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The 'New' Digital Economy and Development[1]

Abstract: *This technical note frames the 'New' Digital Economy (NDE) as including, most prominently: 1) advanced manufacturing, robotics and factory automation, 2) new sources of data from mobile and ubiquitous Internet connectivity, 3) cloud computing, 4) big data analytics, and 5) artificial intelligence. The main driver of the NDE is the continued exponential improvement in the cost-performance of information and communications technology (ICT), mainly microelectronics, following Moore's Law. This is not new. The digitization of design, advanced manufacturing, robotics, communications, and distributed computer networking (e.g. the Internet) have been altering innovation processes, the content of tasks, and the possibilities for the relocation of work for decades. However, three features of the NDE are relatively novel. First, new sources of data, from smart phones to factory sensors, are sending vast quantities of data into the "cloud," where they can be analysed to generate new insights, products, and services. Second, new business models based on technology and product platforms — platform innovation, platform ownership, and platform complimenting — are significantly altering the organization of industries and the terms of competition in a range of leading-edge industries and product categories. Third, the performance of ICT hardware and software has advanced to the point where artificial intelligence and machine learning applications are proliferating. What these novel features share is reliance on very advanced and nearly ubiquitous ICT, embedded in a growing platform ecosystem characterized by high levels of interoperability and modularity. The NDE appears poised to extend the organizational and geographical fragmentation of work into new realms, including formerly indivisible and geographically rooted activities that reside at the front end of global value chains, especially R&D, product design, and other knowledge-intensive and innovation-related business functions. The impact on jobs and international competition will crucially depend on the pace of change and the ability of organizations and societies to manage it. This technical note discusses how the NDE can be defined, explores its likely implications for the location of innovation and manufacturing, notably involving developing countries. The likely implications for smaller and developing country firms are discussed, as are positive and negative scenarios for society in general.*

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A. Introduction

Change is in the air. 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 (NDE) powered by advanced “cyber-physical” systems spanning “advanced” manufacturing, transportation, services, and even biological systems (Rose, 2016; Schwab, 2015, 2017). This technical note adopts the term NDE to frame a set of technologies and processes that most prominently include: 1) advanced production equipment, robotics and factory automation, 2) new sources of data from mobile and ubiquitous Internet connectivity, 3) cloud computing, 4) big data analytics, and 5) artificial intelligence. These technologies and processes are mainly based, in one way or another, on advanced information and communications technology (ICT). They seem poised to dramatically reduce demand for routine tasks and transform the location, organization, and content of knowledge work.

Broad policy questions include:

- Who will build the systems underpinning the NDE?
- Where in the world will the NDE emerge, and when?
- How will the NDE alter the demand for labour and skills?
- When and to what degree will the NDE alter the balance of power and incomes within and across industries and societies?
- Will the NDE introduce unacceptable privacy concerns and cyber-security risk, or will such risks and concerns be manageable and outweighed by benefits to users?

Where the infrastructure of the NDE is built and deployed, and *how* its benefits and risks are distributed geographically and across societies, have implications for developing countries, places that are often lagging in terms of technology adoption as it is (UNCTAD, 2017a). Will the NDE reinforce patterns of uneven development or provide a more level playing field for less developed firms, communities, regions and countries? Will the emerging platform ecosystems of the NDE further concentrate wealth and market power in a few technology clusters where core platform owners are located, relegating places that mainly use and create complements for platforms to a dependent status, or can technology platforms provide lagging firms the tools needed to move out of lower value added segments of global value chains (GVCs) and develop innovative products of their own? While it is too early to answer these questions, on balance, this technical note places these questions in context by introducing a series of concrete examples of how the NDE is developing, and explores various scenarios related to the location of production and innovation.

Technological change and globalization have driven fragmentation in the organization and location of many industries for some time. To understand its characteristics, geography and social impacts, the NDE needs to be measured. Because many of the transactions and interactions in the NDE will be electronic, and cross borders without easy detection or characterization, the ability of official statistics to measure basic economic indicators such as investment, trade, and profits could be further hampered. On the other hand, 'big' economic data might help data agencies overcome some of these problems.

This technical note seeks to define the NDE, explores its likely implications for the dynamics and location of innovation and manufacturing, and discussed possible implications for developing countries. Some concluding remarks are provided about the implications of the NDE for industry and society.

B. What is the 'New' Digital Economy?

It is useful, and prudent, to place the NDE 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 and computerized manufacturing in the 1990s, the boom in outsourcing and offshoring in the 2000s and their extension from manufacturing into services, and the increasing fluidity in the global economy that has emerged more recently as multinational enterprises (MNEs) have finally begun to wrestle previously disparate corporate information technology (IT) systems into some semblance of interoperability and coordination.[2]

The Internet has underpinned, enabled and accelerated many of these trends, and it lies at the core of the NDE as well. In other words, the "3rd industrial revolution," based on digital ICTs, has set the stage for the 4th. At a time when the main consumer applications for augmented and virtual reality (VR) technologies are mainly in video gaming, and consumer uses of cloud computing is mainly for data storage and remote data processing, it is useful to look more deeply into corporate applications and industrial systems, where the emergence of the NDE is the most advanced.

The NDE is emerging from a combination of technologies, mainly from the ICT space, that are becoming pervasive across mechanical systems, communications, infrastructure, and the built environment, and thus playing an increasingly important role, not only in social and political life, but in research, manufacturing, services, transportation, and even agriculture (e.g. precision farming and agricultural robots[3]) (see e.g. UNCTAD, 2017b).

The technologies underpinning the NDE, most importantly and in rough order of maturity, include: 1) advanced robotics and factory automation (sometimes referred to as advanced manufacturing), 2) new sources of data from mobile and ubiquitous Internet connectivity (sometimes referred to as the Internet of things), 3) cloud computing, 4) big data analytics and 5) artificial intelligence (AI). The transformative potential of the NDE can only be realized if and when these elements mature, become better integrated, more interoperable, and broadly used. This is unlikely to be a simple, even, uncontested, or rapid process. Social and technical factors, such as data security risks or a backlash across various digital divides, could slow or even derail the development of the NDE. The eventual shape and application of new technologies are unknowable and possibly unimaginable. Finally, technologies tend to develop at uneven and unpredictable rates, and deployment can suffer under fragmented and competing standards. These barriers and pitfalls can dim the expectations of even the most ardent optimist, especially when there is a high requirement for connectivity, interoperability

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[2] Integration of suppliers in these digital business systems is proceeding more slowly, but progress is also being made on this front.

[3] Precision farming refers in part to meter-by-meter monitoring of soil and plant conditions, sometimes using data from areal imaging from drones and data-driven application of water and fertilizers (see https://earthobservatory.nasa.gov/Features/PrecisionFarming/). Agricultural robots, such as milking machines and mechanical harvesters, have been in use for many decades but are gaining much broader capabilities as machine vision and AI, and advanced actuators, grippers, and manipulators come into broader use (Amelinckx, 2016).

and integration across organizations and societies. Nevertheless, 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.

Advanced manufacturing, robotics and factory automation

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 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, certain computer numerically controlled (CNC) production equipment earned the label of “robot” because they could be programmed and re-programmed to increase product variety and perform a range of operations in three-dimensional space.[4]

Over time the flexibility and speed of industrial robots and other CNC machinery have increased while costs have come down.[5] Currently, relatively simple statistical process control algorithms can be relied on 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, the collection and sharing of operational data across like machinery, within and even across factories, has made “predictive maintenance” possible, preventing processing errors or machine breakdowns *before* wear and tear of mechanical components or other predictable problems cross critical thresholds.

Industrial robots are also becoming more (artificially) intelligent. As 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. Such “cobots” might eventually perceive human movements and automatically and intelligently adjust their movements and routines on the fly through machine learning (Hollinger, 2016).

As with many products in the digital realm, the continued advance and miniaturization of both mechanical and micro-electronic technologies mean that robots are becoming smaller, cheaper, less power-hungry, and much more powerful. An extreme example on the affordability scale is an emergent class of small robot arms priced between $300-$2,000 that can perform different useful tasks, such as the fabrication of solid objects (3D printing), engraving, assembly and sorting.[6] These small robots can be pre-programmed to perform a variety of operations and some can be controlled in real time with a smart phone. While the initial uptake has mainly been by educators[7] and “maker”

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[4] Even so, most CNC machines have not been considered “robots,” a term largely reserved for machines with flexible, vaguely humanoid arms. The International Standard Organization defines a robot as an “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.)

[5] Manufacturing technologies are also driven forward by innovation. 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).

[6] An example is Dobot, a start-up from Shenzhen, China that began in 2015 with a robotic arm priced at about $1,000.

[7] The education market has become significant recently with the explosion of robotics laboratories in secondary, tertiary, and even primary education.

hobbyists, improved performance (faster, more accurate, and capable of carrying heavier payloads) is making low-cost robots suitable also for small, low-volume manufacturers.[8]

Industrial robots are perhaps the most recognizable part of the "intelligent factory," but advances in inventory control and autonomous industrial vehicles are also contributing to productivity and quality increases in factories. By combining image recognition and augmented reality (AR) technologies, a human operator can be guided through complex or variable assembly steps and receive real time input from an expert in another location able to remotely view what the operator is seeing.[9]

New sources of data and the Internet of Things

Productivity improvements have long been based on 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. 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 semiconductor plant. Needless to say, the art of measurement has become more sophisticated, from Taylor's famous stopwatch, to cards on a *kanban* board signalling 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 test equipment that check the tolerance of parts to the nanometre.

Today, low-cost sensor technologies widen the scope for measurement in factories. Sensors are 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 sensors that can continuously, periodically and automatically transmit data with very low power and bandwidth requirements. Wireless transmission[10] introduces new levels of flexibility in regard to where sensors are practical, allowing remote devices to be linked with centralized systems. 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 be accumulated over time.

The examples provided so far 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 industry and society, 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, Facebook "likes" and status updates, and voice commands given to Amazon Echo or Google Home.

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[8] These small robot arms robots occupy a emerging "prosumer" market space that appears to be opening up due to the ubiquity and low cost of mobile computing, wireless communication, GPS, and other ICT technologies. Another example are the GPS stabilized, tablet-integrated flying robotic cameras (drones), such as those produced by DJI, yet another Shenzhen start-up, and 3D mapping, inspection, documentation, and search and rescue. Such products lie between simple and inexpensive toys and complicated and extremely expensive industrial equipment.

[9] 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).

[10] IoT wireless transmission can be achieved using open source protocols like 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).

For consumers, the much-vaunted Internet of Things (IoT), where people can check the contents of their refrigerators from the store to see if they need milk, or conversely order and pay for milk from a touch screen on the front of the refrigerator door, may still seem like a technology in search of a useful application (and market). However, more and more devices, from televisions to automobiles, are connected to the Internet and automatically sending information to be stored in various “clouds”. Some platform owners may care less about profits from selling devices and more about collecting very detailed information about what users are interested in, what they buy, and what they do, so to gain the capability to push targeted marketing to consumers exactly at the moment and place where they want and need to make purchases. The limits of these technologies are unknown. Hardly a day passes without a new revelation about data being collected by connected machines, for example, the mapping and potential sharing (with advertisers and makers of home digital assistants) of floor plans and room content data by the more recent models of Roomba robotic vacuums (Astor, 2017). Users may (or may not) perceive these technologies as invasive, and watchdogs may decry the end of privacy, but even data that do not identify specific users carry “metadata”: the what, where, and when of activities and transactions, and therein lie new sources of knowledge, innovation, and profits, *if* they can be effectively utilized.

Cloud computing

Cloud computing does not signal a shift back to centralization in computing architecture. UNCTAD (2013, p. 2) describes cloud computing as a system that “enables users, through the Internet or another digital network, to access a scalable and elastic pool of data storage and computing resources, as and when they are required.” The most significant difference from the 1970s mainframe era is that remote computing and storage are no longer centralized within enterprises, but distributed across the Internet, accessible to anyone with authorization and the means to pay for access.

The largest vendor of PC software, Microsoft, now earns more than half its revenue from cloud-based software (Levy, 2017). Instead of downloading programs and installing them on PCs, web browsers have become the means of manipulating software and data that reside online. 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 storage, which is shifting from the PCs and private networks to the cloud.

