disentangles the old and new features of the digital economy; distills three key business strategies underpinning its organization: modularity, open innovation, and platforms; and summarizes some of the benefits and risks for society. It explores the strategy and policy options available for firms and policy-makers in less developed places, with a focus on innovation and market positioning.*

Managerial summary: *How is the digital economy shaping strategic options for managers in less-developed economies? This paper disentangles the old and new features of the digital economy and distills three key business strategies underpinning its organization: modularity, open innovation, and platforms. It then explores strategic options available for firms in less developed places, with a focus on innovation and market positioning. While core platform owners will have the capability and authority to accumulate, access and analyze large pools of data, access to all of the world's relevant data is not required to speed innovation or carve out new market space in the digital economy. The opportunities may be greatest in industrial applications, where the continued importance of physical systems and industry-specific domain knowledge drives adaptation and customization.*

Introduction

Recent public debate has become focused, with increasing frequency and urgency, on the imminent arrival of a "4th Industrial Revolution" which is said to be creating a "new" digital economy powered by advanced "cyber-physical" systems spanning "advanced" manufacturing, transportation, services, and even biological systems (Rose, 2016; Schwab, 2015, 2016). The products and services commonly mentioned in connection to the digital economy can be divided into two main market segments: industrial and consumer, and into four cross-cutting, base technology areas: 1) new sources of data flowing via ubiquitous and often mobile Internet connectivity, sometimes referred to as the internet of things (IoT), 2) cloud computing, 3) big data analytics, and 4) artificial intelligence (AI). In general, these advanced digital technologies could accelerate three ongoing trends in the organization, work content, and geography of industries: a) the continued fine-slicing of activities into ever narrower and more specialized business functions, b) the organization and spatial separation of deskilled or low-skill jobs from knowledge-intensive jobs; and c) the automation of the low-skill tasks and/or their mobility to lower wage locations (Mudambi, 2008). Simply put, a fundamental characteristic of global value chains (GVCs), the increasing spatial separation of innovation from production, could further accelerate.

The idea that the digital economy will advance with great rapidity creates worry about dislocations, especially from rapid reductions in demand for labor-intensive and routine jobs from automation, autonomy, and artificial intelligence. Because they are far from core innovation regions (e.g., Silicon Valley and Southern Germany), firms and industries in low- and middle-income countries run the additional risk of rising technological dependency and further isolation and exclusion from high-value segments of these fast-moving and sometimes oligopolistic digital value chains. They may receive work, but experience an intensification 'thin industrialization" (Whittaker *et al*, forthcoming) because innovation remains in economies where core technology is developed while automation simultaneously decreases demand for unskilled labor. On the other hand, the technologies and platforms underpinning the digital economy hold great promise for increasing the productivity and global connectedness of consumers, workers, firms and industries operating on the margins, and may be providing powerful new tools for accelerating innovation in the periphery as well.

To help parse these opposite potentials, there is a need for an objective and concise description of the digital economy and the strategic options it offers firms and industries in less developed countries. The first half of the paper provides an overview of the main features of the digital economy. It identifies, in relatively simple and non-technical terms, its venerable and novel aspects and briefly summarizes some of the main features of the aforementioned market segments and technology areas. It also characterizes three key business models underpinning the organization of the digital economy (modularity, open innovation, and platforms), and introduces the key concept of platform layering. The second half of the paper asks how the new tools of the digital economy might be used for industrial upgrading in low- and middle-income countries, focusing on innovation and market positioning. The discussion is largely intended to inspire and help with the framing of near-term research on the uptake and impact of the digital economy in less developed economies.

What is the digital economy?

It is useful, and prudent, to place the digital economy in the context of changes that have been underway for several decades, including the arrival of mass market personal computers in the mid-1980s; the maturing of digital design tools, enterprise computing, and computerized manufacturing in the 1990s; the outsourcing and offshoring boom in the 2000s and the complex GVCs that resulted; and the improved operational fluidity that emerged along the way as multinational enterprises have sought to wrestle previously disparate and disconnected IT systems into some semblance of interoperability and coordination (Gereffi *et al*, 2005).

The processes of digitization are most centrally rooted in computerization, which began in earnest in the 1960s with commercial mainframe computers. Since then, ongoing improvements in microelectronic hardware and software have vastly increased the capacities of information, computing and communications technology (ICT) while at the same time decreasing the cost, power consumption, and size requirements of hardware. This has already enabled the transformation of a wide range of products and processes. Mass access to portable computing and communications, global positioning, and the internet have all been facilitated by the rising power and falling costs of digital ICT.[1] From the 1990s, the internet has underpinned, embodied and accelerated many of these trends, and it lies at the core of the digital economy as well. In other words, the "3rd industrial revolution," based on stand-alone automation and digital ICT, is both enabling and embedded within the 4th.

While progress in digital ICT has been rapid yet predictable in a log-linear sense[2], the adoption of new technologies has been more uneven. On one hand, updating technology systems in the midst of ongoing operations is a notoriously difficult task, akin to "changing a tire while the car is moving," and this, along with traditional organizational resistance to altering routines and making large capital investments, renders any "technological revolution" fraught, partial, and sub-optimal in the aggregate. On the other hand, tipping points can be passed when enabling technologies suddenly open possibilities for vast streams of novel products and services. For example, because they aid in interpretation of visual data, the most powerful graphics processing semiconductors — mainly driven by gaming applications — have only recently opened up practical and affordable applications for machine learning-based AI.[3]

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[1] Advances in digital ICT are not entirely driven by improvements in the cost-performance of hardware (i.e., microelectronics). They have emerged from more efficient approaches to software development (e.g., object-oriented programming) and in the design of microprocessor architecture, such as the embedding of higher-level software "microcode" in hardware and shifting from hardware-centric complex instruction set computing (CISC) to software-centric reduced instruction set computing (RISC).

[2] Process improvements in semiconductor fabrication have progressed at an exponential, or log-linear rate, doubling circuit density every sixteen months. This so-far inexorable path of improvement is often referred to as Moore's Law, as it was first expressed by Gordon Moore, co-founder of Fairchild Semiconductor and Intel.

[3] Another driver of these advances, both in ICT hardware and in the algorithms that it runs, has been high speed securities trading. Digital ICT has also provided many of the tools underpinning breakthroughs in disciplines such as

With this background as context, a concise and somewhat stylized list of two main market domains and four cross cutting, base technology areas driving the digital economy, along with some of their key features, are presented in Table 1, with fuller descriptions to follow. To state it plainly, a product or service can be considered as part of the “new” digital economy if it includes one or more of four base technology areas: large scale data generation and aggregation, cloud computing, big data analytics, and artificial intelligence. For example, an assembly line with a robot cannot automatically be seen as part of the new digital economy, but an assembly line with a robot that is feeding data on its performance into the cloud can.

Two application market domains: industrial and consumer

Like many markets, digital economy can be usefully broken down, most basically, into industrial and consumer application segments.[4] On the consumer side, “smart” consumer-facing goods are increasing connected through the internet of things (IoT). The use of connected goods and services generate user data that allows platform owners and third parties to respond to and

material sciences (nano-scale structures) and biology (CRISPR). While the gene editing technology represented by CRIPSR is not related to ICT, it is necessary tool to allow biologists to sift through the human genome, which is made up of more than 3 billion base chromosome pairs.

[4] Of course, there are other market domains that represent important parts of the digital economy, both as a driver and set of end uses, such as military and public administration. In fact, application of advanced digital technologies to increase the efficiency and effectiveness of public administration can be a main focus in less developed economies. However, these market domains are out of scope for this paper.

anticipate their needs, while analysis of aggregated data can be used for other profit-making activities such as targeted advertising.[5]

Insert Table 1 about here

The industrial side is sometimes referred to in terms of "advanced manufacturing," or "Industry 4.0," with descriptions that commonly mention AI-assisted design tools, sensor-laden and networked production machinery, and enterprise and supply chain integration systems that send data to the *industrial* internet of things (IIoT), where it can be analyzed, used to produce simulations, and acted upon to support productivity and quality improvements, better traceability, more timely maintenance, and real-time capacity planning and materials management.

