The Next Production Revolution
Implications for Governments and Business

PART I

Chapter 2

Benefits and challenges of digitalising production

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This chapter examines how new information and communication technology (ICT) applications – in particular big-data analytics, cloud computing and the Internet of Things (IoT) – enable novel production and organisational processes, and business models, mainly in industrial sectors. The chapter focuses on the productivity implications of new ICT applications in early adopting firms in a number of industries (including automotive and aerospace) but also in traditional sectors such as agriculture. An assessment is provided of policy settings needed to realise the potential productivity and other benefits of digital technologies in production, while mitigating a number of associated risks.

Introduction

Digitalisation of the economy and society is progressing rapidly, especially in developed countries. Today, three out of four inhabitants in the OECD area have access to mobile wireless broadband, and up to 95% of all businesses are connected to the Internet. Three-quarters of businesses have an online presence and almost as many engage in e-commerce (OECD, 2015a; 2015b).

Industrial production is undergoing a transformation driven by the conjunction of the increasing interconnection of machines, inventories and goods delivered via the IoT, the capabilities of software embedded in machines, analysis of the large volumes of digital data ("big data") generated by sensors, and the ubiquitous availability of computing power via cloud computing. The resulting transformation has been described by some as "Industry 4.0" (Jasperneite, 2012), the "Industrial Internet" (Bruner, 2013), and "network manufacturing" (Economist Intelligence Unit, 2014). The potential economic benefits of new digital technologies are large. For example, available estimates suggest that the IoT could contribute USD 10 trillion to USD 15 trillion to global gross domestic product (GDP) over the next 20 years (Evans and Anninziata, 2012).

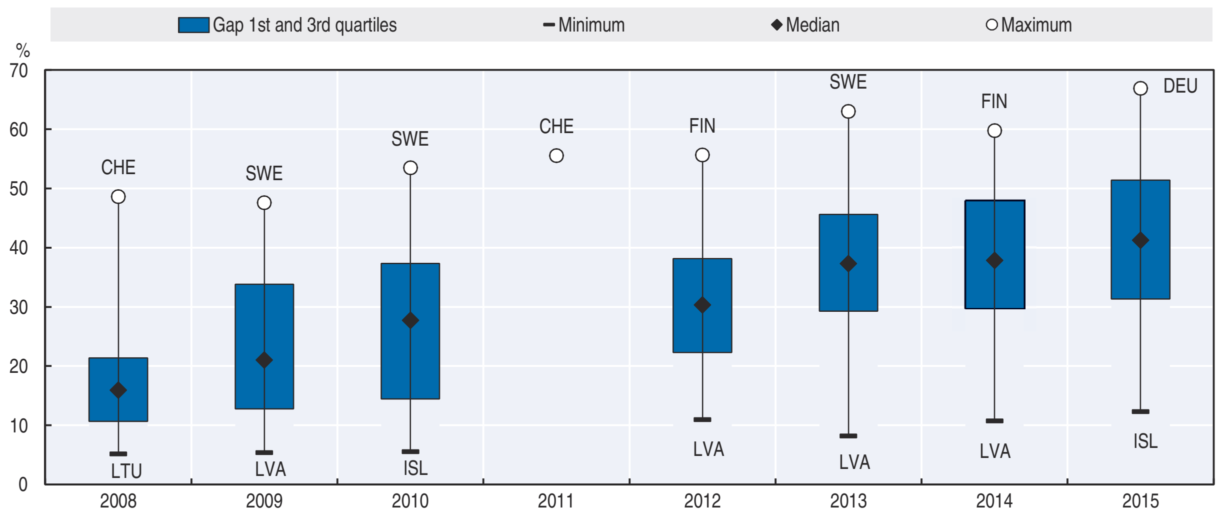
This chapter examines how the conjunction of new digital technologies – in particular big-data analytics, cloud computing and the IoT – enable more customisable goods and services via new production and organisational processes, as well as new business models, mainly in industrial sectors. Based in part on commissioned case study materials, the chapter focuses on the productivity implications of digital technologies in early-adopting firms in a number of industries (including automotive and aerospace) as well as in traditional sectors such as agriculture. It discusses steps that can be taken by traditional firms to successfully transition to digital business models.

Policy suggestions are described which address the main challenges in digitalising industrial production, including: expanding access to data and critical ICT infrastructures and applications; improving interoperability and supporting the development of standards; using existing frameworks – and where necessary refining these – to reduce a range of emerging uncertainties (related e.g. to liability in the context of automation and ownership in an environment where intangible assets such as data can be critical to value creation); reducing risks in connection with digital security and privacy; and fostering competition in new digital contexts. Underpinning all of the above, the chapter likewise points to the need to develop the skills required for the next production revolution.

Adopting advanced ICTs in production

In manufacturing and agriculture, ICTs are transforming production, as businesses are using advanced ICTs such as enterprise resource planning (ERP) and supply chain management (SCM) software to significantly raise productivity.[1] And the use of such software is growing rapidly. In 2015, for example, in the Netherlands, Finland and Sweden, more than 60% of all manufacturing firms used ERP software. By comparison, in 2009, only around 40% of manufacturing firms used ERP software in the Netherlands and Finland, and 50% did so in Sweden. And in Germany, already 70% of manufacturers used ERP software in 2015, compared with some 40% in 2009 (Figure 2.1). In contrast, only 40% of all businesses (across all sectors) in these respective countries used ERP software, with the exception of Germany, where the share was 60% in 2015.

Figure 2.1. **Share of manufacturing firms using ERP software, 2008-15**



Note: This figure does not include data for 2011 except for Switzerland. It includes data for Austria, Belgium (except 2008-09,2014-15), Canada (except 2008-10, 2014-15), Czech Republic, Denmark (except 2008-09), Estonia, Finland (except 2008), France (except 2008), Germany (except 2008), Greece (except 2009-14), Hungary, Iceland (except 2008-09), Ireland (except 2008), Italy (except 2008), Korea (except 2008-10), Latvia (except 2008), Lithuania, Luxembourg (except 2008-09), the Netherlands (except 2008), Norway, Poland (except 2009), Portugal (except 2008), Slovak Republic, Slovenia, Spain (except 2008), Sweden (except 2008), Switzerland (except 2009-10, 2012-2015), Turkey (except 2008-09, 2012-15) and the United Kingdom (except 2008).
Source: Based on OECD (2016f), *OECD.Stat*, database, *http://dotstat.oecd.org/index.aspx?DatasetCode=ICT_BUS* (accessed September 2016).
StatLink http://dx.doi.org/10.1787/888933473741

Digitalisation promises greater control over production, greater flexibility in the scale and scope of production, and reduced operation costs (see Box 2.1 on the use of manufacturing execution systems [MESs]). In agriculture, for example, farmers generate data which companies such as John Deere and DuPont Pioneer can exploit through new data-driven software services (Noyes, 2014). For example, sensors in John Deere's latest equipment can help farmers manage their fleet of vehicles, reduce tractor downtime and save resource consumption (Big-Data Startups, 2013). The digital transformation of industrial production is also making certain industries more service-like, a trend sometimes described as "servicification" (Lodefalk, 2010). This approach has already been taken by firms such as Rolls-Royce, Boeing, Michelin and John Deere, to name a few (see sections below).

Today the IoT allows manufacturing companies to better monitor the use of their products and thus to provide customised pay-as-you-go services priced using real-time operational data. Rolls-Royce, for example, was a pioneer of this approach, when in the 1980s it stopped selling its jet engines alone, and began selling "power by the hour" – a fixed-cost service package over a fixed term (OECD, 2016b).[2] Data is now also used to monitor and analyse the efficiency of products and is increasingly commercialised as part of new services for existing and potential suppliers and customers. Germany-based Schmitz Cargobull, the world's largest truck body and trailer manufacturer, also uses the IoT to monitor the maintenance, travelling conditions and routes of all its trailers (Chick, Netessine and

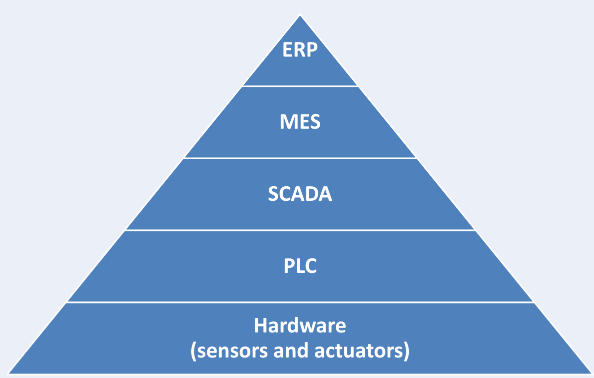
Huchzermeier, 2014). This helps Schmitz Cargobull's customers to minimise usage breakdowns. Energy production equipment manufacturers, as another example, increasingly use sensor data to help their customers optimise contingencies in complex project planning activities (Chick, Netessine and Huchzermeier, 2014).

Box 2.1. **The potential of MESs: The case of MPDV Mikrolab GmbH**

The enormous competitive pressure under which manufacturing companies stand will continue to grow with the ongoing digitalisation of industrial production. Manufacturing firms must be able to react more flexibly and quickly to unexpected changes in order to use all resources as efficiently as possible. These requirements drive companies to use advanced ICTs, not least to master the ever-growing complexity resulting from increasing product diversity and ever-shorter product life cycles and to provide reliable information, ideally in real time, to make better short and long-term decisions.

As the digitalisation of industrial production intensifies, advanced ICTs and in particular MESs, become central in manufacturing companies. MESs are used to manage operations on the shop floor, usually connecting the business ERP system with the shop floor's supervisory control and data acquisition (SCADA) and programmable logic controllers (PLC) systems (Figure 2.2). The scope of a MES can vary from scheduling a small set of critical machines to managing the entire manufacturing process. According to Harris (2017), "The functions of MES programs include: compiling a bill of materials, resource management and scheduling, preparing and dispatching production orders, preparing work-in-progress (WIP) reports and tracking production lots. Advanced systems will also have a product definition library with revision history and can report on production status to an ERP".

Figure 2.2. **Stack of systems used for the automation of industrial production**



Source: OECD, based on Snatkin et al. (2013), "Real time production monitoring system in SME", *http://dx.doi.org/10.3176/eng.2013.1.06*.