For the average consumer, the transition to cloud computing has been relatively slow, with cloud services primarily used for online storage, backup, and synchronization across devices. In corporate systems, by contrast, the cloud offers huge advantages and the uptake has been much faster. First, the cloud can provide a computing infrastructure that is flexible in regard to scale, location, and capabilities. Storage, software, and services can be rented for a predictable subscription fee, and accessed from anywhere via the Internet. Investment in software development and hardware can be shared across the user base and maintenance, upgrades, and help desks can be outsourced. As a result, very few large companies still own all of their own computing resources.[11] If anything, it is the

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[11] For example, although it involved a seven-year transition, the largest user of Internet bandwidth in the United States, Netflix, now relies mainly on network service providers such as Comcast, Verizon, and AT&T to store and serve up streaming content to customers, and on the cloud resources of Amazon Web Services for search, personalization, and even the sensitive billing and payments portion of its system (Brodkin, 2016).

externalization and aggregation of computing resources and data in the cloud that justifies the modifier "new" in the term NDE.

While data integrity and security are obvious risks, the cloud offers even greater promise as a place where data can be analysed in vast quantities. This promise is heightened by the ever-increasing flows of new data entering the cloud 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

The cloud is more than a place to store data and run programs. It is a receptacle for the huge volumes of data flowing in autonomously from the IoT. If the sensors and devices that make up the IoT automatically feed 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 analysing 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.

On the industrial side, we see companies such as General Electric offering a host of generic, industry-specific, and customized data analytics services for manufacturers on its Predix platform. 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 location of disease outbreaks though real time analysis of Google search terms (McAfee and Brynjolfsson, 2016, 2017). Reliance on user reviews is a central feature of a range of online retail businesses, from e-commerce sites such as Amazon and Alibaba, to travel services such as TripAdvisor, Hotels.com, AirBnB, HomaAway, and C-Trip. 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 increase accuracy of analysis (e.g. the "wisdom of the crowd,") and high velocity improves responsiveness and relevance. The volumes of data are 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."

One of the biggest challenges to using big data for making decisions is data integrity. How can decision makers know data have not been altered from their original? "Blockchain" is a powerful encoding and data sharing method that encrypts data, for example, with time and location stamps, so values cannot be altered after the fact. Asking about data integrity is different than asking about data accuracy or what a piece of data means. A defective sensor might provide faulty data, for example, and a value of 10 degrees Celsius from a temperature sensor may or may not mean a machine or process is operating out of range. Data accuracy and meaning have always been determined through analysis, but the importance of data integrity rises when data pools become very large, and especially when data are pooled and made available publically or across organizations. This is exactly what blockchain systems are intended to facilitate. When data are unalterable, and can be monitored in fully transparent “public ledgers”, such as those underlying “crypto-currencies” such as Bitcoin or Etherium, it enables data sharing. Blockchain technology creates the potential for a shared data layer that will enable automatically executable contracts and royalty payment systems, distributed file storage, peer-to-peer retailing, secure crowdfunding, transparent polling and corporate governance (Epstein, 2017). Similar verification can be obtained by comparing data from multiple sensors in the IoT. While data owners have undeniable power in the NDE, blockchain technologies and other transparent data verification methods could shift the emphasis within cloud computing from data ownership to data analysis. In other words, if everyone has access to the same data, then competitive performance shifts to speed, quality and accuracy of analysis.

Artificial intelligence

If the cloud contains vast quantities of data, and analytics lead to a deeper understanding about the sources of data (human and machine) and social and business dynamics they represent — including how the NDE is functioning — 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 publically available, often open sourced and for free, since 2008. However, to date they have been too slow and unstable to come into mainstream use.[12] Advances in microelectronics, especially very powerful graphic processing chips (GPUs),[13] mean that large pools of data can be analysed 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) with the addition of “unsupervised learning,” where the no solution is defined *a priori* and machines are able to classify unlabeled data on the fly, allowing system performance to improve without human intervention (Mar, 2017).

This is a highly technical subject, so an example may be useful. Facial recognition is something that humans are extremely adept at, and a task that has historically eluded computers. Since the dictionary definition of AI is “the capability of a machine to imitate intelligent human behaviour,”[14] computers that can recognize and identify human faces are by definition artificially intelligent. Facial recognition, and by extension computer recognition of common objects, involves the characterization and comparison of hundreds, or even thousands of unique polygons. A modern GPUs can identify millions of polygons in real time (data velocity) and, when combined with databases containing hundreds of thousands or even millions (data volume) of different faces (data variety), the applications for AI can become much more powerful and practical than they have in the past. For example, self-driving vehicles require instantaneous object recognition, and systems with image processing rates surpassing 150 frames per second have recently been developed (Redmon *et al,* 2016).

Artificial intelligence has a long history, in part tied up in two competing approaches, rule-based decision-making vs. machine learning (McAfee and Brynjolfsson, 2017). Computers are good at

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[12] Key innovations came from “deep learning” efforts at University of Toronto and Carnegie-Mellon University in the early 1990s.

[13] Ironically, perhaps, advanced in GPUs have been driven by rich video gaming applications.

[14] See https://www.merriam-webster.com/dictionary/

making decisions based on logical rules, while replicating the “neural networks” of the brain to allow machines to “learn” and create new programming in response to stimuli, has proved to be extremely challenging from a mathematical and computer hardware perspective. However, as problem solving tasks escalated, the rule-based approach ran into the limits that programmers have in knowing and clearly defining rules *ex ante*. At the same time, faster processing and big data are providing the computing power and wealth of examples needed to bring machine learning into practical application. Machine learning occurs when computers alter their programming based on data analysis, just as human learning creates new neural pathways, referred to as “forward propagation.” Machine learning has improved on human learning by altering existing code — “backward propagation” — at the same time that new code is created, increasing system performance in a more rapid and thoroughgoing way. As a result, IBM’s Watson and AI programs like it have been shifting from research and demonstration tools into the realm of SaaS, where they can provide 3rd party AI services to business on an *á la carte* basis. Furthermore, IBM is shifting the market focus of Watson from a sole focus on cloud-based big data analytics for large organizations, toward an easier to incorporate platform for entrepreneurs and product designers.[15]

C. Business models and industry organization in the NDE

The technological advances of the NDE have come with a set of business models and industry organization characteristics that are all, in one way or another, meant to dynamically cope with growing system complexity. There is no way any one individual or organization can fully understand or control the underlying technology of the NDE or the specific domains where it operates. Collaboration across fields — such as computer and data science with biology, political campaigning or banking — is necessary, but not sufficient. Systems must be designed to dynamically cope with immense and growing complexity without breaking. The systems of the NDE must: 1) rely on 3rd parties for complementary products and services, 2) draw on outside and even communally held sources of knowledge and technology, and 3) be partitioned into self-contained, manageable, affordable, yet interoperable segments. In other words the NDE must be based on platforms, open innovation, and modularity.

The importance of platforms

The architecture of the NDE is, and will likely continue to be, characterized by a set of (more or less) interoperable technology and product *platforms* (Parker *et al*, 2016; Kenny and Zysman, 2016). The complexity of the technologies and embedded products and services underlying the NDE means that no single company (or country, region, or technology cluster, for that matter) can master, control, or own all system elements. Over time, information technologies, including the electronic control of mechanical systems,[16] have developed as a set of nested modules and platforms based on both *de jure* and *de facto standards,* stretching from discrete functional elements (technology platforms) to higher-level tools, hardware systems, and software environments[17] (core platforms) upon which developers

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[15] To further its uptake among entrepreneurs, the company is offering “unlimited and free” access to Watson’s AI tools to start-ups on the crowdsourcing site Indiegogo (Dalton, 2017).

[16] Systems that marry electronics and moving machinery are sometimes referred to as “cyber-physical” systems (e.g. Schwab, 2016).

[17] 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

can create a variety of goods and services for end users (higher-level platforms).[18] And because modular system elements can be altered and upgraded without redesigning the entire system, there is no obvious limit to the depth and complexity of the NDE.

At each level of these nested ecosystems, 3rd party complementors (e.g., the makers of smart phones apps) have emerged to provide products and services that allow platforms to be customized or enhanced for a variety of uses and markets. In addition to providing market opportunities for 3rd party vendors, this also enhances the value of each platform. This in turn attracts more users to the platform, which in turn attracts more 3rd party vendors in what is known as a "network effect." Furthermore, because they are modular systems, platforms can form the basis for additional platform layers, stylistically depicted in Figure 1 as technology, core, and higher-level platforms.

The notion of platform layering suggests that a sequential series of platforms can underlie modern product-based competition. While the centrality of "two-sided" markets and the drive to create network effects in NDE strategies do appear to be historically novel, the sequential value added chain appears in platform ecosystems in two ways: 1) within each platform layer as 3rd party complementors are connected to users (here, the platform owner acts as an intermediary between suppliers and buyers), and 2) in the value-added sequence across platform layers that flow from lower to higher level platforms. As Van Alstyne *et al* (2016) state, intermediaries (such as department stores) have long acted as platforms to connect producers to users, creating two-sided marketplaces. In the NDE, the difference is that platforms, such as Amazon's online shopping platform, are much easier to set up, cheaper to maintain (albeit Amazon's huge fulfilment centres are indeed made of bricks and mortar) and therefore also easily scalable (with scale generating vast pools of data).

The concept of a value added chain linked across layered platforms is well illustrated by the smart phone. It rests on several platform layers, and has in turn been harnessed as a mobile platform for the delivery of higher-level product platforms, such as mobile social networking and online retail (see Figure 2).[19]

The result is an ecosystem of shifting and overlapping platforms consisting of multiple platform layers (with different owners), and also a myriad of platform users and casual users, with "two-sided" markets at each stage that connect 3rd party complementors, via the platform, to platform users and, finally, end users. For example, Uber's platform connects drivers to riders, just as Amazon connects buyers to product vendors, and Airbnb connects apartment owners with renters. Within the deeper plumbing of the NDE, there are thousands of 3rd party vendors providing complementary products and services for specific technology platforms, including cloud computing and AI platforms. As a result,

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hardware-centric complex instruction set computing (CISC) to software-centric reduced instruction set computing (RISC)).

[18] 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), will not be the focus here.

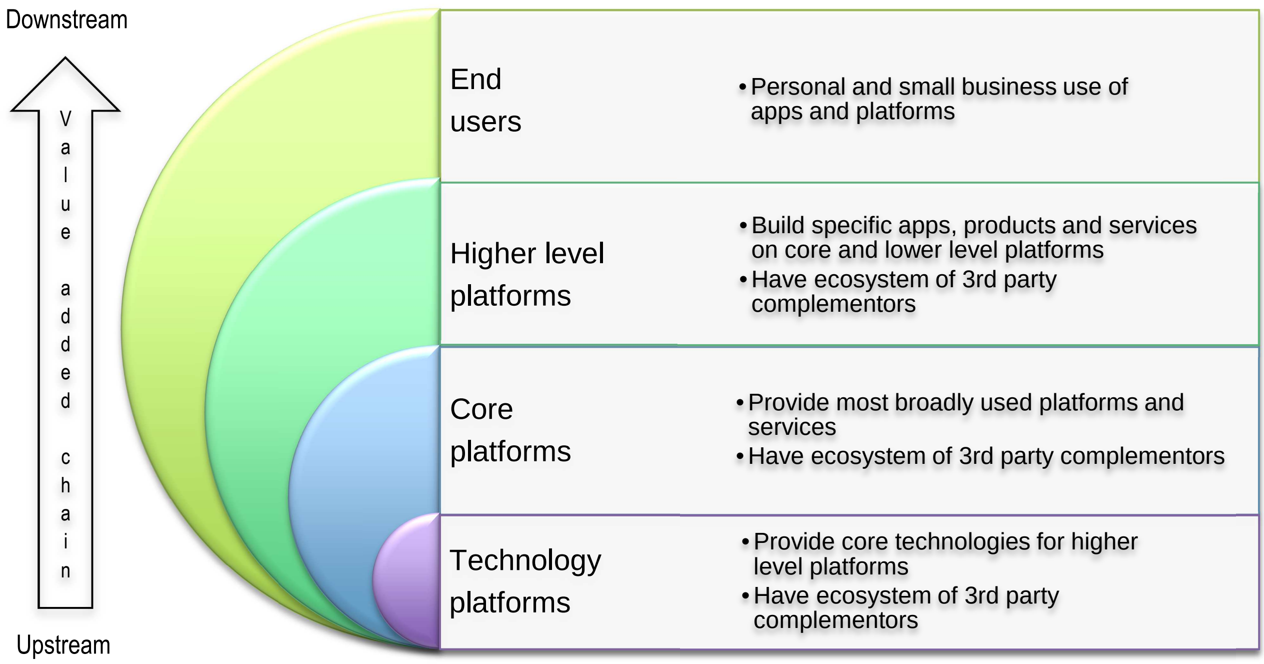
[19] At the most basic level "upstream" in the value chain, calls made from smart phone depend on a set of general interconnect standards that are agreed upon at the industry level (2G, 3G, 4G), and implemented by various consortiums and alliances as specific interconnect standards such as CDMA and GSM (see Figure 3). As mobile handsets have become more complex over time, semiconductor firms such as Qualcomm and MediaTEK have developed chip sets that handle much of the complexity of the system, and as Google's Android operating system replaced proprietary operating systems, generally incorporated key software code from ARM. Handsets designed by Samsung and others depend on these embedded technology platforms, just the providers of retail and mobile services such as Amazon and Facebook depend on users owning powerful smartphones to access their services.

platforms are sometimes invisible to users (e.g., chipsets and any 3rd party technology embedded within them, such as ARM software for mobile telecom chips meant to run the Android operating system). In other cases users are aware they are using a platform (e.g., Amazon, Uber, or Facebook and the products, services, and personal networks they link to).