Industrial robots have been available for decades, but they have steadily become more intelligent, agile, and flexible. The mechanized mass production revolution of the early 20th Century brought in dedicated production equipment for repeated, large volume operations (Chandler, 1962). It was time-consuming and expensive to change what machines did, and the range of possible operations was severely limited. In the 1980s and 1990s computer numerically

[5] For example, iRobot's Roomba home vacuum can collect data on furniture placement and room sizes in user's homes that is of value to furniture sellers, see: https://www.nytimes.com/2017/07/25/technology/roomba-irobot-data-privacy.html

controlled (CNC) production equipment arrived that could be programmed and re-programmed to increase product variety and perform a range of operations in three-dimensional space.[6]

Over time the capabilities of these stand-alone industrial robots and other CNC machinery have increased while costs have come down.[7] Currently, relatively simple sensors and statistical process control algorithms can be employed to shut down or adjust production processes automatically when they move out of tolerance. However, with the rise in computing power and advent of low-cost sensor technology, it has become more operationally and economically feasible to share operational data within and even across factories and international borders in huge "data lakes". With enough data, entire factories can be digitally simulated and machine learning algorithms can generate "predictive maintenance" solutions that aim to prevent processing errors or machine breakdowns *before* wear and tear of mechanical components or other predictable problems cross critical thresholds. As industrial robots become more agile and aware of their surroundings, they might work safely side by side with people to augment and assist workers, rather than replacing them (robots without such features tend to be dangerous and have traditionally operated within enclosed spaces on the factory floor). Such "cobots" can

[6] While the term "robot" has largely reserved for machines with flexible, vaguely humanoid arms, the International Standard Organization defines a robot more broadly as any "automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications." (See https://ifr.org/standardisation.)

[7] Manufacturing technologies are also driven forward by new product development and basic science. In the most advanced and experimental manufacturing environments, such as the creation of new materials, complex pharmaceuticals and synthetic biologics, it can become difficult to separate new products from new processes (Bonvillian, 2017).

sometimes perceive human movements and automatically and intelligently adjust their movements and routines on the fly through machine learning (Hollinger, 2016).

Industrial robots are perhaps the most recognizable part of the "intelligent, or smart factory," but advances in inventory control and automated guided vehicles (AGVs) are also contributing to productivity and quality improvements in factories. By combining image recognition and augmented reality (AR) technologies, workers can be trained in complex or variable assembly steps and receive real time input from an expert in another location able to remotely view what the operator or maintenance worker is seeing.[8]

Four cross-cutting, base technology areas of the digital economy

New sources of data and the internet of things

Productivity improvements have long been based on collecting data, from Frederick Winslow Taylor's time and motion studies of workers in the early 20th Century, to Japan's "lean production" principles of continuous improvement and total quality management in the 1970s and 1980s, to the "Six Sigma" movement toward "zero defects" in the US in the 1990s (Staley, 2019). Improvements come from measuring things, from the time it takes a worker to take a part from a bin, to the dimensions of a given part, to the number of defects coming from a specific supplier, to the relationship between air filtration levels or humidity and yields in a

[8] Google Glass, after failing to catch hold in the consumer realm, has recently had a revival in an "Enterprise Edition" for this type of application (Bershidsky, 2017).

semiconductor fabrication clean room. As this list suggests, the art of measurement has become more sophisticated, from Taylor's famous stopwatch, to cards on a *kanban* board signaling a need for more parts, to barcode readers that follow parts through a factory to allow traceability across the supply chain, to laser scanners and x-ray test equipment that check the tolerance of parts to the nanometer.

Today, low-cost, low-power, and radio-frequency identification (RFID) sensor technologies are widening the scope for measurement and tracing in factories. Sensors can be embedded, not only in robots and production equipment, but in operator wearable devices, industrial vehicles, buildings, and pipelines. This is enabled by the falling cost of RFID tags that can continuously, periodically and automatically transmit data with very low power and bandwidth requirements. Since data can be collected on an on-going basis from multiple sources and in multiple points in the system, vast amounts of data can accumulate over time. Wireless transmission introduces new levels of flexibility in regard to where sensors are practical, allowing remote devices and systems to be located, networked, integrated, monitored, analyzed and centrally controlled. Indeed, in addition to data collection, the remote control of machines and other systems is one of the main advantages of factory and operational systems that include the IIoT.

These examples come from the industrial sector, and manufacturing has indeed been a main source of innovation for data-driven productivity improvement. But today, on-going digitization and the advent of the internet mean that data are gushing from every corner of society though the internet of things (IoT), not only from sensors built into production lines, but also from electric meters, security cameras, customer service call logs, mouse “clickstreams” from online activity, point-of-sale registers, social media “likes” and status updates, and voice commands given to mobile and stationary digital assistants. Indeed, core platform owners care less about profits from selling devices and more about collecting very detailed information about what users are interested in, what they buy, where they go, and what they do, so to gain the capability to push targeted marketing at the exact moment and place where users want and need to make purchasing decisions. An analog in industrial settings are dashboards where managers can monitor the performance of specific machines and workers from their desktop or mobile device in real time.

Cloud computing

Prior to the widespread adoption of the personal computer, beginning in the early 1980s, computers were accessed via “dumb” terminals consisting of only a monitor and a keyboard. All computing, including calculations and the programs that ran them, resided on centralized “mainframe” computers. Information storage was also centralized, first encoded on paper (punch cards) and later on magnetic and optical medium (tape and hard drives). With the advent of the personal computer, everything moved to the desktop: application software, processing (on a central chip or chip set), and storage (on floppy disks and hard drives).

While cloud computing has echoes of computing's past, it does not signal a simple return to centralization in computing architecture. The most significant difference from the 1970s mainframe era is that remote computing and storage are no longer centralized within enterprises, but can be distributed across the internet, accessible to anyone with authorization and the means to pay for access.[9] Instead of downloading programs and installing them on PCs, web browsers have become the means of manipulating software and data that reside online. Computing infrastructure and storage space, applications, and platforms can be rented (usually according to a monthly subscription) and kept updated by the vendor. The shift of software as a product, purchased in physical form on a disk or as a download, to software-as-a-service (SaaS) and platform-as-a-services (PaaS), means that software is always available, from anywhere with a suitable Internet connection, and is always up-to-date. The same goes for computing infrastructure and storage (including for on-demand and streaming video services), access to which has rapidly shifted from the PCs and private networks to the public cloud. This is part of a broader "servicification", or everything-as-a-service (EaaS) trend which includes not only software, but hardware devices and systems as well, such as personal computers, 3D printers, industrial robots, and solar energy systems that are owned, maintained, and updated by vendors and third parties.

[9] Cloud storage and computing resources run over the internet but are not public goods. Companies such as Apple, Dropbox, and Facebook run their own "private clouds," but these are dwarfed by "public clouds," which offer services, for a fee, to both consumers and corporate clients such as Netflix. The main services provided over the public cloud are computing and storage infrastructure, applications, and platforms, all running on demand "as-a-service." According to Miller (2018), citing McAfee, Amazon Web Services controlled 42% of the public cloud market in 2017, followed by Microsoft with 30% and others, including Google, Rackspace and IBM, with about 3% each.

Many expect the demands on cloud-based systems to go up with increasing in data volume, especially from data-hungry applications such as video and virtual reality streaming to distant consumers; live streaming in applications such as social networking, experiential journalism and distance learning; and linking factories for centralized monitoring, control and data analysis (e.g., Miller, 2018). Bandwidth limitations have created latency issues, especially across great ditances and in places with ICT infrastructure is poor, that has driving momentum to add "edge computing" to the cloud by placing additional data storage and computing resources (applications) close to users. By enabling faster, more reliable and more secure data access far from the central nodes of the internet,[10] edge computing could speed the adoption of advanced solutions such as AI, virtual reality and connected manufacturing in less developed countries, without foregoing all of the advantages of centralization, such as synchronization and large-scale data analytics. When combined with 5G cellular networks, which promises to bring very high data rates the "last mile" to mobile users, the decentralized character of computing could proceed even further. Once again, the decentralization associated with edge computing and 5G does not represent a simple return to de-centralization, but a method for overcoming bandwidth

[10] Edge computing can improve network security in several ways. First, content caching and data redundancy can render denial of service attacks less potent because requests for service cannot be concentrated in centralized data repositories. Second, local processors are more difficult for nefarious actors to hack than IoT devices fully controlled from the cloud. Third automatic software updating can keep systems more secure by applying patches and upgrades, essentially removing vulnerable out-of-date software from the system.

bottlenecks in pursuit of the secular trend in computing toward greater geographic coverage, resiliency, ubiquity, and performance.