Several of the major automation providers such as Emerson, General Electric, Honeywell, Invensys, Rockwell and Siemens offer MES solutions, as do major ERP system vendors such as Microsoft, Oracle, Sage and SAP. These vendors tend to focus on large firms as their main customers. MPDV Mikrolab GmbH, a small and medium-sized enterprise (SME) based in Mosbach, Germany, is one of the leading suppliers of MES with a focus on SMEs. MPDV offers a broad range of field-tested and specialised MES applications to more than 930 firms worldwide, under the HYDRA brand.

Box 2.1. **The potential of MESs: The case of MPDV Mikrolab GmbH** *(cont.)*

MPDV has reported that clients using HYDRA have been able to increase their overall equipment effectiveness (OEE measures how effectively a manufacturing operation is utilised) by more than 15% in the first two years.

Research provides evidence for the benefits of using an MES. Adler et al. (1995), for example, showed that 10% to 30% of the production personnel and support group's time could be reduced with an MES, subject to complementary investments in business process reengineering. Strategic Direction (2004) also shows that MES enable a reduction of overall lead time by around 30%. A more recent study by Nasarwanji et al. (2009) confirmed potential savings in labour overheads. However, the authors also show that these savings start to be realised only after exceeding 80% of the factory's capacity utilisation.

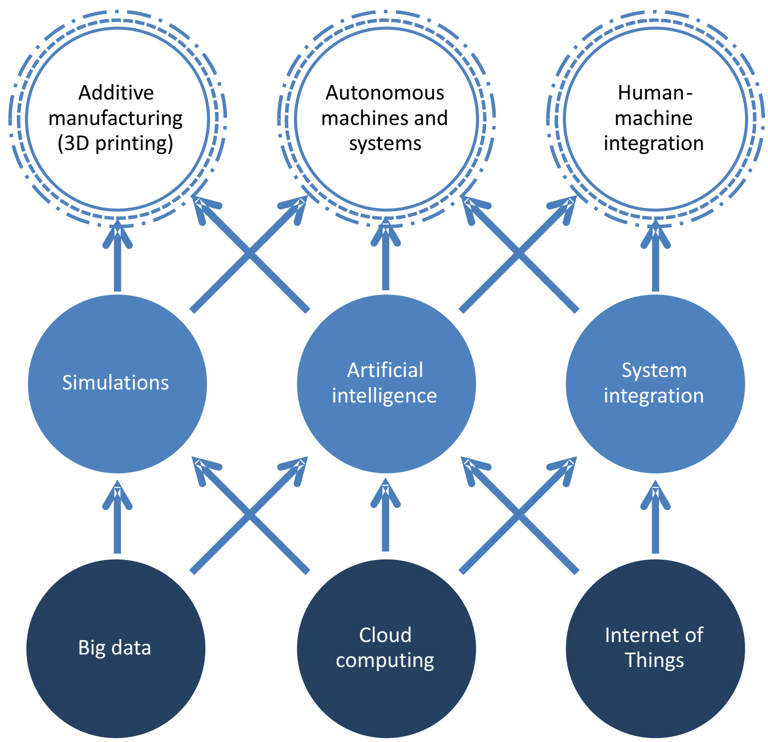
Source: OECD, based on *www.plattform-i40.de/I40/Redaktion/DE/Anwendungsbeispiele/232-mpdv/beitrag-mpdv.html* (accessed 15 January 2017), Adler, D. et al. (1995), "Does a manufacturing execution system reduce the cost of production for bulk pharmaceuticals?"; Nasarwanji, A. et al. (2009), "The impact of manufacturing execution systems on labor overheads", *www.iaeng.org/publication/WCE2009/WCE2009_pp734-737.pdf*; Strategic Direction (2004), "Meeting the manufacturing challenge: Performance advantage of MES", *http://dx.doi.org/10.1108/02580540410567265*, Snatkin, A. et al. (2013), "Real time production monitoring system in SME", *http://dx.doi.org/10.3176/eng.2013.1.06* and Harris, D. (2017), "Compare manufacturing execution systems (MES): Buyer's Guide", *www.softwareadvice.com/manufacturing/execution-systems-comparison/*.

Quantitative evidence on the economic impact of the digital transformation of industry is limited. But estimates from Japan suggest that the use of big data and analytics in some divisions of Japanese manufacturers could lower maintenance costs by almost JPY 5 trillion (corresponding to more than 15% of sales in 2010). More than JPY 50 billion could also be gained in electricity savings (MIC, 2013). Estimates for Germany indicate that the use of advanced ICTs in industry could boost productivity by 5% to 8%. Industrial component manufacturers and automotive companies are expected to achieve the biggest productivity improvements (Rüssmann et al., 2015). Other estimates suggest that "Industry 4.0" could boost value-added in Germany's mechanical, electrical, automotive, chemical, agriculture and ICT sectors by an additional EUR 78 billion (or 15%) by 2025 (BITKOM and Fraunhofer, 2014).[3]

The confluence of digital technologies drives the transformation of industrial production

Two major trends make digital technologies transformational for industrial production: the reduction of the cost of these technologies, enabling their wider diffusion, including to SMEs; and, most importantly, the combination of digital technologies, enabling new types of applications. Figure 2.3 depicts the key ICTs which are enabling the digital transformation of industrial production.[4] The technologies at the bottom of Figure 2.3 enable those at the top, as indicated by the arrows. The technologies at the top of Figure 2.3 (in white), which include additive manufacturing (i.e. 3D printing), autonomous machines and systems, and human-machine integration, are the applications through which the main productivity effects in industry are likely to unfold. In combination, these technologies could one day lead to fully automated production processes, from design to delivery (Box 2.2). The technologies in Figure 2.3, and their applications, are discussed in the following paragraphs.

Figure 2.3. **The confluence of key technologies enabling the industrial digital transformation**



Box 2.2. **A possible manufacturing process in 2025**

In the near future, possibly as early as 2025, manufacturing could become an almost completely autonomous activity. Present-day capabilities suggest that the following hypothetical scenario could be feasible:

A group of designers have created a new device. They show 3D-printed prototypes to potential buyers and, as a result, receive a contract from an overseas retailer. The design, packaging and component list is uploaded to an online marketplace where manufacturers compete for the contracts to create the parts and assemble the device. One contractor wins the contract to assemble the device. This contractor uses cloud-based computer-aided design tools to simulate the design and manufacturing of the device. Machine-learning algorithms test which combination of robots and tools is the most efficient in assembling the device. Some components, such as systems-on-a-chip and sensors, can be sourced from existing manufacturers. Others might have to be specifically created. Robotic devices execute mass production of the components.

All the components and the associated data are then sent to the assembly facility. On the assembly line, the robots in the line retool and arrange themselves. Robotic vehicles move the components across the floor to the correct robot workstations and the robots start to assemble the devices. Every time the robots assemble a device, machine-learning algorithms in the cloud analyse the data and compare these to the simulations, resimulating and establishing whether the process still fits the parameters and whether the process can be optimised. The finished product is boxed by a robot, and the box loaded by another robot onto a self-driving truck, which takes it to the retailer.

Box 2.2. **A possible manufacturing process in 2025** *(cont.)*

At the retailer, robots unload the truck and place the product in the correct warehouse storage location. When the product is ordered, a smaller delivery robot transports it to the customer's front-door. If sales of the product exceed expectations and orders increase from around the world, the designers might need more production capacity. They again turn to the market, with manufacturers in the regions where the product has been ordered competing to produce larger or smaller batches of the product. The results of the earlier machine-learning algorithms are communicated to the successful factories around the world, where different robots assess how to manufacture the product. When a factory has finished producing its order, the robots reorganise and retool for a different product. From the moment the design is finalised, until the product arrives to the customer, no worker has been employed to manufacture the device. Employees monitored the process. However, neither in the plastics moulding, nor the assembly, nor the logistics were humans necessary.

Big-data analytics are transforming all sectors of the economy including traditional sectors

The term "big data" refers to data characterised by their volume, velocity (the speed at which they are generated, accessed, processed and analysed) and variety (such as unstructured and structured data). However, volume, velocity and variety (the three Vs highlighted as the characteristic of big data) are in continuous flux, as they describe technical properties that evolve with the state-of-the-art in data storage and processing. Others have also suggested a fourth V, for value, which is related to the increasing social and economic value of data (OECD 2013).

The use of big data promises to significantly improve products, processes, organisational methods and markets, a phenomenon referred to as data-driven innovation (DDI) (OECD, 2015b). In manufacturing, data obtained through sensors are used to monitor and analyse the efficiency of machines to optimise their operations and to provide after-sale services, including preventative maintenance. The data are sometimes also used to work with suppliers, and are, in some cases, even commercialised in the form of new services (for example, to optimise production control). In agriculture, geocoded maps of fields and real-time monitoring of every agricultural activity, from seeding to harvesting, are used to raise agricultural productivity. The same sensor data can then be reused and linked with historical and real-time data on weather patterns, soil conditions, fertiliser usage and crop features, to optimise and predict agricultural production. Traditional cultivation methods can be improved and the know-how of skilled farmers formalised and made widely available.

There is still little macroeconomic evidence on the effects of DDI, but available firm-level studies suggest that using DDI raises labour productivity faster than in non-using firms by approximately 5% to 10% (OECD, 2015b). In the United States, Brynjolfsson, Hitt and Kim (2011) estimate that output and productivity in firms that adopt data-driven decision making are 5% to 6% higher than what would be expected given their other investments in, and use of, ICTs. These firms also perform better in terms of asset utilisation, return on equity and market value. A study of 500 firms in the United Kingdom found that firms in the top quartile of online data use are 13% more productive than those in the bottom quartile (Bakhshi, Bravo-Biosca and Mateos-Garcia, 2014). Barua, Mani and Mukherjee (2013) suggest that improving data quality and access by 10% – presenting data more concisely and consistently across platforms and allowing it to be more easily manipulated – would increase labour productivity by 14% on average, but with significant cross-industry variations.[5] Nevertheless, big data is still mainly used in the ICT sector, particularly in Internet services firms. According to Tambe (2014), for example, only 30% of Hadoop investments come from non-ICT sectors, including, in particular, in finance, transportation, utilities, retail, health care, pharmaceuticals and biotechnology firms. But manufacturing is becoming increasingly data-intensive (see McKinsey Global Institute [2011]).