The platform structure of the NDE allows final systems with extreme levels of embedded complexity and a broad range of capabilities. It also lowers the barriers to entry for both 3rd party technology vendors, which can sell discrete modules, products and services into the system; as well as opens up vast opportunities for companies, such as Facebook, to build higher-level platforms on top of lower-level platforms (e.g., PCs and mobile phones). To put it simply, because of the rich ecosystem of technology and product platforms, web services companies such as PayPal, Airbnb, or Alibaba, did not have to create the PC, the smartphone, the Internet, or any of the software programming languages they use to build or maintain their websites. Nor did they have to create the cloud storage services that they can use to collect and analyse their vast stores of data.

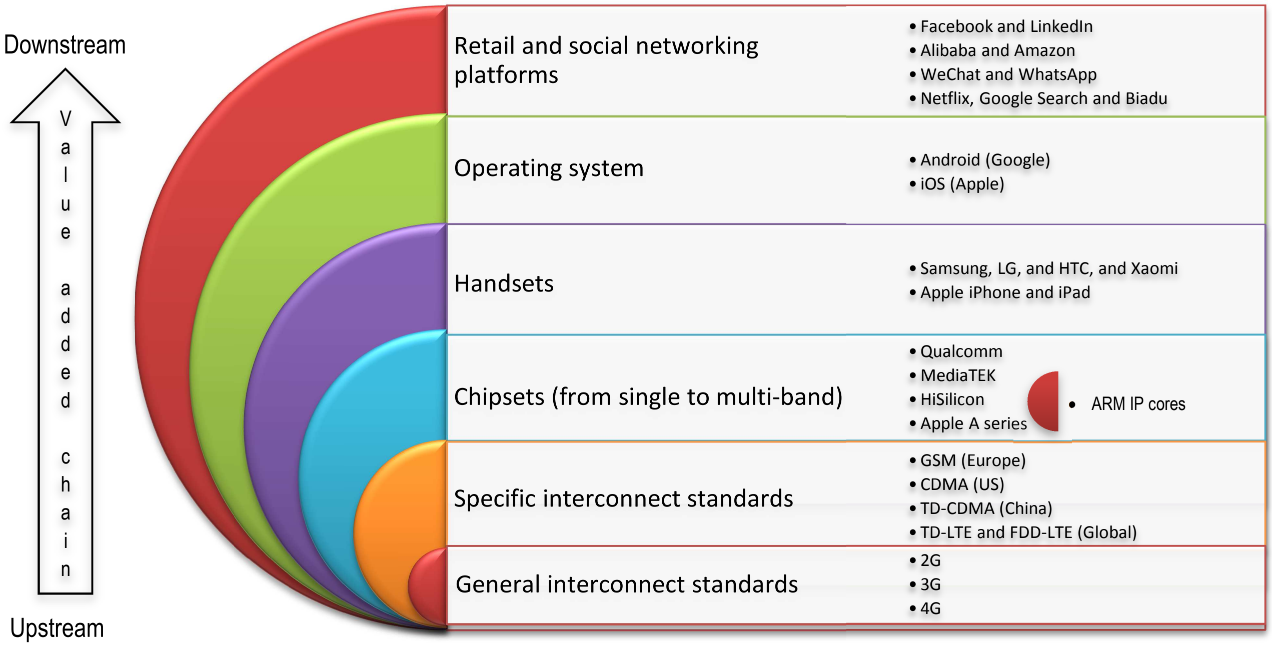
To sum up, the NDE can be described as a platform-based ecosystem of ICT-based products and services. It is rapidly evolving through a combination of ubiquitous and continuous measurement and data collection. IoT data is flowing from sensor-laden factory automation and business process systems as well as Internet-connected user devices, most obviously smart phones but including a growing lost of Internet-connected products, from home appliances to automobiles. The IoT is generating "big data" pools that, because they reside in the "cloud", can be mined and analysed for patterns and correlations that would otherwise remain hidden, with these results fed into AI systems where machine learning and automated decision-making can be used to suggest upgrades to system elements and, speculatively, to the entire system.

Figure 1. Platform layering as a value chain in the NDE ecosystem



Source: T. Sturgeon, for UNCTAD.

Figure 2. Platform layering in mobile telecom



Source: Thun and Sturgeon (2017).

Platform owners, such as Facebook, Google, Amazon, Microsoft, Alibaba, General Electric, SAP, and many others, already have big data and AI at the center of their business models, and the capability for analysis will be much broader and deeper once larger swaths of society are connected via the IoT and improved AI technologies are developed and deployed. The result may be a cycle of data streaming from connected factories and users, data pooling in the cloud, big data analysis, and AI-driven machine learning that results in continuous and rapid cycles of platform upgrading and system-level leaps in productivity and innovation. This is especially true if decisions made by AI affect the structure and operation of the NDE itself. In such cases the loop from data generation to machine learning is complete and the entire ecosystem of platforms could leap ahead.

A stylized depiction of this process is shown in Figure 3. First, factory and user data are generated from a set of advanced manufacturing and end user platforms, each of which operates as a modular system of layered technology, core, higher-level, and end use platforms. These data flow, via the IoT, into the cloud, which itself operates as a set of nested modular platform ecosystems. Once in the cloud, the tools in analytic platforms can be applied to make sense of big data, with the results subsequently operated on by AI tools.

Finally, the machine learning capabilities of AI, at least in theory, introduce the potential for the entire system to improve without human intervention. The question mark in the title and Platform Upgrading box of Figure 3, and the different shape of the box, are meant to indicate that autonomous system-level platform upgrading is still speculative; an idea that remains in the realm of science fiction. System self-improvement through machine learning is possible today in the context of specific software programs,[20] but not in the larger scale, interconnected systems underpinning the NDE (e.g. networks of machines connected through the Internet). In other words, there is very little scope, in the near or medium terms, for the vast, diverse, and poorly linked systems in the NDE to become connected in a coherent enough way for the system, as a whole, to engage in machine learning.

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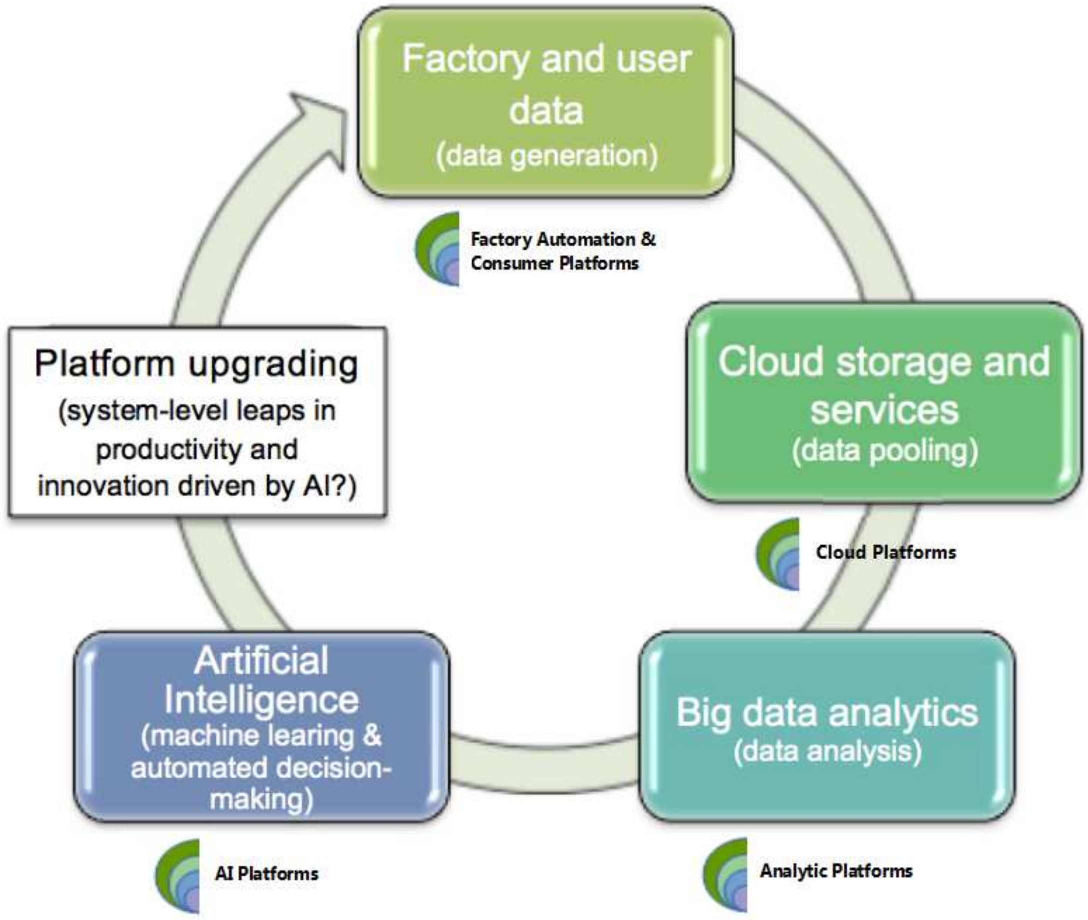
[20] Machine learning is perhaps the most advanced in high-speed securities trading (Deboeck, 1993).

Figure 3. A cycle of platform upgrading in the New Digital Economy?



Source: T. Sturgeon, for UNCTAD.

Open innovation, open standards

The complexity and multiplication of technology domains in the NDE have led industry players to make heavy use of “open innovation” (Chesbrough et al, 2006) to create the resources needed to develop and ensure the interoperability of a range of sub-system elements, from network infrastructure, to operating systems, to AI test datasets and algorithms. Open innovation refers to the strategy of relying on external, often shared and sometimes crowdsourced resources as an integral part of a company’s innovation process.

For example, annotated databases are important for developing and testing the accuracy of machine learning algorithms. Large, pre-classified and annotated image and other datasets for the development and testing of AI software have been made available by consortiums of companies and research institutions. Microsoft’s Common Objects in Context dataset includes 328 thousand images with 2.5 million labelled objects of 91 types. Object labelling within images was carried out in part by “crowd-workers” hired through Amazon’s Mechanical Turk platform, where workers can earn small amounts of money for performing simple, repetitive tasks online. The training dataset for the 2016

ImageNet Large Scale Visual Recognition Challenge (ILSVRC)[21] contains annotations in 1000 categories and 1.2 million images. ImageNet is a large-scale open-sourced image database project sponsored by Google, Amazon, and the Stanford and Princeton universities.