While data integrity and security are obvious risks, the cloud offers great promise as a place where data can be collected and analyzed in vast quantities. This promise is heightened by the ever-increasing flow of new data entering various clouds each day. The question of how to make use of cloud-based data is answered, in part, by the field of data science, or big data analytics.

Big data analytics and AI

The cloud is more than a place to store data and run SaaS programs. It is a receptacle for the huge volumes of data flowing in the IoT. If sensors and devices feed enough data into the cloud, duly tagged with fine-grained meta-data (about its source, location, etc.), they can be "mined" for insights that enable "data-driven decision making" by businesses, government agencies, and any person or organization with access to the data and the means to carry out further analysis. This is not simple or easy, since large sample sizes increase the robustness of analysis, but also introduce risks. One of the central challenges of analyzing big data is to develop methods for screening out the "noise" from poor data quality (including incorrect metadata tags) and weighting and interpreting data from different sources and of different kinds.[11]

[11] Such technical problems can quickly become societal problems, as when such incorrect or racially biased metadata tags are used to retrieve personal credit information data in AI-assisted loan processing systems (Rona-Tas, 2019).

If the cloud allows the accumulation of vast quantities, or "lakes" of data, and analytics leads to a deeper understanding about the sources of data (human and machine) and social and business contexts they inhabit, then AI, or machine-learning algorithms, can begin to make "predictions and decisions in an increasingly automated way, and at large scale" (Brynjolfsson, 2016). AI technologies have been publicly available, often open sourced and for free, since 2008, but have been too slow and unstable to come into mainstream use until very recently.[12] Advances in microelectronics, especially very powerful graphic processing chips (GPUs), mean that large pools of data can now be analyzed and mathematically represented in graphic matrices, allowing machine learning to be carried out without deep domain knowledge of how objects are being incorporated in the model. The current excitement (and worry) about AI is coming from its gradual move beyond "supervised machine learning," where humans tag images and other data and define the "right" solution in advance (which mainly creates an appearance of machine intelligence) to "unsupervised machine learning," where the no solution is defined *a priori* and machines are able to classify unlabeled data on the fly, allowing results to be obtained and system performance to improve without human intervention (Mar, 2017).

There are real and potential benefits from big data analytics and AI, both for society and business strategy. In the realms of public health, social science, marketing, and innovation, we are seeing new possibilities emerging for "crowd-sourced" insights, such as tracking the timing and

[12] For example, AI, machine learning, data visualization, and related data science algorithms and training data are all easily downloadable for free on open source software code repositories such as GitHub.

location of disease outbreaks though real-time analysis of public search terms (McAfee and Brynjolfsson, 2016 and 2017). Reliance on user reviews is a central feature of a range of online retail businesses, from e-commerce travel services sites.[13] While use of data for targeted marketing or improving operational performance is not new, McAfee and Brynjolfsson (2016) identify three new aspects of big data: volume, velocity, and variety. Because it is scalable and always available and accessible, the cloud is allowing businesses to accumulate unprecedented volumes of data, available in near real time, in a wide variety of forms (written, numerical, audio-visual). Volume and variety can increase accuracy of analysis (e.g. the "wisdom of the crowd,") and high velocity improves responsiveness and relevance.[14]

There are also real and potential risks, especially from the aggregation of personal and consumer data for the purposes of segmenting the quality of customer service, price discrimination, and social control. Customer lifetime value (CLV) scores refer to rankings surreptitiously used by companies to gauge the potential long-term financial value of customers: those with low scores are not offered discounts or can wait longer for customer service, for example (Safdar, 2018). Big data and AI can also enable "first degree" price discrimination, where prices are adjusted in real time based on a consumer's perceived need for a product or service and willingness to pay, estimated from prior shopping and purchasing histories analyzed in the context of millions of

[13] Examples include Yelp, Amazon, Alibaba, TripAdvisor, Hotels.com, AirBnB, HomeAway, and C-Trip.
[14] The volume of data flowing in the digital economy is indeed staggering. According to McAfee and Brynjolfsson (2012), "…it is estimated that Wal-Mart collects more than 2.5 petabytes of data every hour from its customer transactions. A petabyte is one quadrillion bytes, or the equivalent of about 20 million filing cabinets' worth of text."

prior purchases from shoppers with similar habits (Shiller, 2014). Indeed, automated-decision making, data mining and predictive analytics is widely used in ways that discriminate against the poor (Eubanks, 2017).

Similarly, using images from cameras located on streets and in other public spaces, authorities can use a combination of big data and AI to almost instantaneously identify individuals from their faces, gaits, and other characteristics for the purposes of public safety — and social control. While many public spaces are currently surveilled in this way, and there are arguably justifiable benefits from the use of such systems in some contexts (e.g., airport security), there are obvious risks in the broader realms of privacy and opportunities for democratic association. On this front, Chinese officialdom's use of big data and AI by to identify individuals — in only a few seconds through a network of nearly 400 million cameras — has received the most critical attention,[15] but in the U.S., too, the 2000s saw emerging platform companies and state intelligence agencies using big data about consumers and citizens to create what Zuboff (2019) calls 'surveillance capitalism'.[16]

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[15] Biometric identification systems are used not only to identify and arrest criminals, but to shame people who commit minor infractions (Mozur, 2018). Data of this type contributes to China's Social Credit System, begun in 2014, which aggregates data from a range of government and private sources (such as financial institutions and on-line retailers) to penalize people with low scores or privilege those with high scores (Nittle, 2018).

[16] The companies were under pressure to create new revenue streams in the wake of the dot.com bust (2000), while the agencies were tasked with fighting a war on terror in the wake of 9/11 (2001).

Three business models

To sum up the previous section, new sources of data, from smart phones to factory sensors, are sending vast quantities of data into the "cloud," where they can be analyzed to generate new insights, products, and services and provide the large-scale data necessary for meaningful machine learning. But technology is not the only driver of the digital economy. It is centrally characterized by a set of business models that seek to cope with — and profit from — the growing complexity of systems based on digital ICT. There is no way any one organization can fully understand or control the underlying technologies of the digital economy, or its applications. Systems must be designed to dynamically cope with immense and growing complexity without breaking down. Accordingly, strategies in the digital economy have come to rely on: 1) partitioning of technologies and system elements in self-contained, manageable, affordable, yet interoperable *modular* segments and components, 2) external and even communally held sources of knowledge and technology that can support *open innovation*, and 3) *platform competition*, where distinct platforms — some with associated 3rd party ecosystems offering complementary products and services — can offer new business opportunities and competitive spaces but sometimes layer over or even displace existing industries and traditional firm vs. firm competition (Ezrachi and Stucke, 2016). In other words, business models in the digital economy typically include modularity, open innovation, and platforms as strategic elements.

Modularity

Modularity helps to support business models based on interchangeability, where discrete functional elements can be added or subtracted without redesigning entire systems (Baldwin and Clark, 2000; McDermott *et al*, 2013). Because the input/output protocols that link system elements are known *a-priori*, elements in modular systems can be designed without full knowledge of system architecture or the internal workings of other system elements (Ulrich, 1995). MacDuffie (2013) broadened the strategic significance of modularity by highlighting three of its aspects: as a property (in the design of products and systems), as a process (in operations) and as a (normative) frame. In product design, off-the-shelf or lightly customized modular components and sub-systems can be designed-in or substituted as elements of larger systems as long as suppliers and other 3rd parties have the information they need about the interface to provide compatible components and services. On the factory floor, different machines, tools, and subassemblies with common interfaces and control systems can be substituted for one another, or be easily fitted with compatible attachments and fixtures. When combined with design modularity, compatible components and subsystems can be substituted on the same line, driving up product diversity with, at most, superficial changes to the process. While the advantages of design and process modularity in regard to conservation of design effort (reuse of modules), flexibility, and capacity utilization are obvious enough, MacDuffie documents how the practice, while successful in industries where systems and processes could be robustly codified, failed in industries where industry-level standards were poor or slow to develop for technical or institutional reasons (Whitney, 1996 and Sturgeon *et al*, 2008).