In agriculture, the use of data and analytics (i.e. precision agriculture) provides productivity gains by optimising the use of agriculture-related resources. These include, but are not limited to, savings on seed, fertiliser and irrigation as well as farmers' savings in time (Box 2.3). Depending on the savings considered, estimates of the productivity effect vary. One estimate, for example, suggests that in farming corn in the United States, precision agriculture could improve yields by 5 to 10 bushels per acre, increasing profit by around USD 100 per acre (at a time when gross revenue minus non-land costs stood at about USD 350 per acre) (Noyes, 2014). Extrapolating, one could estimate economic benefits for the United States from precision agriculture to be around USD 12 billion annually. This represents about 7% of the total value-added of USD 177 billion contributed by farms to the GDP of the United States.[6] When excluding farmers' savings in time, more modest benefits per acre from precision farming have been estimated. Schimmelpfennig and Ebel (2016), for example, presented an estimate of increased profits of USD 14.50 per acre. A similar study by Professor Craig Smith of Fort Hays State University, Kansas, focused on the same sources of increased efficiency from precision agriculture for different size farms.[7] This work focused on precision agriculture's "automatic row and section control, which uses a global positioning system (GPS) to prevent excess application of crop inputs, such as fertilizer and crop protection chemicals." (John Deere, 2015). Farmers' cost savings for the corn fields, similar to the large-row-crop farms, evaluated above, were from USD 1 to USD 15 an acre.

Box 2.3. **Precision agriculture with big data: The case of John Deere**

Precision agriculture provides farmers with near real-time analysis of key data about their fields. John Deere entered this business, initially with yield mapping and simple variable rate controls, and later with automated guidance technology (AutoTrac[1]). Those early products have since been enhanced by creating automated farm vehicles that communicate with each other. From the beginning, John Deere built on GPS location data. It then developed initial "wired" capabilities to connect farm machines to each other and to the MyJohnDeere (MJD) Operations Center, which is described by the company as "a set of online tools that provides information about a farm, when and where farmers need it." (Arthur, 2016).

To support vehicles in the field, John Deere developed remote wireless management for farm equipment. It used interconnected satellite and cellular ground-based communications networks, proprietary radio and Wi-Fi. This helped Deere reduce the time to harvest crops or complete other tasks. For example, its self-propelled, programmable vehicles could plant or harvest about 500 to 600 acres a day when used in groups of two or more vehicles, rather than the usual 100 to 150 acres that a single farmer could do alone. One enhancement Deere introduced for planting was to use its Exact-Emerge planter and AutoTrac to expand the number of acres that could be planted under optimal conditions. With the enhanced planter and tracking system, the number of acres planted could increase from 600 to more than 800 per day. For harvesting, operations would also be much more efficient if the vehicles used incorporated AutoTrac.

Box 2.3. **Precision agriculture with big data: The case of John Deere** *(cont.)*

Utilising a combination of sensors and GPS, Deere's tractors not only drive themselves, they also utilise analytic systems. These systems permit vehicles to do planting, watering and harvesting with accuracy to two centimetres. These systems can also communicate with each other. Deere has estimated that it has more than 100 000 connected machines around the world. Tractor cabs also offer Wi-Fi communication with mobile and other on-board sensor systems, as well as other radios for mobile communications with other vehicles. This helps farmers synchronise operations and share data with other farmers.

Using the interconnected devices and smart sensors in this communications network, John Deere combined basic and performance data from its machines with in-field, geo-referenced data to enhance data analytics. Once systems capture these combined data and send them to Deere's Operations Center, they are incorporated into a more extensive database that also includes environmental information. Deere can combine information from the farmer with data about the environmental condition (including weather and climate data and data about the soil quality) as well as data about real yields. This helps farmers identify the sections of their land that are more productive. John Deere's use of data analytics helps farmers optimise crop yield, because "farmers can use the data to decide what and where each piece of equipment will plant, fertilise, spray and harvest … for an area as small as one by three metres." (Jahangir Mohammed, 2014).

In 2011, John Deere cemented its long-term strategy to focus on integrated data-driven products. The new focus also emphasised an increase in research and development (R&D) investments to 5.5% of net sales, compared to its competitors' R&D investments of 4% to 5%. The focus on innovation helped Deere continue the 5% compound annual growth rate for employee productivity (measured by sales per employee) achieved over the past 30 years (Deere & Company, 2016). To buttress its capabilities in this area, John Deere also acquired a number of companies that have pioneered precision agriculture, such as Precision Planting (Agweb, 2015), a leading planting technology firm that also supplies hardware and sensors, and Monosem, a France-based planter equipment manufacturer. John Deere is also hiring data scientists to improve its ability to analyse big data. These professionals will:

- Identify relevant data, sources and applications.
- Utilise big-data mining techniques such as pattern detection, graph analysis, and statistical analyses to "discover hidden insights".
- Implement collection processes as well as develop infrastructure and frameworks to support analyses.
- Use parallel computation languages to implement applications.

Substantial market growth is forecast for John Deere and similar firms offering farmers self-propelled vehicles and precision agriculture systems. Such forecasts predict that the global precision farming market will expand by USD 4.92 billion by 2020. This represents a compound annual growth rate (CAGR) of almost 12% between 2015 and 2020. At the present time, precision farming globally represents a USD 2.8 billion market (Mordor Intelligence, 2016). The US market accounts for roughly USD 1 billion to USD 1.2 billion of these sales annually. Using estimates for the large-row-crop, corn and soybean farms, where about two-thirds of acreage is subject to precision agriculture, it is conservatively estimated that John Deere's sales of precision agriculture are about one-quarter of the United States market total, or USD 250 million to USD 350 million.[2]

Box 2.3. **Precision agriculture with big data: The case of John Deere** *(cont.)*

1. AutoTrac Vision uses a front-mounted camera to see early-season corn, soybeans and cotton at least four to six inches high. It helps farmers avoid damaging crops with sprayer wheels even the planter is misaligned (John Deere, 2017).
2. According to a market forecast, this market would include a number of technologies that are integrated, essentially guidance systems, remote sensing and Variable Rate Technologies. The largest would be guidance systems with GPS, geographic information systems (GIS) and global navigation satellite systems (GNSS) systems, etc. The market forecast finds that various monitoring and mapping systems would be more important and that software applications, i.e. those applications for crop, farm and weather management, would grow faster during the forecast period (see Mordor Intelligence [2016]).

Cloud computing enhances the agility, scalability, and interoperability of businesses

Cloud computing allows computing resources to be accessed in a flexible on-demand way with low management effort (OECD, 2014a).[8] Many high-potential industrial applications, such as autonomous machines and systems, and complex simulation, are very computationally intensive and therefore require supercomputers. Cloud computing has played a significant role in increasing the availability and capacity, and lowering the cost, of highly scalable computing resources, in particular for start-ups and SMEs. This is because cloud computing services can be easily scaled up or down, be used on demand, and paid for either per user or by capacity used. Cloud computing services can take the form of software (software-as-a-service [SaaS]) or be extended to platforms (platform-as-a-service [PaaS]) or infrastructure (infrastructure-as-a-service), and may be deployed privately (for exclusive use), publicly (open to the general public), or under a hybrid format (a mix of the two former arrangements).Businesses mainly adopt cloud computing to increase business agility and decrease ICT investment costs. A survey by the cloud computing technology provider VMware (2011) shows that 57% of all respondents point to accelerating the execution of projects and improving customer experience as the most frequent reasons for adopting cloud computing, followed by the ability to rapidly adapt to market opportunities (56%) and the ability to scale costs (55%). In some countries, such as Austria, Iceland, the Netherlands and Norway, however, a large majority of businesses still consider that benefits linked to the reduction of ICT costs are not noticeable, or are limited (OECD, 2015a).

In addition, the ubiquity of cloud computing makes it the ideal platform for data sharing across sites and company boundaries, thereby enabling system integration within organisations (vertical integration) and between organisations (horizontal integration). Today many businesses compete on how well they can combine their goods and services. This highlights not only the emerging importance of the IoT as a platform for integrating physical objects with the Internet (see section below), but also the importance of the cloud as a platform for service integration. Without a platform that integrates data collected from aircraft, for example, a firm such as Boeing would not be able to provide most of its services today (Box 2.4). The company would be unable to compete with large players in its industry sector, such as Airbus, which in fact is making a similar effort, expanding its ability to monitor its aircraft, including the A 380-1000 (Marr, 2015).

Within many organisations, silos still exist today, preventing the sharing of data and thereby creating frictions (cross-organisational) in value chains. According to a survey by The Economist Intelligence Unit (2012), for example, almost 60% of companies consider that organisational silos are the biggest impediment to using big data for effective decision making. Executives in firms with annual revenues exceeding USD 10 billion are more likely to cite data silos as a problem (72%) than those in firms with revenues below USD 500 million (43%).

Box 2.4. **System integration via the cloud: The case of Boeing**

Aircraft manufacturers such as Boeing and Airbus face a challenge today as modern commercial aircraft are becoming smart "flying boxes of electronics". These companies need to be able to evaluate and manage systems on-board their aircraft as well as manage electronic controls and monitor physical features, such as wing flaps, in real time. In addition, the manufacturers need to provide support and maintenance information to the airlines that fly their aircraft, making them simple to repair and minimising time on the ground. To respond to these challenges, aircraft manufacturers integrate their own historical data – data on aircraft performance and maintenance – with data generated by aircraft and product information from suppliers. To do this, integrated databases are needed to support a wide range of services such as: delivering parts as they are needed (material services); optimising fleet performance and operations (how entire fleets of different airlines' planes are managed and operated);[1] giving access to flight services based upon real-time, in-flight data; and supporting information services that provide insights into managing any of these services.

Boeing is beginning to provide products that combine a physical good (an aircraft) and digital (data-driven) services. The move to add a series of new services to its product is related to a broader objective to build a capability to manage and control its production and service systems. There are three changes that characterise Boeing's recent efforts. First, Boeing has employed a combination of big-data analytics and the IoT to manage and evaluate its supplier network.[2] Second, Boeing has deployed a system of interconnected robots and intelligent software on the factory floor (see Boeing [2013a] and Airbus Group [2016]). This complex, interconnected system requires new management skills and also serves as a link to Boeing's suppliers' information systems. Third, Boeing has developed software to manage and analyse the many on-board aircraft systems.