Open source software and design specification are available for multiple applications in the NDE, including cloud services (e.g. Openstack[22]), cloud infrastructure (Open Compute Project), and computer operating systems such as Linux (UNCTAD, 2013). Linux and related code are freely available online through websites moderated by the Linux Foundation. Linux has an active community of software developers that make improvements, offer new 'distributions' for specific applications, and provide informal online technical support for engineers using Linux software. While the initial motivation for many software engineers was to undermine the near-monopoly-level bargaining power held by Microsoft on PC operating systems, Linux's penetration in PCs has been modest. However, more than a third of Internet servers run on Linux, as do a host of consumer electronics devices (Finley, 2016). At the same time, open source does not always mean resources are free or come without strings attached. Companies such as Red Hat, Canonical, and SUSE have developed for-profit business models by selling proprietary distributions of Linux, often tailored for specific purposes, and providing support for large companies using Linux in their products and to run their IT systems. Google's Android smartphone operating system, which is a proprietary 'distribution' of Linux, is "given away" to handset makers mainly to drive mobile users to Google's search services where they are exposed to advertising (Dallas, et al, 2017).

The Open Compute Project (OCP) was formed when Facebook opted to open up its in-house data centre design specifications in 2011. Data centres, while critical to Facebook's huge cloud operations, are not considered a core competency (Bort, 2015). The company's purchasing power allowed it to bring a range partners on-board, including the cloud infrastructure services provider Rackspace[23], 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 in 2016 (Novet, 2016). Because OCP is open, it allows data centre 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 off-the-shelf servers and server rack architectures provided by traditional vendors such as Hewlett Packard, Dell-EMC, and Lenovo (formerly IBM), and purchase lower cost servers from new vendors based on Taiwan Province of China, such as Quanta Cloud Technology, WiWynn (Wistron), Delta Group, and Cloudline, a joint venture between HP Enterprise and FoxConn (Miller, 2016).

Here, the shift from proprietary to open hardware designs can be seen opening up opportunities for companies based in emerging economies. Indeed, as with Linux, open innovation is often a means of lowering costs by breaking a monopoly or dominant design standard, at least initially; it has become a

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[21] The ILSVRC is a competition for research teams creating "algorithms for object localization/detection from images/videos and scene classification/parsing at scale" (see: http://www.image-net.org/challenges/LSVRC/2016/index).

[22] See: https://www.openstack.org/software/.

[23] Rackspace's business model is to lease data center space from server farm owners such as DuPont Fabros and Digital Realty (Miller, 2016), but the specifications for server technologies is determined by Rackspace.

key part of the on-going standards battles that have characterized the ICT industry since the 1960s.[24] While the largest companies, rely to a significant degree on proprietary technologies, the standards battles underpinning the NDE differ from earlier rounds in that they tend to embrace open innovation much sooner, and often pit one open standard against another. For example, IBM's OpenPower initiative (and Foundation), centered on its PowerPC CPU technology and supported by Google, competes with OCP in the data centre space. The largest public cloud services (such as Amazon AWS, Microsoft Azure), and the Google Compute Platform (GCP) tend to draw on multiple standards as well as proprietary technologies as a hedge against betting on the wrong standard, as leverage in negotiations, and as a tool for learning (Johnson, 2017).

As these examples suggest, open innovation lowers the cost of information search and new knowledge creation. It also generates some surprising "collaborations" across competitors, setting up what Ezrachi and Stucke (2016) call "frenemy" relationships in a dynamic landscape of "virtual competition." Open innovation still involves internally developed and legally protected knowledge and IP resources. Although there are overlaps, it can be distinguished from "free innovation," where developers are self-rewarded; evaluation, replication, and improvement is "open source" and collaborative; and distribution of fully functional products is free and peer to peer (von Hippel, 2017). In both types of innovation ecosystems, there are opportunities and barriers for smaller firms and firms located outside of the core technology clusters where standard setting tend to be concentrated and collaboration is most dynamic, such as Silicon Valley (Sturgeon, 2003). Access to resources can be free, but high capability requirements may exist for full participation, and co-location can be helpful.

Globalization and modularity

Computerization of work, from product design and engineering, over manufacturing and logistics, to services, has enabled the geographic fragmentation of industries. Because computerization typically comes with rationalization of work processes and explicit rules, it facilitates standardization, and therefore the transfer of tasks from one stage to the next, either across organizations (outsourcing) across borders (offshoring), or both (offshore outsourcing). This is not new. In the past 25 years, advancements in the ability to codify and transfer highly complex information from one stage of the value chain to the next, combined with plummeting costs for both the movement of goods and making voice and data connections, has enabled the shift of manufacturing to countries such as China and Viet Nam and the sourcing of a variety of services from countries such as India and the Philippines.

Figure 4 provides a stylized depiction of how this sort of 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 the flow of work in an integrated firm. Work is initially carried out in teams, or departments (ovals), and tasks are completed and coordinated across teams on the basis of tacit knowledge exchange (orange scribble where ovals meet). There is no set format for the result of each team's work, nor for handing the completed task off to the next team or department. The 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 finished. While this can be the only way to work if the content of tasks are novel, highly complex, or otherwise based on tacit knowledge, it can be very slow and unproductive.

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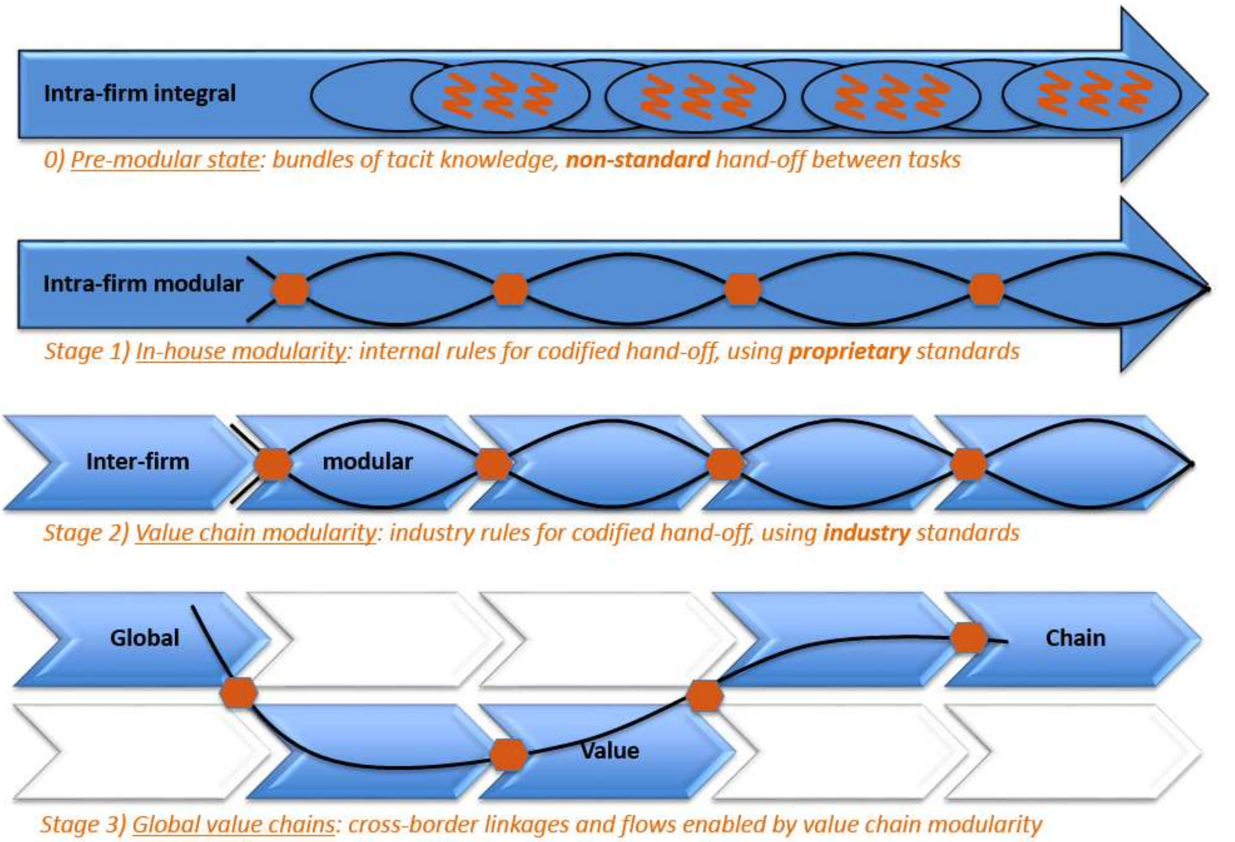
[24] Including the *de facto* opening of mainframe computer architecture based on IBM's 360 line first introduced in the 1960s, battles over personal computer operating systems and CPUs in the 1980s, and so on.

When work is more routinized, and can be codified, companies typically seek to standardize the output format of work (orange hexagon where information is exchanged) and seek external suppliers to lower costs, increase flexibility and free up internal personnel for higher value work. Broad use of external suppliers in an industry, in part driven by suppliers seeking to standardize how they interact with various customers, can lead to industry standard methods for exchanging information across a value chain, methods that typically include the use of 3rd party IT systems. While companies can use modular linkages between affiliates, this type of value chain modularity has the effect of decreasing contractual frictions, theoretically, at least, and therefore increasing the potential for outsourcing. Put concisely, value chain modularity involves the systematic partitioning of formerly tacit information, which can increase efficiency within the firm (intra-firm modularity), and across firms when combined with industry standards for exchanging information (inter-firm modular), and also across geographic boundaries, enabling both outsourcing and offshoring through the use of modular type GVC linkages (Sturgeon, 2002; Gereffi *et al*, 2005).

Figure 4. Stages of value chain modularity and the emergence of GVCs



0) Pre-modular state: bundles of tacit knowledge, **non-standard** hand-off between tasks

Stage 1) In-house modularity: internal rules for codified hand-off, using **proprietary** standards

Stage 2) Value chain modularity: industry rules for codified hand-off, using **industry** standards

Stage 3) Global value chains: cross-border linkages and flows enabled by value chain modularity

Source: T. Sturgeon, for UNCTAD.

While these processes have been well theorized and documented (e.g. Baldwin and Clark, 2000; Dossani and Kenny, 2013), the main point is that value chain modularity will be further enabled — and likely accelerated — by the technologies, tools and platform ecosystems of the NDE. This is because interoperability and known (and increasingly open) standards are critical to the functioning of the NDE, and because the platform structure is 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 modules without disrupting or disabling larger systems. 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.

D. The NDE and development

So far the analysis has focused on the main features and drivers of the NDE and the commonality of platforms, open innovation, and modularity in its structure and on-going development. Most current discussion of social consequences and competitive dynamics is, understandably perhaps, focused on the advanced economies (and especially the United States) that are in the process of forging the NDE. For firms in the heartland of digital innovation, the question is how to compete in the NDE. For governments and workers, the questions are how to seize the opportunities and cope with any negative impacts on national security, jobs, and society more generally (UNCTAD, 2017a). A question that gets asked less often (but see Rehnberg and Ponte, 2017) is what the effects could be on developing countries and smaller firms that are already behind in the use of digital tools. This section focuses on manufacturing and innovation in the NDE, the linkages between innovation and production, and asks where in the world they might take place.