Missing from MacDuffie's three aspects of modularity was a fourth: value chain modularity, which has been an important focus of GVC scholarship (Sturgeon, 2002, Gereffi *et al*, 2005). Value chain modularity arises when complex information about products, production, logistics, and other requirements, can — because they are based on widely known standards and protocols — be easily exchanged across organizational and geographic boundaries. In this way value chain modularity enabled a trend toward outsourcing and offshoring by easing suppler switching and aiding in the coordination of spatially dispersed industries.[17]

Figure 1 provides a stylized depiction of how value chain modularity can emerge within a firm, become standardized, spread to an industry, and eventually underpin the development of GVCs. The top arrow depicts work flow in an integrated firm (Stage 0). Work is carried out in teams or departments (ovals), and tasks are completed and coordinated across teams on the basis of tacit knowledge exchange (roundtables where ovals meet). There is no set format for the output of each team's work, nor for handing the completed task off to the next team or department. The

[17] The standards and protocols supporting value chain modularity are often embedded in digital ICT systems such as computer aided design and manufacturing (CAD/CAM), and enterprise and manufacturing resource planning software (ERP/MRP). Operators can "port" the outputs from these systems to conform with the input requirements of various downstream systems simply by manually choosing an output format or systems can be pre-configured to automatically produce results in a range of formats.

two teams meet, usually in-person, to enable the next phase of work to be carried out, and so on until the project or product is complete. While this can be the only way to work if the content of tasks are novel, highly complex, or otherwise necessarily based on tacit knowledge, it can be very slow and unproductive, and managers commonly search for ways to streamline the flow of work across stages of value added.[18]

Insert Figure 1 about here

When it is possible for tasks to be routinized and codified, companies typically seek to standardize the output format of work (hexagon representing more codified linkage where information is exchanged in Stage 1). Once this proprietary standard is stable, lead firms tend to seek external suppliers to lower costs, increase flexibility, and free up internal personnel for higher-value work (Gawer and Cusumano, 2014). Lead firms with a great deal of purchasing power can demand that suppliers adhere to their proprietary methods for exchanging information in transactions. Broad use of external suppliers in an industry, and the emergence of 3rd party vendors supplying software that formalizes transactions, can lead to *de facto* or *de jure* industry standard methods for exchanging information across a value chain (Stage 2). Industry standards can be driven by industry-dominant lead firms, by highly successful ICT vendors, by suppliers

[18] In the words of Baldwin (2008), managers purposefully and strategically seek to add simplified "pinch points" in the flow of "thick" and complex relational work flows, creating formal "transactions" where none previously existed.

seeking to standardize how they interact with large customers, or in the case of *de jure* standards, consortiums that include some or all these stakeholders. Theoretically, industry-wide value chain modularity has the potential to decrease the contractual and operational frictions that come with organizational and geographic distance, therefore increasing the potential for outsourcing and offshoring in GVCs (Stage 3).

Put concisely, value chain modularity involves the systematic partitioning of formerly tacit information and the development of proprietary standards for exchanging information within a firm to increase efficiency (intra-firm modularity), and across firm boundaries when combined with industry standards for exchanging information (value chain modularity), and also across geographic boundaries, enabling both outsourcing and offshoring through the use of modular type linkages in GVCs (Sturgeon, 2002; Dossani and Kenny, 2003; Gereffi *et al*, 2005). Of course, the stages depicted in Figure 1 can be — and regularly are — reversed or restarted (though rarely in a thoroughgoing manner), putting pressure on firms to consider strategies of vertical (re)integration and/or reshoring. Cano-Kollmann *et al* (2016, p. 258) describe a co-evolutionary process where de-codification re-starts the process of modularization when radically new technologies or system elements are introduced, while at the same time leaving still-relevant standards and protocols in place. This sort of accretion and layering of standards and *thick modularity* is a defining feature of the digital economy.

The central point is that modularity will be further enabled — and likely accelerated — by the technologies, tools and platform ecosystems of the digital economy. This is because interoperability and known (and increasingly open) standards are critical to its functioning, and because platform structures are generally modular, offering specific functionality linked across standardized, or at least very well defined, input and output interfaces. All this allows platform designers, complementors, and users to add, subtract, and update specific functions within digital ecosystems on the fly. This may serve to lower barriers to network entry for firms that know and have the capabilities to conform to the standards, even firms that are distant from markets and business partners.

Open innovation

Open innovation refers to the pre-competitive pooling of R&D activities, design criteria, and software code, either through consortia or though the voluntary "crowdsourcing" efforts of engineers and technologists interested in creating free resources for their communities (Chesbrough et al, 2006).[19] For example, nearly all the world's major computer programming languages are open sourced and available for free. Other examples include open sourced designs for server farms and publicly accessible training databases of coded images and basic algorithms

[19] An example is the Linux operating system, which was developed, maintained, and distributed voluntarily by software engineers as a free resource — originally as an alternative to Microsoft Windows — and now runs the majority of the world's computer servers, controls many consumer electronics products, and provides the basis for Google's Android smartphone operating system.

for machine learning.[20] Like modularity, open innovation helps companies "vertically specialize," that is, develop a strategic focus on a core bundle of competencies, while still providing customers with a rich set of fully functional products and solutions. Open innovations are by definition widely available and free, including to firms and researchers in less developed economies. However, they are rarely used on their own. They are commonly adapted for specific applications and combined with additional open and proprietary technology resources to create what often become proprietary systems.

Platforms

The digital economy is, and will likely continue to be, characterized by a set of (more or less) interoperable technology and product platform ecosystems (Parker *et al*, 2016; Kenny and Zysman, 2016). Platforms gain their power from "network effects" where the utility of the platform increases along with the number of users and customers. They tend to be affordable (or

[20] An example is the Open Compute Project (OCP), formed when Facebook opted to open up its in-house data center design specifications in 2011. Data centers, while critical to Facebook's huge cloud operations, were not considered a core competency (Bort, 2015). The company's purchasing power allowed it to bring a range of partners on-board, including the cloud infrastructure services provider Rackspace, which adopted OCP in 2012. By 2016, OCP was supported by other large data users such as Microsoft, Hewlett Packard Enterprise, Panasonic, and Sony; makers of complementary hardware and components such as Intel, Schneider Electric and Emerson Network Power; and network carriers such as AT&T, Verizon and Deutsche Telekom (Miller, 2016). Google, a holdout, submitted its first rack design to OCP in 2016 (Novet, 2016). Because OCP is open, it allows data center operators greater control and flexibility in regard to components and features, including storage technologies, central processing units, memory, and operating systems. It has enabled Rackspace to move away from proprietary servers and server rack architectures provided by traditional vendors such as Hewlett Packard, Dell-EMC, and Lenovo (formerly IBM), and purchase lower-cost generic servers from new entrants based in Taiwan, such as Quanta Cloud Technology, WiWynn (Wistron), Delta Group, and Cloudline, a joint venture between HP Enterprise and FoxConn. Interestingly, Rackspace's business model is to lease data center space from server farm owners such as DuPont Fabros and Digital Realty, though the specifications for its server technologies are determined by the company (Miller, 2016).

free) for users because platform owners benefit in one way or another from aggregating user data, or by collecting modest fees. Network effects sometimes extend to third party complementors offering compatible products, services or modules to run within or over the platform. Because of this, competition between dominant platforms can sometimes resemble more venerable competitive models where large firms, along with their affiliated and closely-related suppliers, compete for customers in end markets. However, the centrality of software and thoroughgoing modularity in the digital economy mean that successful platforms are more easily scalable, and thus able to create huge network effects quite suddenly, leading quickly to winner-take-most, oligopolistic market outcomes, at least in consumer markets where user wants and needs tend to be similar. Most large platform owners already have the IoT, cloud computing, big data analytics, and AI at the center of their business models.[21]