By making these changes, Boeing is able to do almost real-time analysis of sensor information that it receives from planes that are in the air. These analyses support the development of new services for its customers. This is part of Boeing's move to expand the company's focus from aircraft to customer services. In its latest model, the Boeing 787, "146 000 data points are continually monitored by on-board systems and automatically transmitted to the ground" (Boeing, 2013b).

The three changes highlighted above required a digital infrastructure to support the exchange and analysis of data. To achieve this, the firm created a service "platform" named Boeing Edge, through which airlines that use Boeing's planes can access information about the services described above.

In addition, Boeing has put in place a cloud-based computer system, the Digital Aviation Platform, a PaaS that allows application developers to build software from components that are hosted on the platform. The interconnection between airlines' back office systems and the Digital Aviation Platform is enabled by APIs. Such back office systems include schedules, billing or settlements, clearances, record maintenance, regulatory compliance, accounting and information technology (IT) services. They typically manage information on aircraft maintenance, passengers, and flights (Crabbe, 2013).

Boeing has also created a database-as-a-service infrastructure that relies upon Amazon Web Services. This contains over 20 000 databases that describe the parts used throughout planes as well as the instructions for replacing them. These databases are accessible to airlines through a secure connection.

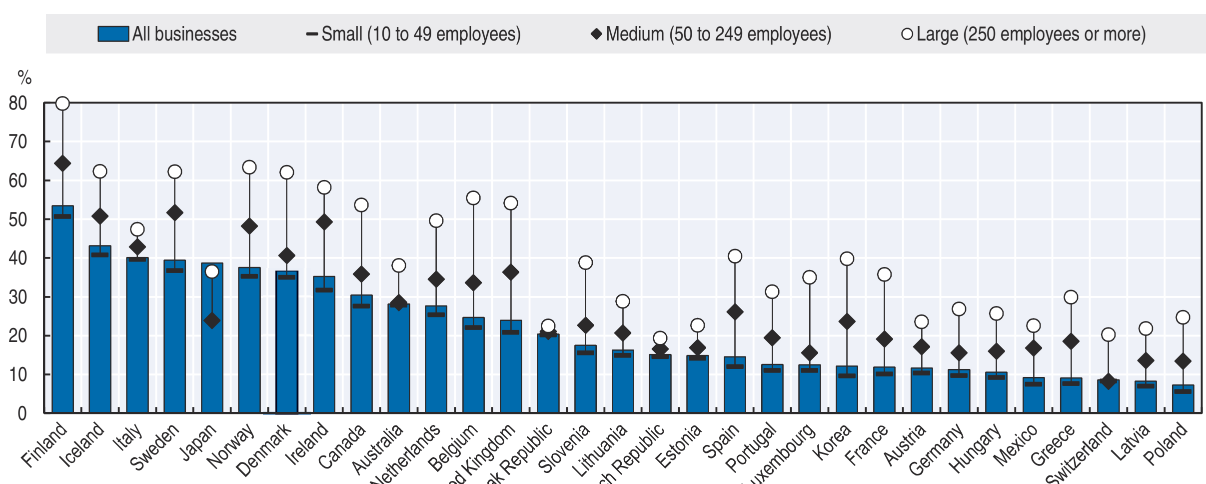
Box 2.4. **System integration via the cloud: The case of Boeing** *(cont.)*

Boeing is also building a Center for Applied Simulation and Analytics (CASA), to create and develop simulation and analytics technologies to evaluate the designs and likely performance of both newly conceived and already operating aircraft.

An effect of the enhanced capacity of Boeing to manage and control its systems is its greater power over its suppliers. In 2015, for example, Boeing influenced mergers of suppliers "by using its power to approve the transfer of its supply contracts from one owner to another … Because of such 'assignability clauses' that give Boeing the right to deny the transfer of existing contracts to a new firm", Boeing can "refuse to transfer the contracts to the new owners, giving it a de facto veto over deals" (Scott, 2015). As data on suppliers' parts is incorporated into Boeing's data analytics systems, Boeing can now exercise even greater influence over its engine and parts supplier base as the use of data analytics gives Boeing greater knowledge of its suppliers' operations. With this greater information asymmetry comes a significant shift in power away from the suppliers in favour of Boeing.

1. While this was previously largely a priority for airlines, Boeing's access to a wide range of information about aircraft performance and management via the IoT has given it a significant role in interpreting real-time data and aircraft performance. This changes its economic role with respect to the airline industry.
2. Boeing implemented a more sophisticated supply chain for its 787 model, but because of problems with suppliers lost billions of dollars in work on the innovative aeroplane (see Denning, 2013).

Figure 2.4. **Percentage of enterprises in each employment size class using cloud computing services in 2014**



Notes: Data for Belgium, Denmark, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Norway, Poland, Slovak Republic, Slovenia, and Spain refer to 2014. Data for Canada and Mexico refer to 2012. Data for Canada only include the use of SaaS, a subcategory of cloud computing services.

Source: Based on OECD (2017b), *OECD.Stat*, database, *http://dotstat.oecd.org/index.aspx?DatasetCode=ICT_BUS* (accessed March 2017).

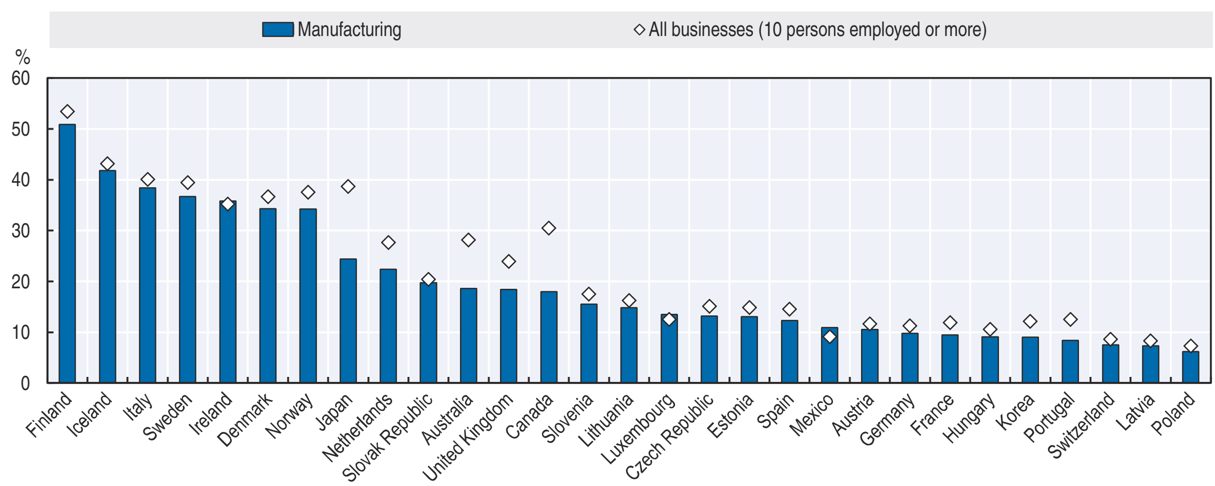
StatLink http://dx.doi.org/10.1787/888933473755

Cloud computing can help to overcome these silos and make organisations more cohesive and automated by enabling data to be stored and accessed from a common data repository in the "cloud" (Rüssmann et al., 2015). This requires the interoperability of cloud computing-enabled services, for example, through accessible application programming interfaces (APIs). However, the lack of appropriate standards and vendor lock-in due to proprietary solutions can be a barrier to the interoperability of these services. This makes the lack of appropriate standards and vendor lock-in the most frequently highlighted barriers to cloud computing adoption besides privacy and security concerns (OECD, 2015a, Chapter 3).

However, significant variation still exists across countries and firm size in its adoption. In countries such as Finland, Israel, Italy, Sweden and Denmark, almost half of all businesses already use cloud computing services, although this percentage is much lower in most other countries (Figure 2.4). There is also large variation in use by business size, with larger enterprises (250 or more employees) more likely to use cloud computing. In the United Kingdom, for example, 21% of all smaller enterprises (10 to 49 employees) use cloud computing services, compared to 54% of larger enterprises. In some countries there is also a notable difference in adoption of the cloud in manufacturing and its adoption in the rest of the economy (Figure 2.5).

Figure 2.5. **Share of manufacturing firms using cloud computing services by country, 2015**

%



Notes: Data for Australia, Austria, the Czech Republic, Estonia, France, Germany, Iceland, Italy, Luxembourg, the Netherlands, Portugal, Sweden, and the United Kingdom refer to 2014. Data for Korea refer to 2013. Data for Canada, Japan, and Mexico refer to 2012. Data for Switzerland refer to 2011. Data for Canada refer to the use of SaaS, a subcategory of cloud computing services.
Source: OECD (2016f), *OECD.Stat*, database, *http://dotstat.oecd.org/index.aspx?DatasetCode=ICT_BUS* (accessed September 2016).

StatLink *http://dx.doi.org/10.1787/888933473767*

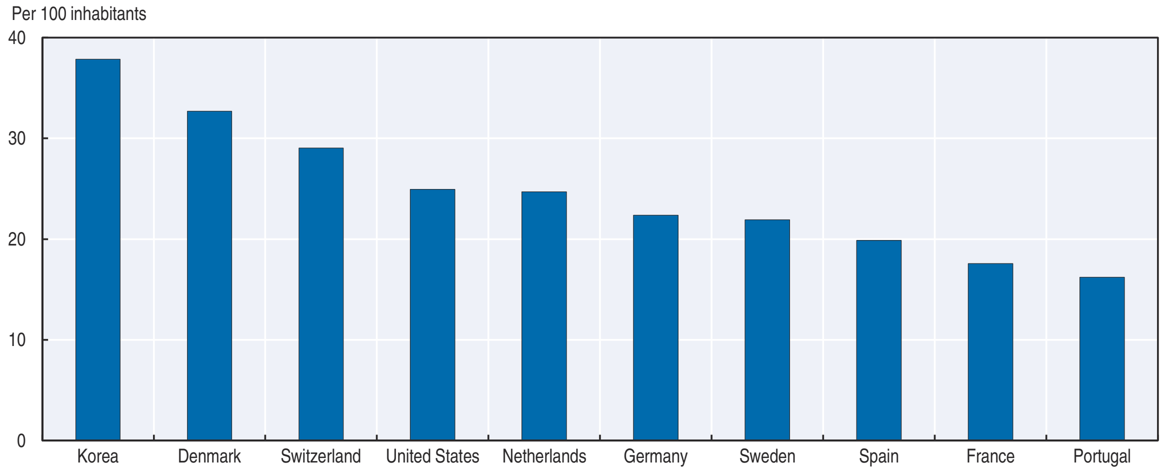
The IoT is a game changer

The IoT is a term referring to the connection of devices and objects to the Internet's network of (public and private) networks. Among the interconnected objects, the IoT also includes sensors and actuators, which in combination with big-data analysis and cloud computing enable autonomous machines and intelligent systems.