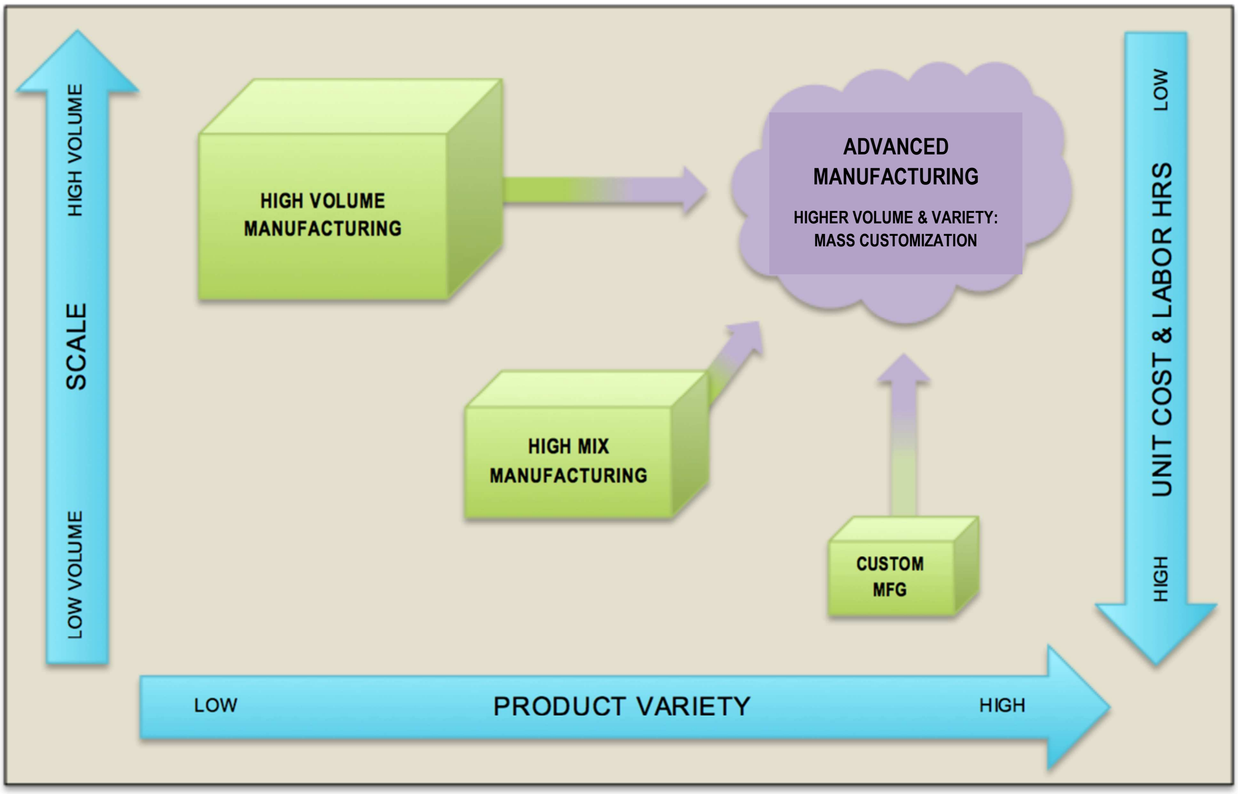
Manufacturing in the NDE, what are the trade-offs?

Industrialization has long been viewed as the path to development and traditionally, industrialization has meant manufacturing. While productivity increases and globalization have rendered this path less certain (Whittaker *et al*, 2010), manufacturing still plays an important role in all developed countries, even though its share of employment in advanced economies falls below 10 per cent. What will the role of manufacturing be in the NDE? Discussions of the topic, generally referred to as “industry 4.0” in Germany and “advanced manufacturing” in the US (Bonvillian, 2012; 2017), tend to highlight specific features, including additive manufacturing (or 3D printing), intelligent and adaptive robots that can safely work alongside humans, ubiquitous measurement with sensor-laden equipment, very high levels of traceability in the supply chain, and the development of new material and processes. But what can be said, *in general*, about the likely role and characteristics of manufacturing in the NDE?

Advances in process and quality control in manufacturing have been on-going since the industrial revolution, with the biggest changes coming in the 1830s with interchangeable parts and in the early 1900s with mass production, when large-scale dedicated production machinery dramatically lowered cost and labour hours per unit, at the cost of product variety. Because tooling (the moulds and dies and stamping forms used to shape individual parts) tends to be product-specific and expensive, full machine automation has typically been too costly for all but the most high-volume environments. With high-mix production, switching from one product to another raises challenges on the shop floor (often met with increased use of labour), and also in engineering, quality control, and materials management departments, where constantly-shifting set of specifications, requirements, and material flows must be accommodated. Smaller scale production has persisted in high-cost locations in the form of truly customized manufacturing, including prototyping, which is often labour intensive and part of local innovation ecosystems, and also in the form of high-mix production for reasons of market responsiveness, low price sensitivity, and requirements for co-location with innovation.

The trade-offs in regard to the production scale, product variety and unit costs/labour hours are summarized in Figure 5. Because low volume and fully customized manufacturing come with tooling manufacturing engineering costs for one or a small number of products, and cannot easily benefit from scale efficiencies for inputs or logistics, unit production and labour costs are high (see lower right quadrant of Figure 5). Products with large-scale demand per unit are produced in high volumes (low product variety), and can benefit from automation (lowering labour hours per item) and other scale efficiencies (see upper left quadrant of Figure 5). High mix manufacturing lies between these extremes. It comes with relatively high labour content, since it has historically not been cost effective to replace labour with less flexible machinery, and higher overhead costs related to logistics, inventory control, and materials management.

Figure 5. Shifting trade-offs with advanced manufacturing: scale, product variety, and unit costs



Source: T. Sturgeon, for UNCTAD.

As markets have grown and internationalized, demand has become more fragmented, and product quality and variety have become more important (Piore and Sabel, 1989). As a result, high-volume manufacturers have sought to compete by increasing product variety without unduly raising costs. Such “mass customization” (Pine and Davis, 1999) has been accomplished by various means. First, in the 1970s and 1980s, Japanese firms (such as Toyota) developed new work organization and supply chain management techniques. “Lean production” allowed greater product variety in mass production environments (among other benefits), in part by slightly increasing labour hours per unit, given that humans have historically been more flexible and responsive than machines (Womack *et al*, 1990). Second, modularity in the form of shared design elements, including underlying product “platforms” and common components, has enabled companies to increase product variation while keeping costs in check, even if the distinctiveness of such derivative products could sometimes be called into question (Chesbrough and Kusunoki, 2001). Third, computerization and the deployment of robots have rendered factories increasingly flexible, reducing the time needed to change production lines from one product to another. Automation, ubiquitous process measurement and parts traceability in the advanced manufacturing environments are motivated by efforts to increase productivity and reach extreme quality control goals, in some cases shifting from parts per million defect rates to parts per billion. Still, there have been limits and the trade-offs depicted in Figure 5 have persisted, with the key cost trade-off in manufacturing being variety versus scale.[25]

How may the scale/variety/cost calculus change in the NDE? Computerization and digital integration of design, manufacturing, capacity planning, and supply-chain management are long term trends, often embedded in enterprise resource planning (ERP) software. Such systems have gradually introduced greater flexibility and speed in the entire manufacturing chain, and as costs have fallen and the ease of use has risen, they have become more relevant for smaller companies. ERP and similar systems are and will continue to be a big part of the NDE as they continue to improve.

What has garnered more attention, however, are rapid improvements in production processes such as 3D printing that dispense with tooling entirely. Additive manufacturing equipment such as 3D printers can manufacture even complex parts by “printing” solid objects from undifferentiated powders, gels, liquids, and metal powders directly from digital design files. 3D printing lowers the cost for truly customized and extremely low-volume production — prototypes for example — as shown in the lower right-hand portion of Figure 5. Fast, low-cost prototyping can speed the innovation process, and also support “on-demand” manufacturing of products that have low or occasional demand.

While, as John Hart, head of MIT’s Mechanosynthesis Group, states, “By their nature, additive methods such as 3D printing are not going to replace high-throughput manufacturing operations” (Paiste, 2014), there is nevertheless a constant push to increase production volumes.[26] Companies are deploying scalable “swarms” of 3D printers to increase throughput, using systems developed by companies such as Formlabs and Stratasys (Kerns, 2017). Early adopters of 3D printing, including aerospace companies such as Boeing, Sikorsky and Airbus, are using it to produce large numbers of parts — Airbus is reportedly planning to produce 30 tons of 3D printed parts per month in 2018 (Kerns, 2017).[27]

Another way the technologies of the NDE can shift the volume curve upward and outward in Figure 5 is by enabling breakthroughs in production processes for heretofore exotic and experimental materials and process technologies, such as light-weight metals, advanced composites, integrated photonics, flexible hybrid electronics, advanced textiles, modular chemical processes, biofabrication, regenerative medicine, energy production and efficiency, and recycling and remanufacturing (Bonvillian, 2017).

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[25] Of course, the variables of cost, volume, and variety are not the only determinants of manufacturing location. Fragmentation in GVCs, where R&D has been geographically severed from production, has been less prevalent in industries and product categories that require edge manufacturing processes, such as the fabrication of very advanced microprocessors, or where frequent engineering changes or process alterations are needed on an ongoing basis, as in very advanced capital equipment and commercial aircraft. Products that are large, heavy, bulky, and/or delicate (such as large screen televisions), or variable or color-matched parts that need to be sequenced in final assembly (such as passenger vehicle seats and interior parts), have tended to be produced in or close to end markets. The location of production can also be affected by industrial polices, such as regulatory requirements for domestic manufacturing of military hardware, or local content requirements and “offset agreements” that trade domestic production for market access (Gereffi and Sturgeon, 2013).

[26] This is evidenced by the Mechanosynthesis Group Robofurnace, “an automated system for high-throughput synthesis of nanomaterials, including carbon nanotubes” (Paiste, 2014).

[27] The production environment for commercial aircraft, made up of tens of thousands of components and produced in modest volumes, can be said to fall into the high mix, medium volume category in Figure 5.

As advanced manufacturing technologies mature, and very flexible machines with higher throughput capabilities become more common, they will certainly be deployed in high-mix and even high volume production environments, enabling higher product variety at lower costs. As a result, the NDE will likely drive some degree of convergence toward the "advanced manufacturing" profile seen in the upper right quadrant of Figure 5 to allow larger-scale production with greater product variety while conserving costs and labour hours per unit, as suggested by the arrows converging toward mass customization.

The geography of advanced manufacturing

Where will advanced manufacturing be located? Because mass markets do not exist for all products, rapid replenishment is sometimes required, and cost sensitivity is not always high, smaller manufacturing units have proven to be a durable and perhaps growing part of the manufacturing landscape, despite higher unit costs (Reynolds, 2017). For example, even in Silicon Valley, where large companies such as Apple have famously turned to low-cost locations such as China for mass production and Mexico for some high mix, medium volume production, there are still dozens of low and medium volume contract manufacturers. They include both local firms (e.g. Amtech, Bentech, AlphaEMS) and branch plants of globally operating contract manufacturers (e.g. Sparqtron, Jabil, Flex, Benchmark, AQS). Boston and other technology clusters around the world have similar agglomerations of small and medium-sized contract manufacturers and firms engaged in manufacturing their own products on a small scale.

Some anticipate that the NDE will be characterized by small-scale advanced manufacturing facilities located close to consumers, similar to a farm-to-table model in food, in what Sanjay Sarma envisions as linked networks of "distributed virtual factories" (Markowsky, 2012). In this vision, jobs will migrate closer to end markets, transportation costs and CO_2 emissions will be lower, inventory requirements will shrink, and consumers will have their needs and desires met with a wide variety of products produced specifically for them as needed.

But the increased flexibility promised by advanced manufacturing, and the high cost of initial deployment, could have the opposite effect by increasing product variety in large-scale manufacturing, putting downward pressure on demand for high-mix and customized manufacturing located within end markets. Large scale production units, have the enduring advantage of purchasing power, which in turn incentivizes high responsiveness and even co-location of suppliers, investments in highly efficient transportation and infrastructure, and proximate institutional supports such as domain-specific education and training. With this in mind, it is possible to imagine that advanced manufacturing will be deployed mainly in places where mass production is currently taking place, such as in China.

Of course, there is a third possibility. The shift toward advanced manufacturing could be a more general, secular trend, with new systems deployed without dramatically altering the location of production. The result then would be a leap in productivity, quality, and traceability in all sorts of manufacturing facilities, mass, high mix and customized, with global decrease in demand for direct manufacturing labour. It is this possibility, especially if it arrives quickly, without time for labour market adjustment, which worries some observers of the NDE such as McAfee and Brynjolfsson (2016) (see also UNCTAD, 2017a).

Innovation in the NDE

What will be the effects of the NDE on innovation for those entrepreneurs and companies outside of the elite power brokers and core platform owners in the NDE? How can smaller companies and firms in developing countries take advantage of the NDE? The richness of digital tools supporting innovation in the NDE, as suggested in Figure 6, include new ways to access finance, labour, inputs and production services, customer service, sales channels, and marketing.