Each of these business models — modularity, open innovation, and platforms — are present in each of the main technology areas in Table 1, as depicted in Figure 2. For example, IoT wireless transmission is typically achieved using open source or 3rd party protocols.[22] Cloud computing services are often built from modular "containers" that perform specific functions within specific clouds, and a given cloud often serves as a platform upon which additional modules, such as data

[21] Examples include Facebook, Google, Amazon, Microsoft, Alibaba, General Electric, SAP, and many others.
[22] Examples include Bluetooth, 3G/4G, and WiFi, membership- or alliance-based protocols such as ZigBee and Z-wave, and proprietary 3rd party protocols such as Sigfox (Greenough and Camhi, 2016).

analytics and AI services, can be developed, modified, integrated, and distributed to users.[23] By extension, all applications in the digital economy are likely to include one or more of its characteristic business models. For example, advanced manufacturing systems are mainly comprised of modular components and machinery, benefit from open innovation inputs, and can act as platforms upon which third party complementors can offer specific fixtures and tools.[24] The fact that the offerings of mobile computing, social media, ecommerce, and internet services companies are based on platforms that connect users and 3rd party vendors is obvious enough.

Insert Figure 2 about here.

Platform layering

While Figure 2 depicts the digital economy as having a unitary structure, each technology area in fact features competing sets of nested platforms that rely on a dynamic mix of shared and dedicated modular platform complementors, as depicted in Figure 3 (Thun and Sturgeon, 2019). Because high complexity is combined with the need for interoperability, the digital economy has developed as a set of nested modules and platforms based on a mix of *de jure* and *de facto*

[23] AI cloud service examples include IBM's Watson, Google's DialogFlow, Microsoft Azure's BotService, and Amazon Web Services' Lex. See: https://www.datamation.com/cloud-computing/artificial-intelligence-as-a-service-ai-meets-the-cloud.html
[24] For example, see the ecosystem promoted by Universal Robots: https://blog.universal-robots.com/pioneering-universal-robots-ecosystem

standards. At a more foundational level, *technology platforms* offer discrete functional elements (such as chipsets and programming languages), upon which *core platforms* can be developed to provide higher-level functionality (e.g., standardized hardware systems, and software environments).[25] Above these, *higher-level platforms* can connect users and buyers to suppliers and vendors of goods and services across "two-sided" platforms (Eisenmann et al, 2006).[26] Such higher-level platforms can support additional platform layers, and because modular system elements can be altered and upgraded without redesigning entire systems, there is no obvious limit to the depth and complexity of the digital economy.

Insert Figure 3 about here

The result are vast ecosystems of shifting, overlapping, and nested platforms consisting of multiple layers (with different owners) each with its own standards, industrial or consumer users, and two-sided markets. The flow of value addition across layers bears some resemblance to a traditional linear value-added chain (see left side of Figure 3).[27] Within layers, each two-sided

[25] Methods for managing complexity in ICT systems run deeper than what is suggested here, and are not entirely driven by improvements in the cost-performance of hardware (i.e., microelectronics). They have emerged in higher-level approaches to software development (e.g., object-oriented programming) and in the design of microprocessor architecture (e.g., embedding higher-level software "microcode" in hardware and shifting from hardware-centric complex instruction set computing (CISC) to software-centric reduced instruction set computing (RISC)).
[26] Strategic questions of how companies can elevate their technology, products, or services to become part of a dominant platform, while of great interest to many observers and a mainstay of the management literature (e.g., Parker et al, 2016), are not the central focus of this paper.
[27] For example, Uber's platform connects drivers to riders, just as Amazon connects buyers to product vendors, and Airbnb connects apartment owners with renters.

market can likewise be conceived in more traditional terms: as a “pipeline” running from the producers of products and services to end users via an intermediary: the platform, which sometimes charges a fee similar to a mark-up charged by retailers in traditional value chains. The main difference — along with a high degree of interoperability across layers (despite very high complexity) and the ability of platform owners to monetize data about buyers and sellers — is the software-based character of digital platforms, which enables the easy scalability of successful platforms and sometimes, their emergence as dominant players in short order based on very strong network effects.

From a geographic point of view, the development of technology and core platforms has so far tended to be highly concentrated in a few technology regions such as Silicon Valley, Seattle, and Southern Germany. By contrast, the development of higher-level platforms tends to be more fragmented and closely tied to local market characteristics and institutional conditions. As a result, the main opportunities for companies tend to come at higher platform layers and be somewhat narrower in less developed countries (see right side of Figure 3).

Upgrading strategies for the digital economy

What are the best strategies for companies in less developed economies seeking to leverage the tools of the digital economy and to compete and prosper in its markets? What should be the focus for the policy-makers, university departments, and vocational training organizations that support them? While more research in countries across the spectrum of development, available skills, and institutional capacity will be required before these questions can be answered with any depth, nuance, or confidence, four tentative focus areas are offered in this section as logical outgrowths of the prior discussion: 3rd party complimenting and higher-level platform competition, industrial rather than consumer application markets, and platform innovation. The section concludes by highlighting the risks of geographic data partitioning, which could continue to sever less developed places from the most innovative and high-value segments of the digital economy.

Focus on 3rd party complimenting and higher-level platform competition

The layered platform structure of the digital economy provides multiple points of entry for 3rd party platform complementors, which can sell discrete modules, products and services compatible with one or more platforms. It also as opens up opportunities for companies to build higher-level platforms on top of lower-level platforms (e.g., solutions running on lower-level platforms or mini-apps that run on super-apps).[28] Because compatible complements and platforms are essentially modules with well-known interfaces,[29] both of these approaches could be attractive for companies located far from the core technology regions of the digital economy. The key is knowing the requirements and having the capability and market knowledge needed to

[28] An example is Tencent's WeChat messaging ecosystem, launched in 2011, which runs on top of existing mobile operating systems (Android and iOS, which in turn run on handset platforms and chipset platforms). As WeChat encapsulated a growing list of functions beyond messaging, such as banking and money transfer, social media, flight and restaurant reservations, etc., it has attracted nearly one billion active monthly users, mainly in China, and in turn spawned an industry of platform complementors that produce "mini-apps" that run on WeChat.
[29] Such as the "application program interfaces (APIs) published by platform owners.

offer complementary or higher-level products and services. When information and skills gaps exist, government policy and education and training institutions can help to fill them.

Focus on industrial applications[30]

An important difference between the industrial and consumer sides of the digital economy is that consumer-facing businesses can challenge the primacy of traditional products and services because they can, like all software-based products, be replicated and scaled independently of physical products.[31] The addition of new buyers and sellers is not encumbered by the detailed characteristics of the products and services it links customers to. As such, consumer-facing platforms can sometimes grow from zero to billions of dollars of revenue, generate winner-take-most network effects, and become globally dominant very quickly.

The industrial side of the digital economy is different because the physical characteristics of materials, products, and systems typically introduce scalability limits that constrain some system elements. For example, an industrial analytics platform is unlikely to scale independently from the products and processes it is meant to improve. It may provide new insights, increase productivity, and enabling better decision-making through big data analysis and AI, but its value lies in its ability to take the physical characteristics of outputs, productive assets and inputs into

[30] This sub-section draws on discussions with Justin Barnes, Executive Director of the Toyota Wessels Institute for Manufacturing Studies (TWIMS) in Durban, South Africa.
[31] For example, Amazon brands only a small portion of the products on its platform, AirBnB own no rental property, Uber no cars, Facebook no newsroom, etc.

account. These production and operational characteristics vary for all but the most standardized products. We see industrial analytics vendors offering a host of generic, industry-specific, and customized data analytics platforms,[32] and although there are attempts to scale these platforms to generate large network effects (Stallkamp and Schotter, 2019), industry and process specificity appear to be driving continued market fragmentation in the IIoT. Production equipment, even with the flexibility enabled by advanced digital features, is still less flexible and generic than the physical assets needed to scale software-based consumer products and services, such as server farms and fulfillment warehouses for ecommerce, which are largely generic. While AI-enabled analysis of big data may allow producers to simulate and reorganize the physical configuration of a plant and guide the optimal use of its physical assets (making IIOT very valuable), this does not (yet) allow the physical elements of cyber-physical systems to be fully freed from scale constraints.