Measurement of the number of IoT devices connected to the Internet has proven hard to obtain, with countries only now starting to collect data. But one source (Shodan, the world's first search engine for Internet-connected devices) finds 363 million devices online with some 84 million registered to the People's Republic of China (hereafter "China") and 78 million to the United States. Korea, Brazil and Germany follow with 18 million connected devices, and Japan, Spain, the United Kingdom and Mexico make up the rest of the top ten countries, with 8 million to 10 million devices each. Efforts to rank devices per capita are hindered by data limitations, but the top ten is shown in Figure 2.6.

Figure 2.6. **IoT devices online, top OECD countries**

Per 100 inhabitants



Source: OECD (2015a), *OECD Digital Economy Outlook 2015*, *http://dx.doi.org/10.1787/888933225312*, based on Shodan, *www.shodanhq.com*.

StatLink http://dx.doi.org/10.1787/888933473770

Available estimates suggest that the IoT could contribute USD 10 trillion to USD 15 trillion to global GDP over the next 20 years (Evans and Anninziata, 2012). Equipping machines with sensors could allow efficiency-enhancing predictive maintenance. A 1% efficiency increase in the aviation industry could, for example, save commercial airlines globally USD 2 billion per year (Evans and Anninziata, 2012). According to Vodafone (2015), adopting the IoT brings average cost savings for industry of 18%, and nearly 10% of IoT adopters have reduced their costs by over 25%. Apart from cost savings, companies cite other areas of identified improvement, including: process efficiency; customer service, speed and agility of decision making; consistency of delivery across markets; transparency/predictability of costs; and performance in new markets (Vodafone, 2015). For example, the use of big-data analytics in combination with the IoT, has enabled a major US automaker to save about USD 2 billion over the last four to five years (Box 2.5). These economies mainly come from optimising supply chains. In addition, the company uses simulations based on big data to optimise truck design so that fuel efficiency is improved and production costs are reduced.[9] The IoT will also give rise to many economic and social benefits not directly related to production, e.g. in health, in the use of smart meters and in the efficiency of vehicle usage.[10]

Box 2.5. **The IoT, big data, and cloud computing used by a major US automaker**

A US automaker has saved around USD 2 billion in costs over the past five years (2011-14 and most of 2015) by developing a significant IoT and data analytics capability. It did this to provide insights into its vehicles' designs, estimating e.g. by how much using aluminium would improve fuel efficiency before a new truck design was put into production. The largest savings were from changes in the automaker's supply chain and increased efficiency in dealerships.

There are two main areas where this automaker has achieved substantial benefits. First, controlling its supply chain better. Second, using data analytics to improve the selection of vehicles, colours and features that dealers will offer to customers.

Box 2.5. **The IoT, big data, and cloud computing used by a major US automaker** *(cont.)*

For its supply chain, it is assumed that parts constitute about one-third to one-half of the value of a vehicle costing USD 30 000. It is also assumed that the firm can reduce costs in its supply chain by about 1% to 1.5% a year by using data analytics (based upon studies of other firms). This assumes that the firm sells USD 20 billion worth of vehicles in the United States annually. This would result in a savings of USD 200 million to USD 300 million a year, or USD 1 billion to USD 1.5 billion over five years. In terms of improving the selection of cars sent to dealers, one measurable gain would come from optimising inventories by reducing the time cars spend on dealer lots. This might represent around USD 50 to USD 100 per car for about 2 million cars a year, or USD 500 million to USD 1 billion over five years. Overall these savings would lead to a total saving of USD 1.5 billion to up to USD 2.5 billion in cost savings over five years.

The investments required to achieve these cost savings were estimated to be between USD 350 million and USD 500 million over five years. It is assumed that this major US automaker used 200 employees in the digital analytics group and that these people were paid about USD 150 000 to USD 200 000 per year on average (this estimate is on the high side because some specialists have incomes of more than USD 300 000 or more a year) with all expenses rolled in. This would sum to a USD 30 million to USD 40 million annual cost, or about USD 150 million to USD 200 million over five years. If it is further assumed that the costs of the software and hardware for data analytics are about the same magnitude or possibly slightly larger, the cost of setting up the automaker's software-defined architecture to support data analytics and create an (internal) IoT would be about USD 200 million to USD 300 million over five years. Overall, this would represent roughly a USD 2 billion return on an investment (ROI) of USD 350 million to USD 500 million over five years, or a ROI of 300% to 470%.

Estimates of how the firm's move into the IoT is likely to impact its financial performance show that the biggest area for savings is likely to come from the firm's efforts to control costs in its supply chain. The firm has already consolidated production on a single platform to reduce the number of parts it needs in a car. With a more sophisticated analytic system, it should be able to achieve additional savings. The automaker is also studying how to link more vehicles with on-board sensor platforms to its cloud. It is experimenting with sensors to help drivers improve their performance. For electronic cars, there is already an Internet-based system that ties into mobile devices. This tells a driver whether the car's battery is charged. The system can also identify nearby charging locations. The firm has not estimated the size of this benefit, nor has it forecast how much it might expand if there is a larger fleet of electrically powered cars in the future.

Currently, the firm's electric vehicles generate about 25 petabytes[1] of data an hour. So the firm expects there will be about 100 times more data than this per car from new satellite technologies which could be introduced over the next two to three years. In addition, the firm's sensors in plants, on factory floors and in research programmes generate a lot of data. The automaker sees the vehicle as a "closed-loop control system". This might result in the firm receiving exabytes[2] of additional data from new systems in tens of millions of vehicles, or zettabytes of data per year by 2019-20. This would be a remarkable rate of growth of over 250% per year, and would raise some big challenges in terms of data management.

1. 1 petabyte = 1 million gigabytes.
2. 1 exabyte = billion gigabytes.

The IoT, together with big data and cloud computing, are the main reasons for the sudden breakthrough in artificial intelligence (AI) applications, like driverless cars. The IoT embeds physical objects in information flows and thereby makes them "smarter". With driverless cars, for example, the road infrastructure, other cars, and web services (such as online maps) tell a car what it needs to know.[11] In this way, it is not necessary to equip a car with image processing systems comparable to human vision for the car to be able to drive on its own, as was previously assumed. Similarly, when all the devices and machines in a factory can supply information, many new robotics applications become possible.

The digital transformation of production is highly disruptive

The use of digital technology often induces the "creative destruction" of established businesses, markets and value networks. This can be particularly challenging for (traditional) businesses, where the competitive environment may discourage investments in disruptive innovation in the short run. This is often the case for two reasons: first, investments in disruptive innovation can take scarce resources away from sustaining the most profitable business units (which are needed to compete against current competition); and second, disruptive innovation is often highly risky given that it may not be profitable in the short run. Disruptive innovation may require substantial changes in organisational structures, business processes or even business models that involve sunk costs (that cannot be recovered).[12] In addition to economic factors, these changes may also be hard to implement in light of internal resistance due to the organisational culture and psychological resistance among management and their employees. Christensen (1997) refers to this challenge as the innovator's dilemma, where successful companies put too much emphasis on current success, and thus fail to innovate in the long run.

The fear of change and disruption combined with short-term thinking in traditional established businesses means that digital innovation is introduced more frequently by ICT firms, and in particular start-ups (see OECD [2015b]). As shown by Criscuolo, Nicolaou and Salter (2012), new technologies and innovations are often first commercialised through start-up companies because they can leverage the advantage of starting without the legacy of an existing business and customer base and thus can create a variety of presumably new business models. Christensen (1997) also argues, controversially, that disruptive innovations are often not valued by existing customers at first. As a consequence, incumbents, which tend to be most responsive to their main customer base, may ignore the markets most susceptible to disruptive innovation, even if they invest heavily in research.

For traditional businesses this means that they will face a more complex competitive landscape where they will "be forced to compete simultaneously on multiple fronts and co-operate with competitors" (Gao et al., 2016).[13] The competitors may include ICT firms such as Alphabet (Google) and Apple, which have competitive advantages in digital technologies. The creation of new business models which could disrupt established industries may be necessary. As a consequence, traditional businesses may have to rethink their business models to stay competitive in the long run.

New business models are characterised by an emphasis on high value-added services

As goods become commodities with low profit margins, many manufacturing firms are developing new complementary services that extend their current business propositions. Rolls-Royce, for example, shifted its business from a product, time and service solution to a service model trademarked as "Power by the Hour" (PBH) (Box 2.6). Digitalisation has been a key enabler for this transformation towards higher value-added (complementary) services.

Box 2.6. **The "servicification" of manufacturing: The case of Rolls-Royce's "Power by the Hour" (PBH)**

Rolls-Royce shifted its business from a product, time and service solution to a service model trademarked as "Power by the Hour" (PBH).[1] With PBH, customers pay only for the time they use an engine. Rolls-Royce could do this only by being able to collect large amounts of data from the sensor networks it installed on engines.

Rolls-Royce's service model evolved through three steps. First, it developed ways to use the data from sensor networks to manage its own service operations. Second, it enhanced the model by more directly managing the services and support for clients. Third, it was able to make large amounts of data more generic across many different customers, optimising its entire data ecosystem. This has enabled Rolls-Royce's service model to become proactive, with the aim of minimising, or eliminating, disruptions caused to its customers (Frank-Partners YouTube channel, July 2016).