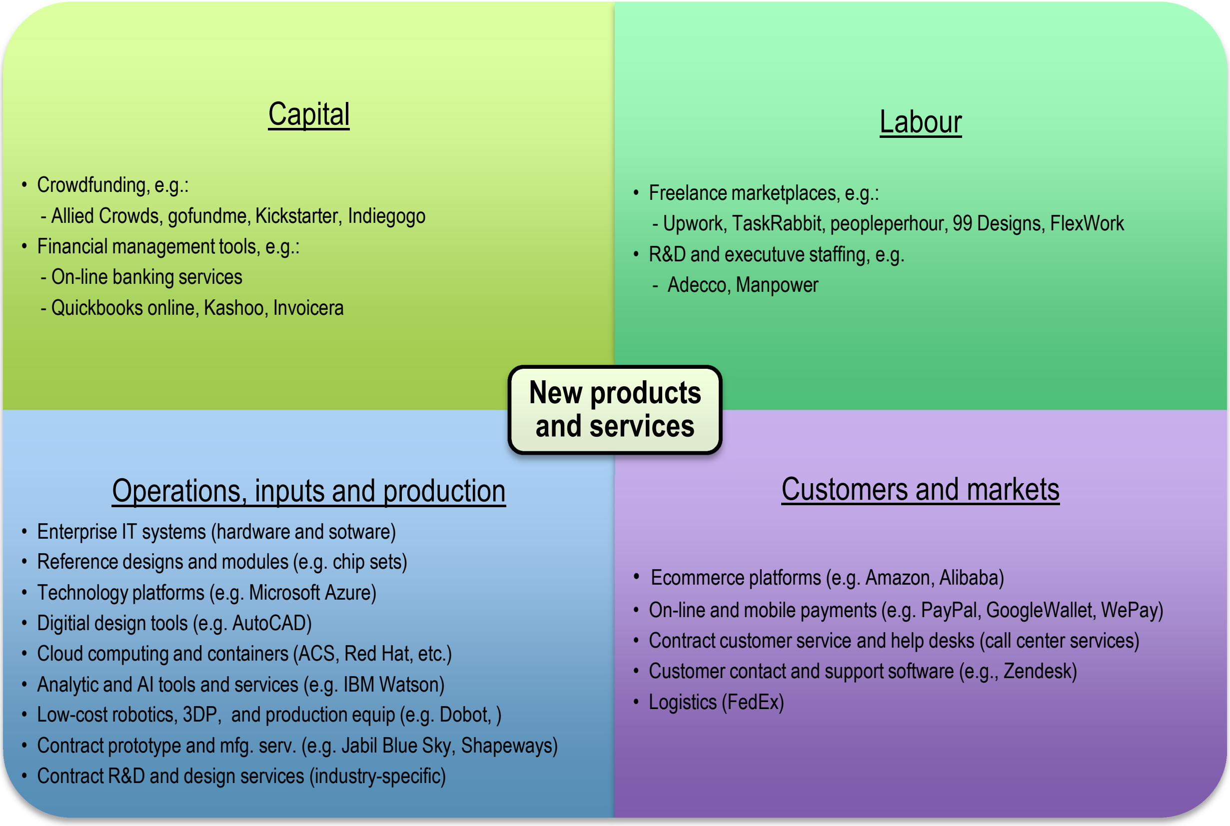
Given this toolkit, the potential of the NDE for innovation and entrepreneurship could be profound. Even when using today's digital tools, product design requires many engineering hours and multiple rounds of validation and testing. Failed tests lead to engineering changes and many additional hours of redesign and retest. At a certain point, designs that work "well enough" are accepted because sunk time and expense threaten to become excessive. The results are high costs, long cycle times, and sub-optimal products. The new tools of the NDE, especially big data and AI, are set to change this. Digital design simulation has been around a long time, moving from simpler applications, like automated circuit and software testing, into more challenging applications, such as simulation of mechanical systems (e.g. fluid dynamics, automotive drive trains, and avionics). However, the world appears to be on the cusp of new leaps in capabilities based on cloud-based crowdsourcing, big data analytics, and AI.

Take the example of Autodesk, the maker of AutoCAD, a popular digital design platform used across multiple industries, including automotive, industrial machinery, construction, and architecture. The company's new Dreamcatcher design automation suite draws on data captured from its large user base (new sources of data), and combines it in the cloud with in-house expertise (data analytics), and applies AI tools to suggest options to design engineers. The company describes the workflow in this way:

> The Dreamcatcher system allows designers to input specific design objectives, including functional requirements, material type, manufacturing method, performance criteria, and cost restrictions. Loaded with design requirements, the system then searches a procedurally synthesized design space to evaluate a vast number of generated designs for satisfying the design requirements. The resulting design alternatives are then presented back to the user, along with the performance data of each solution, in the context of the entire design solution space. Designers are able to evaluate the generated solutions in real time, returning at any point to the problem definition to adjust goals and constraints to generate new results that fit the refined definition of success. Once the design space has been explored to satisfaction, the designer is able to output the design to fabrication tools or export the resulting geometry for use in other software tools.

Figure 7 shows variations of bicycle frame designs automatically generated using Dreamcatcher. Such systems allow users to create and test hundreds if not thousands of design iterations in a matter of hours, radically reducing cycle times and improving product quality. Evaluating potential designs in rich 3D using augmented or virtual reality (AR and VR) is also becoming more common and less expensive (Barbier, 2017). With digital fabrication tools such as 3D printers, mock-ups and prototypes are also easier to generate, enabling easier and faster decision-making regarding ultimate designs.

Figure 6. Examples of tools for the emerging innovation ecosystem in the NDE



Capital

- Crowdfunding, e.g.:
  - Allied Crowds, gofundme, Kickstarter, Indiegogo
- Financial management tools, e.g.:
  - On-line banking services
  - Quickbooks online, Kashoo, Invoicera

Labour

- Freelance marketplaces, e.g.:
  - Upwork, TaskRabbit, peopleperhour, 99 Designs, FlexWork
- R&D and executuve staffing, e.g.
  - Adecco, Manpower

New products and services

Operations, inputs and production

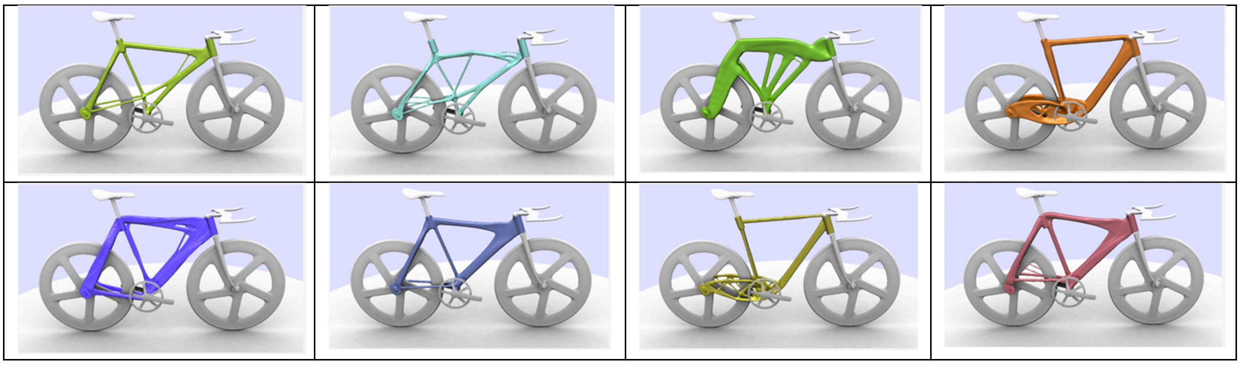
- Enterprise IT systems (hardware and sotware)
- Reference designs and modules (e.g. chip sets)
- Technology platforms (e.g. Microsoft Azure)
- Digitial design tools (e.g. AutoCAD)
- Cloud computing and containers (ACS, Red Hat, etc.)
- Analytic and AI tools and services (e.g. IBM Watson)
- Low-cost robotics, 3DP, and production equip (e.g. Dobot,)
- Contract prototype and mfg. serv. (e.g. Jabil Blue Sky, Shapeways)
- Contract R&D and design services (industry-specific)

Customers and markets

- Ecommerce platforms (e.g. Amazon, Alibaba)
- On-line and mobile payments (e.g. PayPal, GoogleWallet, WePay)
- Contract customer service and help desks (call center services)
- Customer contact and support software (e.g., Zendesk)
- Logistics (FedEx)

Source: T. Sturgeon, for UNCTAD.

Figure 7. Machine-generated bicycle frame design options using Autodesk Dreamcatcher AI suite



Source: Autodesk Research, https://autodeskresearch.com/projects/dreamcatcher.

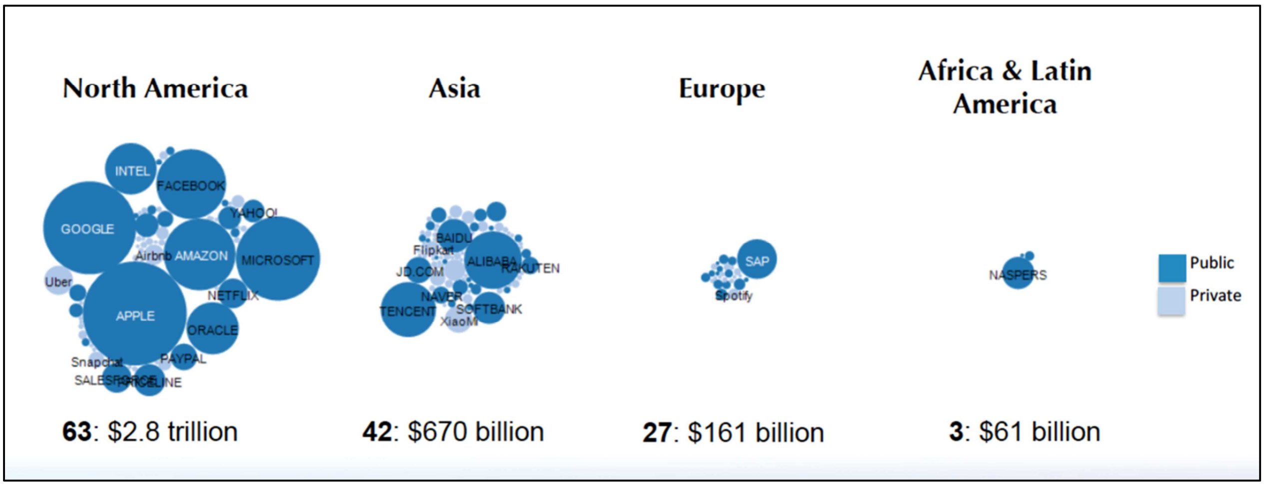
Digital design tools also offer capabilities to investigate the cost and supply-chain availability of components, and export finished designs as instruction sets for automated production equipment anywhere in the world, either in existing manufacturing clusters, close to consumption, or adjacent to innovation. With such capabilities in place, the work hours needed to create new products could fall sharply, along with the expertise needed to design high quality products. With the heavy engineering requirements satisfied by software, 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. New design tools emerging in the NDE could present opportunities in developing countries where technical skills might be low, but knowledge of local market preferences is high.

The geography of innovation in the NDE

Just as with earlier rounds of globalization, there will be counter-trends to the fragmentation and spatial dispersion of GVCs, driving continued growth in technology clusters such as Silicon Valley, where the systems that underpin the NDE are developed, and standard battles are fought and won (Sturgeon, 2003). A look at the headquarters locations of the most important players in the NDE, shown in Figure 8, reveals an extreme level of concentration in North America, which has headquarters of 63 of 135 NDE companies with a market capitalization of more than $1 billion in 2015. A closer examination of the North American companies in Figure 8 suggests an even greater level of sub-national concentration. Their headquarters are, almost without exception, located in a handful of postal codes in and around Silicon Valley, California and Seattle, Washington.

Given this situation, and the advent of new AI-assisted design processes just mentioned, the impact of the NDE on the location of innovation is likely to be two-fold. On the one hand, the need for iterative engineering work could fall along with the expertise required to design new products, and while this might generate additional demand for skilled labour for core platform owners, many fewer highly skilled engineers and workers could be needed in firms that use the systems to produce either higher-level platforms or final products and services. This is because much of the expertise required to design, test and validate new product designs will be embedded in software platforms, especially in the AI portion. While making successful use of such systems certainly requires expertise, job counts and spill-overs to local innovation clusters could be reduced. On the other hand, downstream innovation (not innovation in core platforms, but in new platforms and products created by and around them) could lead to an uptick of innovation outside the heartland of core NDE innovation, as products tailored to local markets are developed and produced more easily, quickly and inexpensively.