Consumer needs, by contrast, are more similar (Economist, 2016). In addition, while industrial companies actively seek to avoid lock-in to any single technology vendor, individual consumers have little incentive to work simultaneously across multiple platforms. Because they remain linked to the specific characteristics of what they are processing, the delivery of industrial systems and services is more likely to require customization and system integration based on

[32] Current examples include General Electric's Predix and Siemens' MindSphere industrial analytics platforms, each encouraging its own ecosystem of third-party application suppliers, integrators, and resellers.

significant industry- and even firm-specific domain knowledge.[33] Thus, the industrial side of the digital economy is likely to remain more fragmented, while the consumer side, without strong intervention from state regulators, is likely to continue to be populated by mega-scale platforms that enjoy the largest network effects and economies of scale.

For strategy and policy in less developed countries, it is clear that most country-scale digital markets do not have the size to generate the network effects needed to compete with global-scale consumer platforms. Striving to replicate or replace dominant global players with domestic versions is possible, but is likely to require regulatory intervention, and could lees to sub-optimal services. However, entry barriers may be significantly lower on the industrial side. With network effects limited by the specifics of products, processes, and materials, there may be many more niches for small or remote companies to provide specialized, industry-specific products, services and applications. Market entry can be eased by the ready availability of open source technology resources, and the possibility of leveraging (if for a fee or in return for access to data) the capabilities technology, core, and higher-level platforms. Furthermore, the requirement for customization is likely to heighten the importance of proximity to users. Therefore, it may be

[33] In the terms of global value chain governance theory (Gereffi et al, 2005), linkages in such digital value chains would be more "relational" and based on sharing tacit knowledge.

prudent to focus on the industrial side of the digital economy, where network effects are weaker, while allowing consumers to benefit from the hyperscale network effects of mega-platforms.[34]

Focus on platform innovation

Since the technological capabilities and market knowledge needed to drive innovation can be lacking in places that occupy production and assembly roles in global value chains, due to "thin industrialization" (Whittaker *et al*, forthcoming), it is useful to ask how smaller companies and firms in less developed countries might take advantage of the digital economy for innovation. The breadth and richness of digital tools supporting innovation in the digital economy is suggested by Figure 4, which provides some examples of the services, tools and technology resources small and remote firms might encounter on-line. These run the gamut from accessing capital, to labor, training inputs, and technical assistance, to operational inputs and services, to highly efficient methods for providing customer service and creating scalable and far-reaching sales channels, logistics, and marketing campaigns. Local versions of these tools, services, and platforms exist in many countries, and global versions are also in wide use. Given this toolkit, the potential of the digital economy for innovation and entrepreneurship in less developed countries can be seen as profound.

Insert Figure 4 about here

[34] Still, there are a plethora of services and consumer markets where local firms can leverage knowledge of local preferences and institutional factors such as labor and tax reporting regulations, engaging in "regulatory arbitrage." (Thanks to Ezequiel Zylberberg of MIT's Industrial Performance Center for this point.)

Take the example of product design. Even when using today's digital tools, product design requires many engineering hours and multiple rounds of validation and testing. Failed tests lead to engineering changes and many additional hours of redesign and retest. At a certain point, designs that work "well enough" might be accepted because sunk time and expense threaten to become excessive. This can lead to high costs, long cycle times, and sub-optimal results. Digital design simulation has been around for several decades, moving from easier-to-model applications like automated circuit and software testing into more challenging applications such as simulation of mechanical and natural systems (e.g. 3D modeling, fluid dynamics, power transmission in drive trains and aviation systems).

However, advanced digital design tools are improving capabilities for automatically generating multiple design options, investigating the cost and supply-chain availability of components, and integrating with automated production equipment anywhere in the world — either in existing manufacturing clusters, close to consumption, or adjacent to innovation. With such capabilities in place, the work hours needed to create new products could fall sharply, along with the expertise needed to design and produce high quality products and components. Once design engineers codify constraints and enter them into the software, *generative design* tools can offer up or simulate multiple solutions. With complex programming or heavy engineering requirements satisfied by software, product designers might come to rely more on their subjective, artistic judgment, and those of others (e.g. focus groups, opinions collected via social media), rather than primarily on technical skills. Evaluating potential designs in rich 3D using augmented or virtual reality (AR or VR) is also becoming more common and less expensive (Barbier, 2017). In sum, the new design and simulation tools emerging in the digital economy could present opportunities in less developed countries where high-level technical skills might be lacking, but knowledge of local market preferences is great.

Participating in digital GVCs and engaging in platform innovation, is, again, a matter of knowing the standards and meeting the requirements of modular interfaces, which suggests that useful policies could focus on filling information gaps, providing appropriate training, reducing import costs for technology, core and lower-level platforms, and perhaps offering subsidies or incentives for acquiring licenses for technology areas related to the digital economy. Training and education in the four base technology areas of the digital economy seen in the lower portion of Table 1 will be critically important, though these programs might also benefit from leveraging global on-line education and free resources from open innovation repositories. Beyond that, the focus could be on ensuring that consumers have control over and are appropriately compensated for use of their personal data, and on policing abuses by platform owners and nefarious third parties.

Data partitioning, a new digital divide?

Access to data is likely to remain partitioned in the digital economy. A stylized depiction of data flows across platform layers, shown in Figure 5, suggests that the sweet spot for control over big data resides with core platform owners, and secondarily with higher-level platforms. While, access to data is contested in practice, and technology licensing contracts often specify limits to data access and flows across digital supply chains, especially in industrial markets, access to larger insights from larger pools of data will either come with a cost or be entirely the purview of core platform and at higher levels, mega-platform owners.

Insert Figure 5 about here

As a result, the "digital divide" could increasingly describe not only the difference between those that are connected to the digital world and those that remain disconnected, or those with "digital readiness skills" and those without them, but also widening inequality within groups and places that *are* connected. More people and places will be connected to the digital economy, and might benefit from it, but it is entirely possible that the levers of control and the extraction of profits will lie in the hands of only a few, mirroring dynamics in GVCs where lead firms (brands and retailers) have been able to extract more profit than all but the most dominant technology suppliers (Linden et al, 2009), and where "global suppliers" have in some industries crowded out domestic supplies (Sturgeon and Lester, 2004).

Thus, the role of policy is critical. Policy makers have an obligation to shape digital technologies in ways that protect citizens and key institutions from abuse or damage and mitigate market concentration. As MIT President Rafael Reif put it, “Fortunately, the harsh societal consequences that concern us all are not inevitable. Technologies embody the values of those who make them, and the policies we build around them can profoundly shape their impact. Whether the outcome is inclusive or exclusive, fair or laissez-faire, is therefore up to all of us” (Dizikes, 2019). However, since most advanced digital technologies are not “made” in less developed countries, we have to acknowledge that the opportunities for such shaping can be limited.

Concluding remarks

The main driver of the digital economy is the continued exponential improvement in the cost-performance of ICTs, mainly microelectronics, following Moore’s Law. This is not new. The digitization of design, advanced manufacturing and robotics, communications, and distributed computer networking (e.g. the internet) have been altering the processes of innovation and the possibilities relocation of work for many decades. However, there are three trends within the digital economy that are relatively novel. First, there are new sources of data, from smart phones to factory sensors, resulting in the accumulation of vast quantities of data in the “cloud,” and creating information “lakes” that can be mined for new insights, products, services — and create new risks to society (e.g. social control through mass surveillance). Second, business models based on modular and sometimes open technology and product platforms — platform innovation, platform ownership, and platform complimenting — are, in a range of industries and product areas, accelerating ongoing changes in industry structure and, in some instances, radically altering the terms of competition. Third, the quantitative advancement in semiconductor technology described in Moore's Law has, in some areas, especially graphics processing, advanced to the point where qualitative changes have begun to occur in the practical applications for machine learning-based AI. What these novel trends share is reliance on very advanced ICT.