This new business model changed from product and sales support to a services business. It insured that Rolls-Royce captured its aftermarket service business rather than permitting third parties to create parts to service its aircraft engines. The new business model also meant that the risks of using an engine were more equitably distributed between the supplier and the customer.

Rolls-Royce started this approach by integrating its customers very closely within its own operations. It began by working closely with American Airlines to create the Total Care solution focusing on the customer's end-to-end needs. This led to the creation of Operations Centres where Rolls-Royce's engineers oversee the day-to-day management of a customer's fleet. In many cases, these centres are embedded within a customer's operations, beginning with closely linked operations in the defence industry in the United Kingdom (Frank-Partners YouTube channel, July 2016).

Rolls-Royce now focuses on "zero-based disruption" for its customers. To achieve this, Rolls-Royce does sophisticated modelling of the solutions it offers customers. It does this on a product basis as well as for customer fleets. This shift of focus to prognostics means actively taking data off engines and aggregating the data to understand how the entire fleet works. Rolls-Royce can then aggregate the data across customers to gain an overview of how data is used. In the future, Rolls-Royce will also focus on dispatch availability, ensuring that when an aircraft rolls onto a runway, it has the highest chance of taking off without problems originating from its engines.

Rolls-Royce's new service model provides two ways of improving the firm's performance:

- **Rolls-Royce can reduce the costs of scheduled repairs by cutting maintenance costs and preventing breakdowns, thereby lengthening the time that an engine can stay on the wing. This increases its service revenues.** One of the US national laboratories has estimated that "Predictive maintenance of assets [can save] up to 12 % over scheduled repairs, reducing overall maintenance costs up to 30 % and eliminating breakdowns up to 70 %." (Sullivan et al. [2010]; cited in Daugherty et al. [2015]). If Rolls-Royce's savings are on this scale, based upon fiscal year 2014 revenues, it could be saving 12% on its cost to provide services. These cost savings might range from USD 400 million to USD 600 million. Rolls-Royce not only extends the expected lifetime of an engine, it also collects additional income from the services to support an engine. It does this by extending the life of an engine from the usual four to six years to six to eight years. This would permit Rolls-Royce to increase revenues on services for both its civilian and defence aerospace operations. This could mean increasing earnings of service revenues by 15% to 20 % per year.

Box 2.6. **The "servicification" of manufacturing: The case of Rolls-Royce's "Power by the Hour" (PBH)** *(cont.)*

Based on fiscal year 2014 revenues, this would be an additional USD 1.0 billion to USD 1.35 billion annually. So, the total annual benefit from the new service model could be more than USD 1.4 billion to USD 1.95 billion.

- **Rolls-Royce can provide a form of service assurance to its customers when it provides dispatch availability and "zero-based disruption":** By reducing disruptions to its customers' ability to operate, Rolls-Royce is adding performance assurance to the usual services it offers through its Operations Centres and Business Centres. However, it is difficult to estimate this type of economic impact stemming from zero-based disruption.[2]

1. With Power by the Hour, "Customers and suppliers of mission-critical products, such as semiconductor manufacturing equipment, commercial aircraft and military weapon systems, are recognising that the acquisition of world-class products is not sufficient, but rather it is necessary to provide superior, cost-effective maintenance and support services throughout the after-sales phase of the customer-supplier relationship. A major focus of these efforts involves re-designing the contractual and implicit relationships between customers and suppliers in the service support supply chain." (Knowledge@Wharton, 2007).
2. Information on the economic value of "zero-based disruption" is not available. A case study of FANUC's zero downtime efforts suggests that it might reduce General Motor's downtime and save General Motors USD 40 million per year (see Roboglobal, [2016] and Cisco [2016]).

Historically, the digital transformation of business models was first enabled by the formalisation and codification of business-related activities, which led to the computerisation of business processes via software. This has "enabled firms to more rapidly replicate improved business processes throughout an organisation, thereby not only increasing productivity but also market share and market value". Brynjolfsson et al. (2008) have referred to this phenomenon as scaling without mass. Internet firms pushed the digital transformation to a new level. This enabled them to better scale without mass, when compared to the rest of the economy.[14]

The business models of the most successful Internet firms today go beyond the formalisation and codification of processes via software, and now involve the collection and analysis of large streams of data (OECD, 2015b). By collecting and analysing big data, a large share of which is provided by Internet users (consumers), Internet companies are able to automate their processes and to experiment with, and foster, new products and business models at a much faster rate than the rest of industry. Instead of relying on the (explicit) formulation and codification of business processes, these firms use big data to "train" AI algorithms to perform more complex business processes without human intervention. Innovation enabled by AI is now used to transform business processes across the economy. Thanks to the convergence of ICTs with other technologies (owing in particular to embedded software and the IoT), the digital transformation has the potential to affect even traditional sectors such as manufacturing and agriculture.

The analysis of successful digital business models suggests that actions that take advantage of the applications mentioned above can digitally transform traditional businesses. These actions include:

- **The digitisation of physical assets**, which refers to the process of encoding information into binary digits (i.e. bits) so that it can be processed by computers (OECD, 2015b). This is one of the most straightforward steps to digitally transform businesses. An early example is the entertainment and content industry, where books, music, and videos were digitised to be provided over the Internet. Thanks to the deployment of 3D scanners and 3D printing, digitisation is no more limited to content, but can now include real-life objects. 3D printing promises, for example, to shorten industrial design processes, owing to rapid prototyping, and in some cases raise productivity by reducing material waste (see Chapter 5). Boeing, for example, has already replaced machining with 3D printing for over 20 000 units of 300 distinct parts (Davidson, 2012).

- **The "datafication" of business-relevant processes,** which refers to data generation, not only through the digitisation of content, but through the monitoring of activities, including real-world (offline) activities and phenomena through sensors. "Datafication" is a portmanteau term for "data" and "quantification" and should not be confused with "digitisation", which is just the conversion of analogue source material into a numerical format (OECD, 2015b).[15] Datafication is used by many platforms which monitor the activities of their users. And with the IoT, this approach is no longer limited to Internet firms. For example, data collected on agricultural machines, such as those made by Monsanto, John Deere and DuPont Pioneer, are being used as an important data source for optimising the distribution and genetic modification of crops (GMC) (Boxes 2.3 and 2.6).
- **The interconnection of physical objects via the IoT** enables product and process innovation. Scania AB, a major Swedish manufacturer of commercial vehicles, now generates one-sixth of its revenues through new services enabled by the wireless communication built into its vehicles (Box 2.7). This allows the company to transition towards a firm increasingly specialised in logistics, repair and other services. For example, with the interconnection of its vehicles, Scania can better offer fleet management services. The interconnection of physical objects also enables the generation and analysis of big data, which can be used for the creation of more services: for example, Scania offers a set of services to increase driving (and therefore resource) efficiency, such as data-based driver coaches.
- **The codification and automation of business-relevant processes via software and AI.** software has enabled and incentivised businesses to standardise their processes, and where processes are not central to the business model, to sell the codified processes via software to other businesses. An example is IBM's Global Expenses Reporting Solutions, which were originally developed to automate the company's internal travel-related reporting. IBM turned the in-house system into a service, which it has sold globally (Parmar et al., 2014). Another example is Google's Gmail. This was originally an in-house e-mail system, before it was announced to the public as a limited beta release in April 2004 (McCracken, 2014).

Box 2.7. **Co-operation or competition: The case of Scania's Connected Vehicles**

Scania AB, a major Swedish manufacturer of commercial vehicles, is increasingly using its so-called "communicator" to collect data to monitor and analyse the efficiency of its vehicles. Scania aims to increase the share of its services sales to 25% to 30% of total sales by 2020. Scania's services have traditionally comprised technical and financial services, but are increasingly shifting towards various connected services. The company intends around one-sixth of its sales in the product service area to be connected services by 2020.

There are several reasons why Scania has chosen to put more emphasis on services. Since service sales are not affected by economic fluctuations in the same way as sales of newly produced vehicles, the company has an ambition to create a better balance in the company's sales over the business cycle. Scania also sees conversion to services as a way

Box 2.7. **Co-operation or competition: The case of Scania's Connected Vehicles** *(cont.)*

of increasing sales by creating new services that meet changing customer demands in the transport sector. The combination of services and vehicles also makes it possible for Scania to more clearly create its own niche in the market for heavy vehicles. In this area, Scania wants to strive for its connected vehicles to work smoothly in transport companies with fleets containing vehicles from different manufacturers.

According to Scania, the industry trend is towards transport companies specialising in logistics, but outsourcing repairs and other services. The relationships between Scania and its customers are also shifting to more of a partnership, where the parties jointly work to develop and optimise the profitability of vehicles and thus to improve the customers' profitability. To do this, it is important for product development towards more sustainable, safe and efficient vehicles to take place in co-operation with customers. Using various (digital) services, Scania aims to influence both the customers' costs and revenues. On the cost side, this may involve more efficient fuel consumption or service programmes. On the revenue side, the primary profitability factor is the actual time the vehicle is available for transport work.

The developments towards connected vehicles create a need for access to new cutting-edge expertise and capacities. This means that vehicle manufacturers such as Scania need to enter new kinds of partnerships with ICT companies. At the same time, this development also opens up new competition from ICT and other kinds of companies that see opportunities to take over parts of the value chain in the transport industry. Furthermore, other stakeholders, such as insurance companies and suppliers of automobile components, also see new business opportunities, for example from having better access to vehicles' sensor data.

For automotive industry firms such as Scania, a crucial issue is therefore where in the mobility value chain the major value will be generated in the future and how today's technical developments affect this. Scania has chosen to move towards greater delivery of services that meet changing customer needs in transportation. At the same time, market developments have made it more difficult for Scania to take payment for certain services that were previously a strategic part of its product portfolio. One example is the support for the management of a transport company's vehicle fleet, so-called "fleet management services". Over time, fleet management services have been standardised, and today there are many third-party suppliers that put pressure on prices.

Finally, Scania also faces a number of challenges that are directly affected by public policies. For example, the company increasingly relies on an excellent mobile network infrastructure. Given that Scania does not own communication networks, it must instead join roaming partnerships with global telecommunication operators to guarantee that its digital services work.

Last, but not least, the transition towards driverless vehicles, which Scania foresees occurring in the next 5 to 25 years, raises new challenges related to issues of liability tied to traffic safety that are difficult to anticipate legally.