Figure 8. Headquarters region of digital economy companies with more than US$1B market cap in 2015



Source: Van Alstyne (2016), based on research by Peter Evans, KPMG.

It remains to be seen if the geographic concentration suggested by Figure 8 is a result of the youth of the NDE, where companies have been spawned quite recently from within existing dominant clusters in computing, software, and networking; or if these clusters will draw in the most innovative segments of more traditional industries as they adapt to the NDE. While the NDE, broadly defined, includes many existing technology clusters (e.g. Pittsburgh, Boston, Toronto, Munich and Tokyo), in the winner-take-all game of platform competition, there could be a winner-take-most geographic analogue, driving spatial inequality both domestically and internationally.

Still, it seems safe to assume that the opportunities provided by the NDE for firms in places outside of established technology clusters will be significant. While General Motor's move to concentrate its AI-based self-driving technology development in the San Francisco Bay Area (Associated Press, 2017), an example of the centripetal spatial dynamic just mentioned, examples of the centrifugal dynamic also abound. These include Uber's (increasingly troubled) testing of driverless vehicles in Philadelphia (Kang, 2017), the apparent emergence of a driverless vehicle cluster in Boston led by start-ups such as nuTonomy (Vaccaro, 2017), and the recent proliferation of fully electric vehicle producers in China (Helveston *et al*, 2017). It is important to note that the big three Internet companies in China, Baidu (Internet search), Alibaba (e-commerce), and Tencent (social networking and mobile services), sometimes referred to as the BAT companies, are dominant in China's huge domestic market. Tencent's WeChat social networking platform has 800 million users, though almost all of whom are within China.[28]

When the lens is shifted from core platforms to higher-level platforms, platform complementors, and platform users, the possibilities open up significantly. The resources listed in Figure 6 prove only a hint at the vast and growing set of digital resources that could be used by start-ups, smaller, and globally remote companies to innovate, grow, improve operations, and connect to markets. These tools cover the gambit, including aids to R&D and innovation, capital, labour, operations, inputs, and marketing and market access. In regard to capital, Allied Crowds is a website that aggregates hundreds of alternative financing providers with a specific focus on developing countries, including equity (angel and venture capital) investors, crowd funding, and donors who might assist firms (if allowed by local regulations) in bypassing local banking systems and otherwise overcome financing hurdles, and also offer a way for companies to make themselves known (i.e. marketing). These tools create possibilities, and they exist not *despite* the powerful technology firms and core platform owners concentrated in places such as Silicon Valley and Seattle, but *because* of them.

Linkages between manufacturing and innovation in the NDE

A crucial question is how tightly innovation will be geographically tied to production in the NDE. Historically speaking, industrial, innovation, and manufacturing policies have been based on the assumption that the two have strong spatial linkages. Innovation policies hope to spawn new industries that will in turn generate large-scale employment, including in manufacturing. Investment attraction policies hope to create manufacturing employment, in the first instance, but also embody hopes that knowledge-intensive activities will eventually follow production as a spill-over. When there is no well-defined, modular break-point between innovation and production (as depicted in Figure 4), successful innovation might require manufacturing to be co-located, since new products sometimes also require new processes to produce them. Yet, as seen in important industries such as electronics, software, and motor vehicles, effective modular linkages between the innovation and

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[28] While it is relevant that these firms developed within the "Chinese Firewall," a term given the Chinese government's extensive attempts to block content it deems subversive from the Chinese Internet, including a refusal to grant operating licenses to Google and Facebook, knowledge of the Chinese market had also been important, especially for Tencent/WeChat, which has developed an entirely mobile platform that includes innovations that appeal specifically to Chinese users (e.g. the "red envelope" feature of WePay that allows easy gifting of money to friends and family in line with traditional norms), and Alibaba, which has essentially outcompeted Amazon in China mainly based on its product mix and fulfillment (Thun and Sturgeon, 2017).

production stages of the value chain can facilitate a separation of innovation and production can be geographically separated into distinct technology and production clusters (as depicted in Figure 9).

Bonvillian (2012) frames this as a shift, in industries with high levels of value chain modularity, from an “innovate here/produce here” structure to an “innovate here/produce there” structure. Because dynamic industries can change in terms of products, process technologies, business models, and regulatory requirements, it is possible for pressures for co-location to increase in industries that have been heretofore evolving along the lines of innovate here/produce there. The question then becomes, which part of the industry will “move” to be close to the other? From the perspective of advanced economies like the United States, Western Europe and Japan, this is usually framed as a replacement of a “hollowing out” trend with “re-shoring”, where manufacturing returns to the heartland of innovation, either because productivity increases in production (e.g. as a result of automation) have rendered labour cost differentials unimportant, because manufacturing needs to be tightly linked to innovation for technical coordination reasons (referred to as “decodification” by Gereffi *et al*, 2005), or for some other set of reasons, such as industrial and trade policies that shift the incentives toward domestic manufacturing. Of course, emerging economies, such as China, Brazil, and Viet Nam have long been incentivizing investments in R&D in combination with manufacturing (Zylberberg, 2017). These countries and others will certainly seek to leverage any new requirements for co-location of innovation and production in ways that will generate more substantial R&D spill-overs within their borders.

Excitement about re-shoring has waxed and waned repeatedly, with little real impact on the direction of change in the global economy toward the innovate here/produce there model underpinning GVCs. Not every industry has moved manufacturing offshore, but of those that have, very little has “come back” (A.T. Kearney, 2014). While past evidence suggests that there will be variation across industries (Sturgeon and Memedovic, 2010), and that firms will have strategic choices in regard to business models (Berger *et al*, 2005), it is reasonable to assume that a maturing NDE will lead to a further loosening of spatial ties between many business functions, including innovation (and within innovation), production, logistics, marketing, distribution and after-sales service.

The emergent features of the NDE appear poised to extend the organizational and geographical fragmentation of work into new realms, including formerly indivisible and geographically rooted activities that reside at the front end of GVCs, especially R&D, product design, and other knowledge-intensive and innovation-related business functions. The digitization of work, and of products and services, means that more industries will be underpinned by ICT, connected to the cloud, and based on global platforms. All of this loosens the constraints on co-location, and provides firms, large and small, with new ways to pursue “optimization” strategies in regard to the location of markets and distribution, on the one hand, and the location and sourcing of business functions and intermediate inputs on the other. Again, changes to the regulatory environment could change locational incentives dramatically.

Scenarios for developing countries in the NDE

Given the scenarios just outlined, what impacts is the NDE likely to have on developing countries? While the features of the NDE might add up to radical change, it is in line with earlier advances in computerization, beginning in the 1980s, accelerating in the 1990s, and becoming mainstream in the 2000s, that allowed the organizational and geographic separation of R&D and design from manufacturing, leading to the creation of GVCs. Higher value business functions, such as branding and product design have tended to stay in established technology clusters, but vast new investments in manufacturing have been made in lower cost and market-proximate locations such as China, Viet Nam, South Africa, and Brazil and Mexico, creating large numbers of production jobs but also jobs in adjacent categories such as materials and supply chain management, manufacturing engineering, logistics and distribution (Berger, 2005; Baldwin, 2016; IBRD/World Bank, 2017).

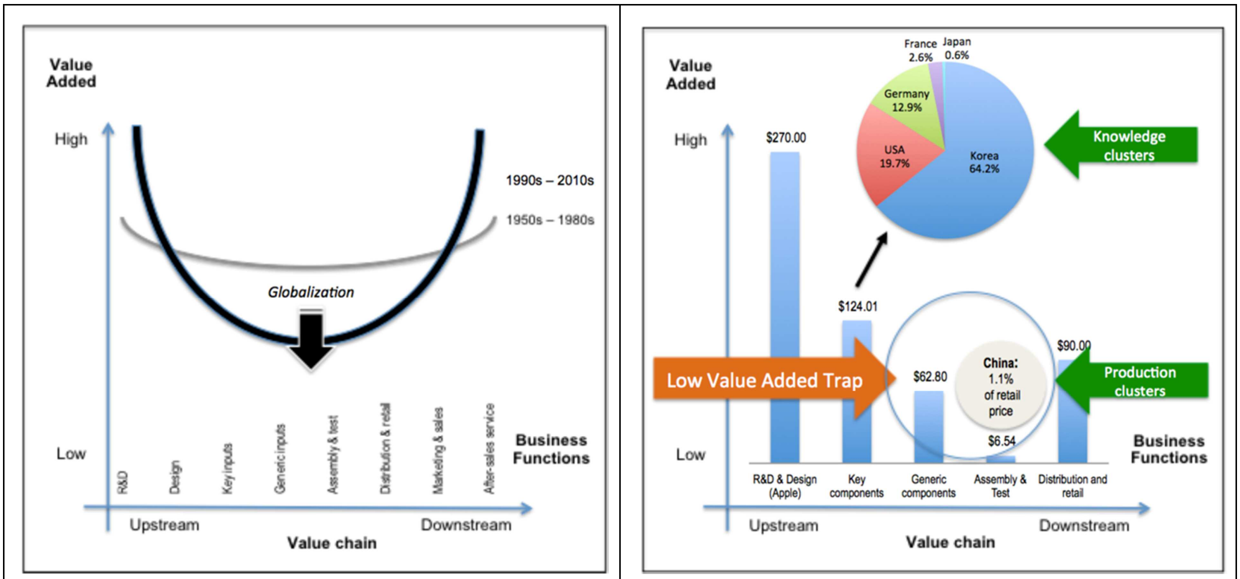
However, even countries and regions that are deeply connected to GVCs, such as China and other export-oriented economies in East Asia, India, Eastern Europe, North Africa, and Latin America (e.g. Mexico) can fall into "low value added traps." This is because a greater share of value (and profits) tend to accrue to the "lead" firms in GVCs that control branding, product conception, and retail distribution; as well as to the suppliers of advanced production equipment and technology platforms and intellectual property owners that provide the key inputs and even *de facto* standards for others in the chain (e.g. Intel or Qualcomm CPUs).

While there are a growing number of important MNEs and a few successful suppliers of higher level platforms from the developing world, GVCs are still dominated by firms from the traditional technology clusters in industrialized countries (Blyde, 2014). Firms that provide routine assembly tasks and other simple services within GVCs tend to have lower profits, pay their workers less, and be more vulnerable to business cycles. This idea was first articulated (from direct experience) by former Acer CEO Stan Shih as the 'Smiling Curve' of value added (see Figure 9), and first demonstrated by the research of Linden *et al* (2009) with the case of the Apple iPod. A 2011 study by the OECD (2011), based in part of the work of estimated that China's value added to a $600 iPhone 4 (mainly assembly and packaging) was only US $6.54, about 1% of the retail price.

This raises a series of questions. Will the NDE open up new opportunities for developing countries, or deepen existing geographic divides? Will automation allow production to migrate closer to the point of consumption by decreasing the importance of large-scale direct labour which has been the engine of growth for so many recent developers? Or, will such shifts drive recent developers more quickly into higher value activities, for example, when AI provides entrepreneurs in developing countries with platforms on which to develop sophisticated products suitable for export to advanced markets? Will the ICT-enabled fragmentation of knowledge work lead to new waves of global investment in R&D, deepening and broadening the formation of GVCs?

Just as with manufacturing, there are three broad scenarios for developing countries in the NDE. The first is that the routine business functions such as manufacturing, software coding, and back office services, which have served as the backbone for rapid development, could be the first to be re-shored or even eliminated by advanced manufacturing and automation. This could drive a retreat from GVCs and huge social disruptions in recent developers, where export oriented factories currently employ tens, and even hundreds of thousands of workers in very concentrated manufacturing clusters (around Shenzhen, Hanoi, and Guadalajara, for example). In the second scenario, the tools of the NDE could empower developing country firms to move up the value chain, become less dependent on the innovation and coordination functions of lead firms in GVCs, and produce globally competitive and compatible products on their own. Rehnberg and Ponte (2017) depict this scenario, using the example of 3D printing, as a possible flattening of the value chain curve from "smiling to smirking." The third scenario is that the innovate here/produce there geographic division of labour suggested in Figure 9 remains relatively stable as the NDE alters products and processes in existing technology and production clusters. The balance between the centripetal and centrifugal effects on the geography of industries, and the alterations in complexity and fluidity in GVCs patterns seen today, will doubtless constitute a core research questions for scholars of GVCs in the coming decades.