Being transformational, the digital economy will likely create both winners and losers, opportunities and risks. For large companies, organizations, and governments, we have already seen the vulnerability — to hacking, identity theft, espionage, larceny, ransoming, and industrial sabotage — that come with connecting private communications, industrial systems, and public infrastructure to the internet (Hampson and Jardine, 2016). As a result, some of the companies most deeply engaged in advanced digital manufacturing currently do not dare to make connections outside the immediate premises of their factories for fear of data breaches, and this obviates the advantages that might come with data sharing and pooling across the larger organization and supply-bases. Ignoring such risks can have grave consequences, while taking them seriously can undermine the promised benefits of the digital economy. For smaller companies, the cost and expertise required to purchase, operate, and continually upgrade advanced digital systems may drive a larger wedge between the large — and mainly multinational — firms with the scale to justify the needed investments, and smaller, locally-oriented and firms in less developed countries.

Nevertheless, the layered and modular character of the digital economy could continue to enable the fine slicing and relocation of value chains, opening up opportunities for participating in digital GVCs. It is an intriguing prospect, from a less developed country perspective, that small firms and entrepreneurial start-ups, anywhere, might have access to crowd funding and build products based on technology, core, and higher-level platforms, for example. Large and small companies, in rich and poor countries alike, can increasingly rely of the new, and often low-cost or free tools of the digital economy to make their organizations more efficient, reach and serve customers more effectively, speed new product development, and created highly tailored products and services without the need for deep domain- or system-level expertise. With AI-assisted tools built into design software, and data analytics included as a feature of in platforms to help refine subsequent design iterations, platform innovation could become more affordable, efficient and effective. While core platform owners might have access to more comprehensive data than higher-level platform owners or end users, access to *all* of the world's relevant data is not required to speed innovation or carve out new market space in the digital economy.

The eventual shape and impact of the digital economy is unknowable and likely unimaginable. Much will depend on the pace of change. A gradual rollout of advanced digital technologies can leave time for adjustment and adaptation while sudden and thoroughgoing changes will cause more disruption and displacement. Since the digital economy is not monolithic, there will doubtless be a range of experiences, but we know from history that technology adoption is not a simple, continuous, uncontested, or automatic process. Technologies tend to develop at uneven and unpredictable rates, and deployment can suffer under fragmented and competing standards, especially when there is a high requirement for connectivity, interoperability and integration across organizations and political jurisdictions. Mercantilism and rising techno-nationalism could create additional institutional and legal barriers that could further impede the digital economy. Social, technical, and institutional factors, such as data security risks or a regulatory backlash across various digital divides, could slow or even derail the development of the digital economy — or reshape it for the better.

So, what can we expect from the digital economy? First, as stressed by McAfee and Brynjolfsson (2017), the impact of any revolutionary technology is often over-estimated in the short term and under-estimated over the long term. Second, in prior technological disruptions, from steam engines to electric power to digital computing, the logic of efficiency has often run ahead of the capacities of organizations and society at large to adapt, requiring significant reshaping and accommodation in order to reach a more mature and humane footing (Bodrozic and Adler, 2018). If the digital economy follows such a cycle, we may already be crossing an inflection point where the techno-optimists extolling the revolutionary benefits of the digital economy are feeling its sobering effects: negative societal and competitive outcomes that result in new regulation and antitrust enforcement actions (Klein, 2019). At the same time, less developed economies may experience weaker backlash and feel the drag of legacy systems and routines less intensely. If government and institutional support is effective in making long-term investments in talent development and closing information gaps, progress along the digital frontier could be quite rapid and beneficial.

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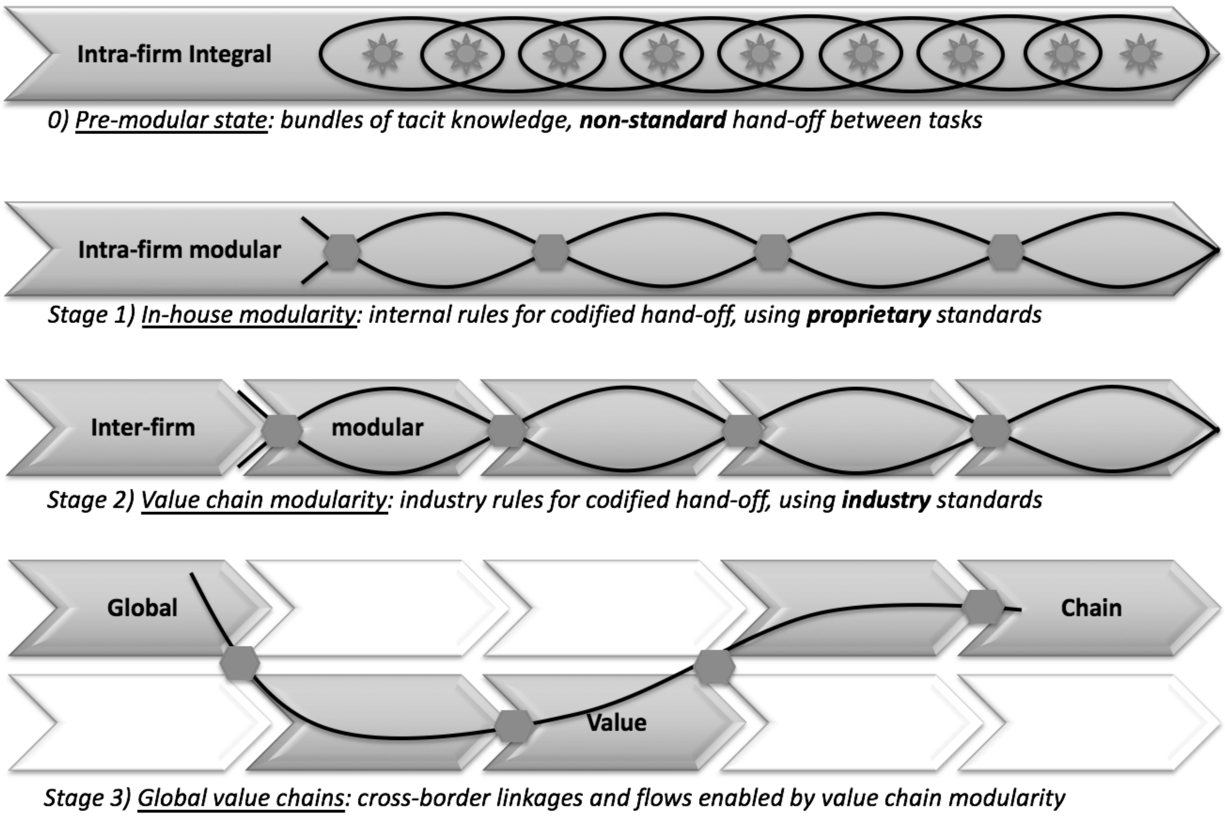
Tables and Figures

Table 1. Market domains and cross-cutting, base technologies of the Digital Economy, with examples

Market domains of the Digital Economy	
Industrial **(advanced manufacturing / Industry 4.0)**	**Consumer** **("smart" consumer products and services)**
• Rising functionality and falling costs in advanced production equipment, including three dimensional printers (3DP), intelligent robots and cobots, and drones • Connected (IIoT), intelligent, and autonomous control systems and enterprise software • Advanced simulation (e.g., digital twins), augmented and virtual reality • New materials and processes, small high-precision motors and actuators, and nano-manipulation • Integration of the four technology areas listed below in product design, manufacturing, logistics, and customer relationship management	• Smart phones and other mobile devices • Social networking • Connected and intelligent home appliances (IoT) • Connectivity and autonomous features in vehicles • Automated and AI-assisted customer service • Ride hailing and delivery services • E-commerce • Etc.