- **The trading of data** (**as a service**) is made possible as soon as physical assets have been digitised or processes "datafied" (see bullet above on "datafication"). Data generated as a by-product of doing business can have huge value for other businesses (including in other sectors). The French mobile communication services firm, Orange, uses its Floating Mobile Data (FMD) technology to collect mobile telephone traffic data that are anonymised and sold to third parties, including government agencies and traffic information service providers. In addition, businesses can take advantage of the non-rivalrous nature of data to create multi-sided markets, where activities on one side of the market go hand in hand with the collection of data, which is exploited and used on the other side of the market. Very often, however, it will be difficult to anticipate the value that data will bring to third parties. This has encouraged some businesses to move more towards open data (see OECD, 2015b).

- **The (re-)use and linkage of data within and across industries** (i.e. data mashups) has become a business opportunity for firms that play a central role in their supply chain. Walmart and Dell have successfully integrated data across their supply chains. But as manufacturing becomes smarter, thanks to the IoT and data analytics, this approach is becoming attractive to manufacturing companies as well. Sensor data, for example, can be used to monitor and analyse the efficiency of products, to optimise operations at a system-wide level, and for after-sale services, including preventative maintenance operations (see the example of Schmitz Cargobull discussed earlier).

The competitive landscape is becoming more complex with co-opetition becoming the new default

The increasing importance of ICTs such as big-data analytics, the IoT, and AI gives companies that can take advantage of these technologies a significant competitive advantage. ICT firms able to extend the scope of their businesses to other sectors can have an advantageous starting position. For established (traditional) businesses, however, the situation is challenging: they not only need to better understand how to best use ICTs, they also have to forge new partnerships with ICT firms to gain the necessary technical capabilities.

Some traditional businesses have decided to acquire promising ICT start-ups (for example John Deere acquiring Precision Planting), while others have started to co-operate with ICT firms, which however, could rapidly become competitors (Box 2.7). This slightly ambiguous relationship between co-operation and competition has been referred to in the literature as "co-opetition".

The complexity of the competitive landscape can be observed in the automobile industry, where traditional automotive firms not only compete with their direct competitors, including new entrants such as Tesla, but increasingly compete with ICT firms such as Apple, Alphabet (Google) and Uber Technologies (Uber), to name a few. This profound change in the competitive landscape is driven by a number of social and technological trends. Among these trends, the following three are seen as the most important in the automobile sector:

- **The increasing degree to which ICTs, in particular software, are embedded in vehicles.** The cost of developing new vehicles is increasingly dominated by software, with high-end vehicles relying on millions of lines of computer code. It is estimated that 90% of the new features in cars have a significant software component (e.g. improved fuel injection, on-board cameras and safety systems). Hybrid and electric vehicles in particular require huge volumes of computer code: the Chevrolet Volt plug-in hybrid uses about 10 million lines of computer code. A major part of the development costs for entirely new vehicles is also software-related (while manufacturers guard the exact figures closely, estimates of around 40% are not uncommon) (OECD, 2015d).

- **The trend towards autonomous (self-driving) vehicles, which means that software systems using AI will account for most of the value-added in an automobile.** Software would constitute the major part of the development costs (rising to between 60% and 80% when including infotainment systems[16]). It is therefore not surprising that firms with strong software capabilities, in particular in AI, have entered the field of self-driving cars. Google is often perceived as one of the pioneers, as it started its Self-Driving Car Project in 2009 (although many of the leading automobile companies have been working on the concept for at least a decade[17]). Tesla's recent firmware update enabling its semi-autonomous "Autopilot" system has also put significant pressure on incumbents in the automobile market to accelerate the release of products with comparable features (see for example, Toyota Motor announcing it will invest USD 1 billion through to 2020 to develop self-driving cars).
- **A possible paradigm shift towards "mobility as a service" which may make car ownership less attractive.** Mobile smartphones and applications (apps), combined with the analysis of big data, have enabled collective consumption of private durable goods by providing access to excess capacity of these goods. In the case of cars, many shared mobility services have emerged, ranging from the rental of private cars (Zipcar), rides (Uber, Lyft, BlaBlaCar) and parking spaces (JustPark), to the rental of free floating (Car2go, DriveNow) and station-based cars (Autolib') and bikes (Vélib') (OECD, 2015a). A great deal of capital is therefore flowing to these firms. For example, Apple has recently invested USD 1 billion in Didi Chuxing, a ride-hailing service competing with Uber in China.

All these trends have favoured the market entry of ICT firms in the automobile and mobility services sector, increasingly through strategic alliances, but also mergers and acquisitions (M&As). A number of these alliances have focused on the development of autonomous (self-driving) vehicles. For example, in May 2016 Fiat Chrysler Automobiles and Alphabet, Google's mother company, announced that they would jointly develop a fleet of 100 self-driving minivans. The following month, BMW announced that it would team up with Intel and Mobileye to develop a fully automated driving system. In terms of M&As, General Motors recently paid USD 1 billion for the acquisition of Cruise Automation, a start-up specialised in the development of hands-free driving software systems.

There have also been an increasing number of collaborations and investments focusing on mobility as a service. For example, Volkswagen recently invested USD 300 million in an Israeli start-up, Gett, an Uber rival operating mainly in New York, London, Moscow and Tel Aviv. Similarly, Toyota Motor Corporation invested in Uber Technologies, while General Motors invested in USD 500 million in Lyft, Uber's top US rival, which has plans to develop a nationwide on-demand network of self-driving cars. For the platform providers the objective is often to gain access to fleets of cars, while the car manufacturing companies are interested in gaining access to the mobility data and analytic capabilities of the platform providers.

In light of these collaborative efforts, some observers have noted that automobile manufacturers may be pushed towards the lower end of the value chain if they lack competencies in software and AI-enabled services. For example, when commenting on Apple's announcement to invest in a car project, Ewing (2015) concluded that:

"The main risk for car makers is probably not so much that an Apple car would destroy Mercedes-Benz or BMW the way the iPhone gutted Nokia, the Finnish company that was once the world's largest maker of mobile phones. Rather, the risk is that Apple and Google would turn the carmakers into mere hardware makers – and hog the profit."

That said, the traditional carmakers' big advantage is still their capacity to manage the complexity of manufacturing reliable, comfortable vehicles including the management of the supply chain. And these companies still possess very strong brands. To what extent a newcomer will be able to outsource the manufacturing process, like Apple outsources the production of the hardware for the iPhone, or to partner with manufacturing firms, as Google does with Android, is hard to tell. In any case, it will be crucial for all stakeholders to clearly identify their core business areas and the activities in the value chain where they can best lever their competitive advantages. The exploitation of existing intellectual property rights (IPR) and data as "points of control" could turn out to be key to firms' strategies, with important implications for competition in these markets to be expected (see OECD [2015b]).

The automation of manufacturing and agriculture

In manufacturing, robots have traditionally been used mostly where their speed, precision, dexterity and ability to work in hazardous conditions are valued. Traditional robots, however, could only operate rapidly in very precisely defined environments. Setting up a robotic plant would take months, if not years. The robots might have sensors on-board but most of their movements would have to be pre-planned and programmed, which would not allow for much flexibility in production. For this reason, the production of consumer electronics is still often done by hand, because the life cycle of consumer electronics and the time to market is so short that a robotic factory would not be ready to make the current product by the time the successor should be on the market. However, this is radically changing because AI machines are becoming more flexible and autonomous and can now perform a wider range of more complex manual work. Some modern factories, such as the Philips shaver factory in Drachten in the Netherlands, are almost fully robotic (Markoff, 2012). This particular factory employs only one-tenth of the workforce employed in Philips' factory in China that makes the same shavers.

In agriculture, autonomous machines are increasingly used. In cattle farming, for example, machines milk cows, distribute food and clean stables without any human intervention. The milking robot from Lely, for example, autonomously adjusts the feeding and milking process to optimise milk production for each cow. Some studies have therefore suggested that it is only a matter of time before humans are removed altogether from agricultural farming.

A scenario might ensue in which farm enterprises become local caretakers of land, animals and data. They might monitor operations that are centred at the lower end of the value chain, much like the current concept of contract farming.[18] Food producers, retailers or even end consumers could interact directly with the network around the farmer, including seed suppliers, smart (autonomous) machines, veterinarians, etc. In such a scenario, the job of the farmer would be more like a contractor making sure that the interactions between the supply and demand sides of the agricultural system work together properly. In an alternative scenario, farmers could become empowered by the data and intelligence provided by analytics, tailoring the processes to their knowledge of local and farm-specific idiosyncrasies.

As the IoT enables integration of physical systems, it will also foster the integration of living systems – including plants, animals and humans – within physical systems.[19] Such integration may further empower humans: augmented reality-based applications, for example, could provide workers with the real-time information to improve decision making and work procedures. For example repair instructions could be displayed directly in workers' field of sight using augmented reality glasses (Rüssmann et al., 2015). And by using information available in real time, employees could organise shift scheduling themselves, as the case of KapaflexCy in Germany shows (Box 2.8). That said, examples presented so far suggest that there are also risks that such integration may lead to a dehumanisation of production. In highly automated production processes, integration and interaction between humans and autonomous systems have already emerged in particular for tasks for which human intelligence is still required and no cost-efficient algorithm exists, making human workers appear rather as servants than users of IoT-enabled systems (Box 2.9).

Box 2.8. **Self-organised capacity flexibility for Industry 4.0: The KapaflexCy research project**

To produce highly customised products, companies must become more dynamic, agile and customer-oriented. This requires maximum flexibility, from technical facilities and personnel. For lean production, the deployment of personnel must be matched as closely as possible to real-world demand. In practice, this process is usually inefficient: team leaders and shift managers co-ordinate the presence and absence of employees, usually verbally, and sometimes by e-mail.

In the KapaflexCy research project, a number of institutions working together developed a self-organised capacity control system (the institutions concerned were Fraunhofer IAO, together with BorgWarner, Bruker Optik, Stuttgart Airport, the Institute for Occupational Safety and Technology Management, Introbest, Kaba, SAP and Trebing and Himstedt). This system allows companies to control their production capacities with the direct involvement of executive employees in a highly flexible, short-term and company-wide manner. Even with fluctuating orders and unstable markets, companies can react more quickly, avoid unproductive times and reduce the cost of capacity control. Employees experience a transparent personnel deployment plan and co-ordinate their deployment times. The balance between work, family and leisure has been improved, and motivation increased.