Figure 9. The "smiling" curve of value added, with $600 iPhone 4 example



Cost differentials lower the share of value added for routine business functions, which are shifted to developing countries.

Functions become geographically segmented between knowledge clusters, for higher value-added functions, and production clusters, which pool lower value-added functions, creating low value-added traps (China, the exporter of record, contributes only 1.1% of a $600 iPhone's value)

Source: T. Sturgeon, for UNCTAD, with iPhone example drawn from OECD, 2011.

E. Concluding remarks

What's new about the NDE?

The main driver of the NDE 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 NDE 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 pools that can be used to create new insights, products, services — as well as risks to society. Second, business models based on technology and product platforms — platform innovation, platform ownership, and platform complimenting — are, in a range of industries and product areas, radically altering industry structure and 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 and increasingly ubiquitous ICT.

The range of new technologies, techniques, and scientific avenues being opened up, at least in part, by the new tools of the NDE are almost too numerous to mention. In addition to the applications already referred to in this study, space exploration, low cost targeted gene editing techniques (e.g. CRISPR), and ultra-small scale manipulation of matter, often referred to as nano-technology, can be added.[29]

Winners and losers, opportunities and risks

Being transformational, the NDE will likely create both winners and losers, both opportunities and risks. A positive, if somewhat utopian vision of the NDE might centre on the ubiquity and democratization of information — not hard to envision nearly twenty years after the introduction of Google search and ten years into the smart phone era — and the decoupling of economic growth from natural resource constraints enabled in part by the shortening of supply chains with the advent of on-demand manufacturing (e.g. 3D printing) and super-efficient containerized urban agriculture (Chambers and Elfrink, 2014). The NDE, therefore, could usher in a newly equitable and environmentally sustainable growth model based on the maximization of human empowerment and wellbeing rather than maximization of profits and resource extraction and utilization (Erkoskun, 2011). Personal robots may certainty be helpful to the infirm and disabled, and be flexible enough to become well integrated into everyday life (Rus, 2015).

However, there are legitimate worries that the NDE will introduce frightening new risks, and that not everyone will prosper from its evolution. For workers, large and sudden productivity increases enabled by the NDE could shorten the employment adjustment period that has softened the impact of earlier rounds of automation. The penetration of computerization and AI into knowledge-intensive services could mean that many more jobs will be at risk of disappearing, even as output and productivity rise (McAfee and Brynjolfsson, 2016). On the other hand, advanced economies have been remarkable in their ability to create new industries, demand new skills, and create new and different jobs (Autor ,2015).

Nevertheless, the disruption from automation and globalization tends to be experienced unevenly, and at the very least, it is all but assumed that a new class of super intelligent and dexterous robots will cause direct labour in factories to fall further in the coming decades (McAfee, Brynjolfsson, and Spence, 2014), driving “employment polarization at the level of industries, localities, and national labour markets” (Autor, 2015, p. 12), and especially in places that are highly dependent on manufacturing, even if temporarily.

Moreover, the economic and social effects of the NDE are expected to be broader than job loss from factory automation. Ride sharing is already revolutionizing individual mobility and autonomous road vehicles, especially freight trucks, seem to be knocking on the door of mainstream deployment (Vincent, 2016). Services from help desks to education and training to payments and banking are increasingly delivered with automated help-desk systems that include voice recognition and AI features. The “gig economy” (De Stafano, 2015) may be creating a precarious class of “on demand” workers, or “dependent contractors” (Smith and Leberstein, 2015), including knowledge workers, that

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[29] Nano-technology includes nano-manufacturing for the creation of new materials and the emergence of a new class of nano-machinery. Nano-technology is impacting a range of fields, not least the fabrication of semiconductors, creating a virtuous technological circle between the processes of innovation and the tools available to engage in innovation.

are part of a broadly emergent “precariat” without any clear institutional means for organizing (Standing, 2016). While ride sharing and apartment rental platforms tend to receive a lot of press attention, platforms to connect home care workers to clients (e.g. Care.com), and those that connect clients to an “on demand” workforce through platforms,[30] involve much larger numbers of workers, on the order of millions per platform, rather than the hundreds of thousands working for ride sharing platforms (Smith and Leberstein, 2015).

And, the jobs suitable for on-demand work, copyediting, data cleaning, moderation of online content, transcription, and even driving, could be the most vulnerable to replacement by AI computer systems. In the ‘new’ centers of offshore IT services, such as Bangalore, hiring is down and significant layoffs have been seen for the first time (Narayan, 2017).[31] Even if many more intellectually stimulating and satisfying jobs are created, rising inequality, potential for worker abuse, and downward pressure on wages are all worrying aspects of the NDE.

For consumers, there are risks beyond real and potential job losses from automation and AI. For example, big data and AI could enable “first degree” price discrimination, where prices are adjusted constantly and in real time based on a consumer's perceived need for the product or service and willingness to pay. When such variables can be estimated from prior shopping and purchasing histories analysed in the context of millions of prior purchases from shoppers with similar habits, consumer bargaining power could be harmed (Shiller, 2014). On the other hand, automation, mass customization and shorter supply lines could lower prices and vastly improve consumer satisfaction (Bhasin and Bodla, 2014).

While the actual and potential benefits of connected IoT devices in the home are still being proven, many smart phone apps, such as free, easy-to-use map navigation and music streaming services have already more than proven their worth to users. Data flows to platform owners underpin, at least theoretically, on-going enhancements and upgrades to digital products and services. But the price for these services is users who passively, and sometimes unknowingly, provide app-makers and platform owners with very fine-grained information about their whereabouts and personal habits. For example, Facebook collects user data that includes city, gender, age IP address, and, a full record of the website users link to and how they tag content (when logged in). In addition, the company combines information and assumptions about users harvested from their online activity with information from public sources and data brokers to assemble dossiers on users with nearly 100 variables (job title, parents’ birthdays, etc.) to help target advertisements more precisely (Dewey, 2016).

For large companies, organizations, and governments, we have already seen the vulnerability — to hacking, identity theft, espionage, larceny, ransoming, and even 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 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

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[30] Example include Crowdflower, Crowdsource, Clickworker, and Mechanical Turk, or MTurk, a crowdsourcing site operated by Amazon Web Services that connects researchers to individuals that help with scientific experiments and tedious data analysis tasks in exchange for small payments.

[31] For example, in late 2016 Larsen & Toubro, India’s biggest engineering firm, reduced its workforce by 14,000 employees, or 11.2%, and in 2017 more layoffs were seen at IT services firms including Cognizant, Wipro, Infosys and Tech Mahindra.

and pooling across the larger organization and supply base. Ignoring such risks can have grave consequences, while taking them seriously can undermine the promise of the new era.

For smaller companies, the cost and expertise required to purchase, operate, and continually upgrade advanced manufacturing and IT 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 developing country firms. The winner-take-all dynamics seen in platform-based industries (e.g. Google, Uber, Facebook, and WeChat), where network effect advantages accrue to first-movers and standard setters (Parker *et al*, 2016), could lead to accentuated polarization in the industrial base as the standard-bearers for the NDE consolidate their gains.

Despite these concerns, the NDE holds much promise for businesses able to take advantage of new technology and mitigate risks. Large and small companies that rely of the new tools of the NDE, in rich and poor countries alike, can make their organizations more efficient, reach and serve customers more effectively, speed new product development, and invent entirely new products and services without the need for deep pockets or deep system-level expertise. 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 NDE.

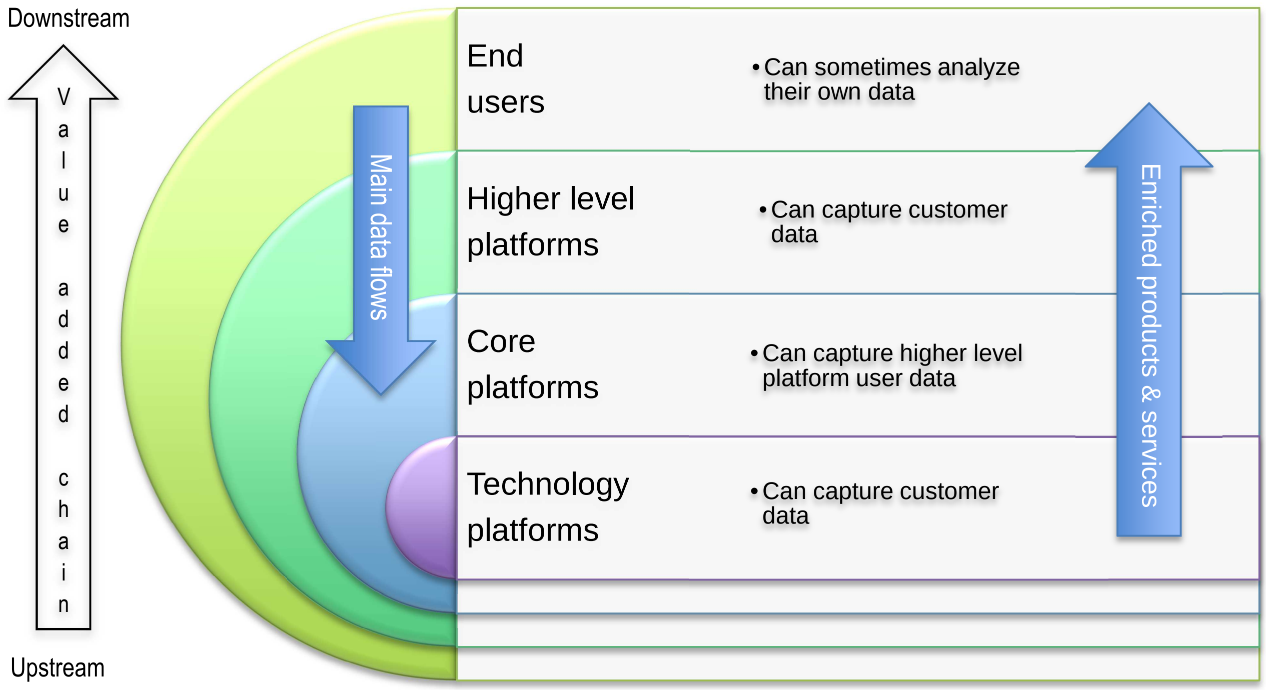
It is an intriguing prospect, from a developing country perspective, that small firms and entrepreneurial start-ups, anywhere, might have access to crowd funding and build products based on technology, core, and higher-level platforms. With AI-assisted tools either built into design software, and analytics included as either a feature of the platform or an analytical tool to help refine subsequent design iterations, innovation could become more efficient and effective and opportunities for growth could multiply. With such tools lowering the cost of entry into the NDE, it is easy to see the potential benefit for economic development anywhere where entrepreneurs and engineers with the right capabilities can make use of them.

Data partitioning, a new digital divide?

Despite its promise, access to data is likely to remain partitioned in the NDE. A stylized depiction of the data flows in the NDE, shown in figure 10, suggests that the sweet spot for data access resides with core platform owners, and secondarily with higher-level platforms. Entrepreneurs with small companies will have access to their own data, and be able to analyse it by making use of AI tools and platforms, but access to larger insights from larger pools of data will either come with a cost or be entirely the purview of platform owners.

So, 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 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 NDE, and 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. Whatever the advantages of the NDE for average users, greater advantages will probably accrue to those with the capability and authority to accumulate, access and analyse big data.

Figure 10. Actors, data access, and data flows in the NDE ecosystem



Source: T. Sturgeon, for UNCTAD

It appears that we could be at the beginning of a new and disruptive technological wave. 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 absorb and adapt to them, requiring significant reshaping and accommodation in order to reach a more mature and humane footing (Bodrozic and Adler, 2017). While the full impact of the NDE on jobs, international competition, and the location of production is unknown, outcomes will crucially depend on the pace of change and the ability of organizations and societies — including regulators and the producers of economic statistics — to understand it, measure it, and manage it.

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