Cross-cutting, base technologies of the Digital Economy
1) Ubiquitous data collection and network connectivity • Consumer (IoT) and industry (IIoT) generated data flows from ubiquitous sensors and video monitoring, clickstreams, location data, "smart" products and machinery, etc. • Vertical and horizontal network connectivity within and across organizations and geographies (connected organizations, factories, supply chains, and people)
2) Cloud computing • Centralized storage and software-as-a-service with on-demand and mobile access • Distributed ('edge") data collection and application processing • Constant and automated updating of software and systems
3) Big data analytics • Data mining based on multivariate analysis techniques • Huge sample sizes leading to more robust results, new insights, and high fault tolerance
4) Artificial intelligence (AI) • From neural networks to machine learning, autonomy, prediction, replication, and self-maintenance and regulation

Figure 1. Stages of value chain modularity and the emergence of GVCs



Source: Adapted by author from UNCTAD (2017)

Figure 2. Business models and cross-cutting, base technologies in the digital economy

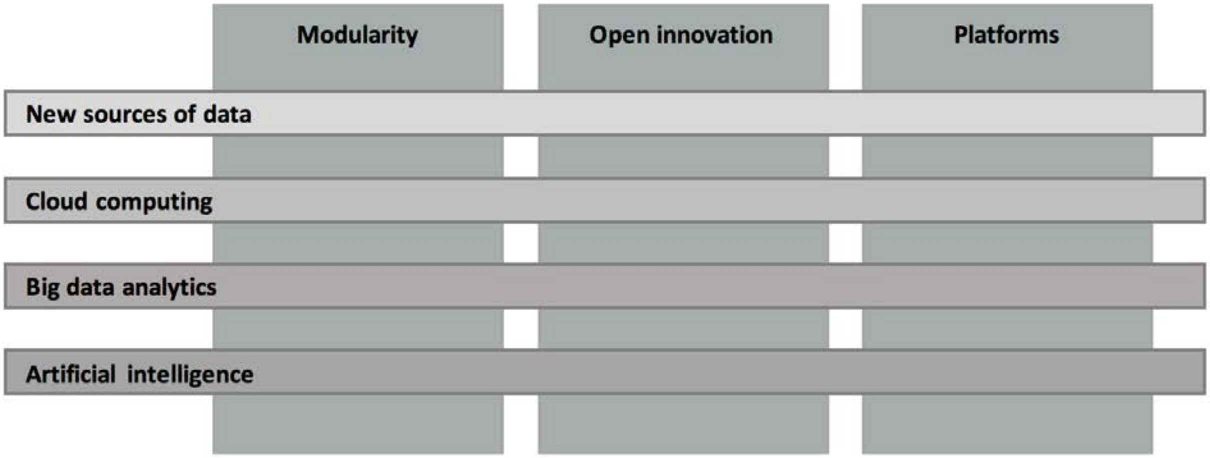


Figure 3. Platform layering as a value chain in the Digital Economy

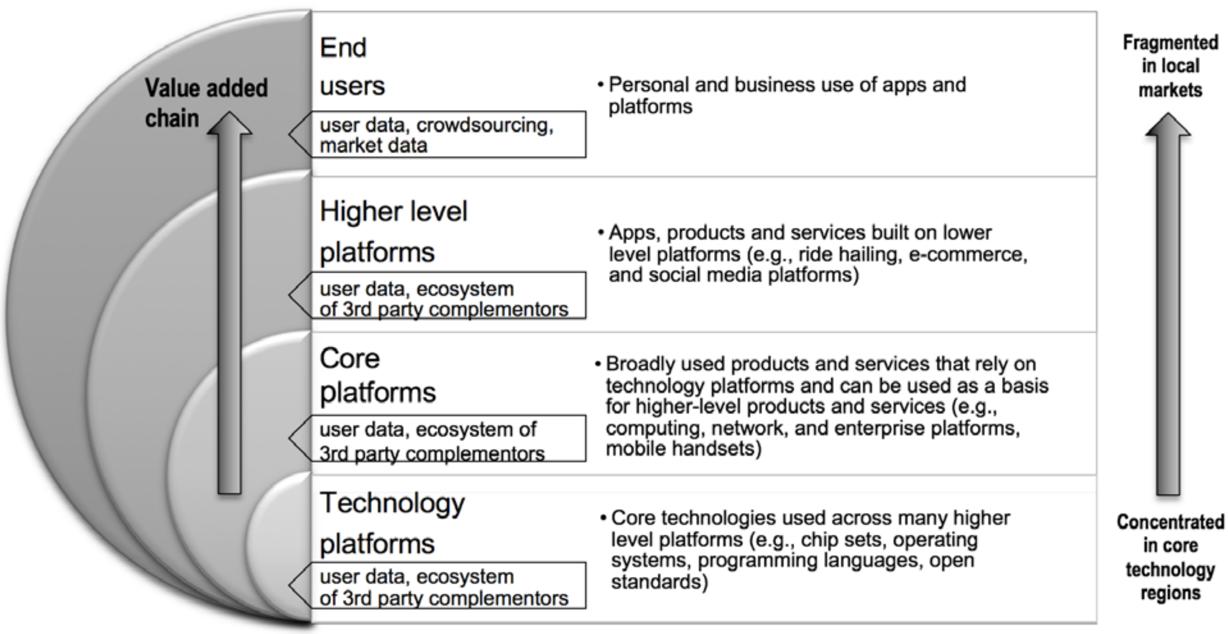


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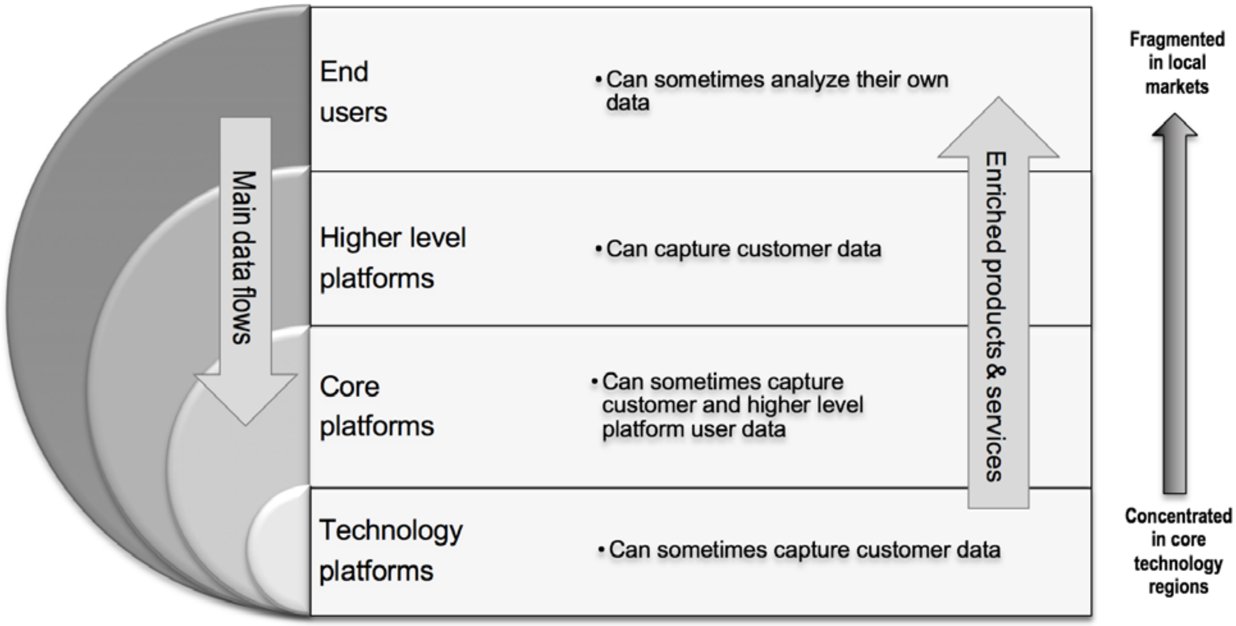
Figure 4. Examples of tools for the emerging innovation ecosystem in the digital economy

Source: Adapted by author from UNCTAD (2017)

Figure 5. Actors, data access, and data flows in the digital economy



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Upgrading Strategies for the Digital Economy

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