Source: OECD, based on *www.plattform-i40.de/I40/Redaktion/DE/Anwendungsbeispiele/096-kapaflexcy-selbstorganisierte-kapazitaetsflexibilitaet-fuer-die-industrie-4-0/beitrag-kapaflexcy-selbstorganisierte-kapazitaetsflexibilitaet-fuer-die-industrie-4-0.html* (accessed 15 January 2017).

Box 2.9. **Crowdsourcing of human intelligence tasks: "Human computing"**

While computing and automation technologies are steadily improving, humans still do many tasks more effectively than computers, such as identifying objects in a video, and transcribing audio recordings. For such tasks, firms have tended to hire temporary workers. But crowdsourcing a workforce for human intelligence tasks (HITs) is an increasingly used alternative. This process, which gives firms flexibility, is often referred to as "human computing", because humans are here used solve problems that computers cannot.

Amazon is still the most prominent provider of human computing services over the Internet, since it launched its crowdsourcing marketplace for digital work called Amazon Mechanical Turk (MTurk) in 2005. Clients advertise small projects that cannot be fully carried out by computers. Workers – called "turkers" – complete those one-time tasks, for sums ranging from as little as USD 0.01 for a short task to USD 100 for more complex jobs. Currently, some 500 000 workers from 190 countries are registered at Amazon MTurk. Particularly for people living in developing countries, MTurk and similar services have been highlighted as an economic opportunity. For example, Samasource, a non-profit organisation, provides data-related services to large companies in the United States and Europe.

Box 2.9. **Crowdsourcing of human intelligence tasks: "Human computing"** *(cont.)*

It divides work into small batches and sends these for completion to delivery centres in developing countries (Gino and Staats, 2012).

While they represent job opportunities for some, MTurk and similar services such as Samasource have been criticised by some as "digital sweatshops", given that, in the words of one scholar, these services "[circumvent] a range of labor laws and practices, found in most developed countries" (Zittrain [2009], cited in MIT Technology Review [2010]). So-called "micro-workers" typically earn below average hourly wages (Uddin, 2012; Cushing, 2013; Horton and Chilton, 2010). But a survey of working conditions as perceived by 200 workers on MTurk suggests that the workers believe their chances of being treated fairly are as good, or better, online as they are offline (MIT Technology Review, 2010; Horton, 2011). However, issues related to worker conditions remain, despite a 2014 petition from MTurk workers to Amazon CEO Jeff Bezos calling for improved conditions (Harris, 2014; Dholakia, 2015).

Source: OECD (2015b), *Data-Driven Innovation: Big Data for Growth and Well-Being*, *http://dx.doi.org/10.1787/9789264229358-en.*

Large warehouses, which have so far been major employers, are an example of such a system. Many warehouses today use digital technology to direct workers to particular shelves and instruct them on the items to pick. The worker then scans the barcodes of the items picked and deposited. Workers walk many kilometres each day.[20] Other warehouses use conveyor belts for products. The humans are controlled by computers. However, in some of the warehouses, the model of working has changed. In these warehouses the shelves come to the workers, carried by small driving robots such as those manufactured by Kiva Systems, a company acquired by Amazon after it started using Kiva's robots. Kiva Systems creates a different type of warehouse, where workers stand still and the shelves are dynamic. The location of goods is continuously optimised, so that the most popular products are situated on the shelves that need to travel the shortest distance.[21] A laser shows the worker what product needs to be picked and where it needs to be deposited. The effect is a highly efficient warehouse that needs fewer workers to handle the same volume of orders.

New policy opportunities and challenges lie ahead

Despite its potential benefits, the digitalisation of industrial and agricultural production still falls short of its potential. There are a number of concurrent reasons for this, as the case of the adoption of precision farming technology in the Netherlands shows (Box 2.10). This section will discuss the key policy issues which, if properly addressed, can maximise the benefits of digitalisation.

Box 2.10. **Drivers and challenges in the adoption of precision farming technologies**

The concept of precision farming has captured the imagination of industry and policy makers, even if the market for precision farming solutions is still young.

In a survey of Dutch farmers about 55% of respondents indicated that they own tools that support precision farming (University & Research Centre, WUR). Most commonly these were GPS-equipped tractors and, to a lesser extent, tools that monitor crops and soil.

Box 2.10. Drivers and challenges in the adoption of precision farming technologies *(cont.)*

However, the integration of machine-generated data into business management systems (BMSs) is limited. The use of BMS by farmers is primarily driven by existing regulatory and customer requirements regarding food safety. In other words, these tools are mostly used for registration purposes rather than for yielding actual management information. BMS becomes more valuable to farms as they grow in size and require better information processing. About 45% of respondents use collected data for planning fertilisation, irrigation and pesticide spraying. However, planning such activities is not generally based on real-time data collected and processed automatically by machines. In other terms, the full potential of the technology is not being exploited.

The ease of use of ICT tools, and farmers' ICT skills, are the most important factors driving the adoption and use of precision farming technologies. Other influences are farm size, the opportunities for cost reduction, total farm income, land tenure arrangements, access to information (via extension services and service and technology providers), and location (Perpaoli et al., 2013).

Adoption rates for precision farming vary across sub-sectors. Various sources suggest that the use of data and data analytics in livestock farming, and in greenhouses, is more advanced than in crop farming. This could be because the former two sectors have shorter production cycles and operate in controllable environments, which makes precision farming solutions and automation more profitable.

Another important enabler of diffusion is the penetration of (mobile) broadband. The European AgriXchange research project concluded that the lack of broadband in many rural areas in Europe is an important barrier to innovations that build on the collection and exchange of data.

Overcoming barriers to ICT diffusion, interoperability and standards

The digitalisation of industrial production requires the diffusion of key ICTs, particularly among SMEs. However, many businesses lag in adopting ICTs. For example, the adoption of cloud computing, SCM, ERP, and radio-frequency identification (RFID) applications by firms is still much below that of broadband networks or websites (Figure 2.7). Nevertheless, it is these advanced ICTs that enable the digitalisation of industrial production.

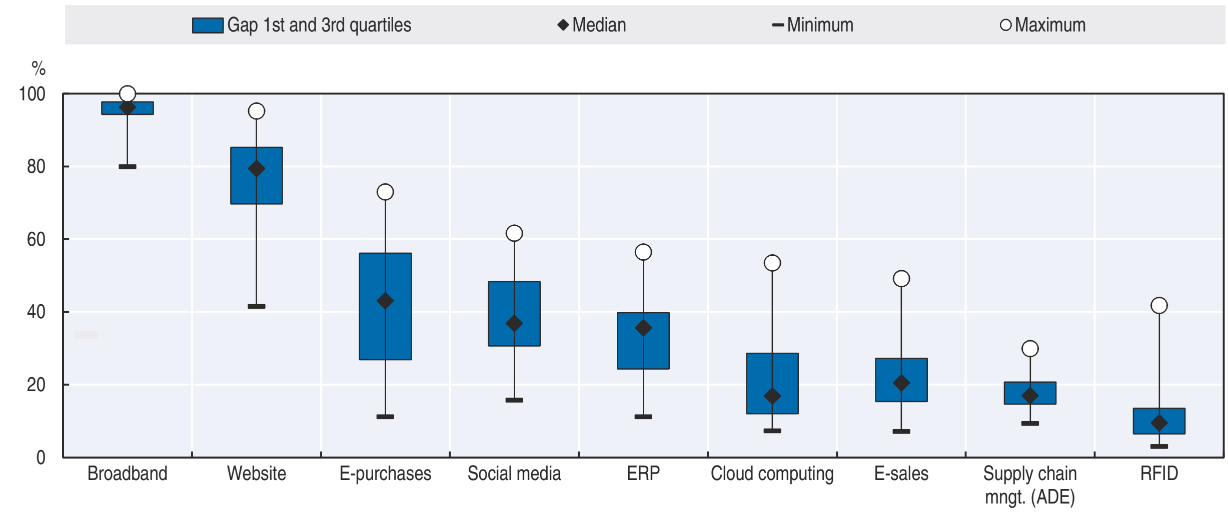
Factors preventing firms from using advanced ICTs include technological lock-ins,[22] often due to proprietary solutions, a lack of (open) standards, and risks of security breaches (large firms in particular express concerns about data security). In addition, smaller firms often have difficulties to implement organisational change, due to limited resources, including the shortage of skilled personnel.

Device identification is one of the most important aspects of interoperability. In particular, achieving interoperability among heterogeneous identifiers may prove to be a challenge for deployment of the IoT. This is because the IoT concerns billions of objects that are a part of existing Internet-based networks and which need to be uniquely addressable.

Another interoperability issue will arise when users attempt to use IoT devices and applications from different manufacturers and suppliers. This may raise problems, e.g. when using IoT applications on different systems or networks – say from one country to another – or moving a device such as a car to a new service provider or network. A World Economic Forum executive survey (WEF, 2015) confirms that lack of interoperability ranks among the top three barriers to IoT adoption (after security concerns, but before uncertainty in the return on investment). Furthermore, there is evidence that most data generated by sensors do not reach operational decision makers due to interoperability issues (McKinsey Global Institute, 2015).

Figure 2.7. **Diffusion of selected ICT tools and activities in enterprises, 2015**

Percentage of enterprises with ten or more persons employed



Source: Based on OECD (2017b), *OECD.Stat*, database, *http://dotstat.oecd.org/index.aspx?DatasetCode=ICT_BUS* (accessed March 2017).

StatLink *http://dx.doi.org/10.1787/888933473783*

Regulatory barriers may also prevent the effective adoption of some ICTs. For example, large-scale IoT users such as car manufacturers which need to control the SIM cards in their cars cannot do so in many countries. Consequently, once a car has a SIM card from a mobile network, the car manufacturer cannot leave the mobile network for the lifetime of the device. Therefore, users with large number of devices (sometimes referred to as million-device users) can effectively be locked into long-term (often 10- to 30-year) contracts. It also means that when a car crosses a border, the large-scale user is charged the operator's costly roaming rates.

Addressing potential skills bottlenecks

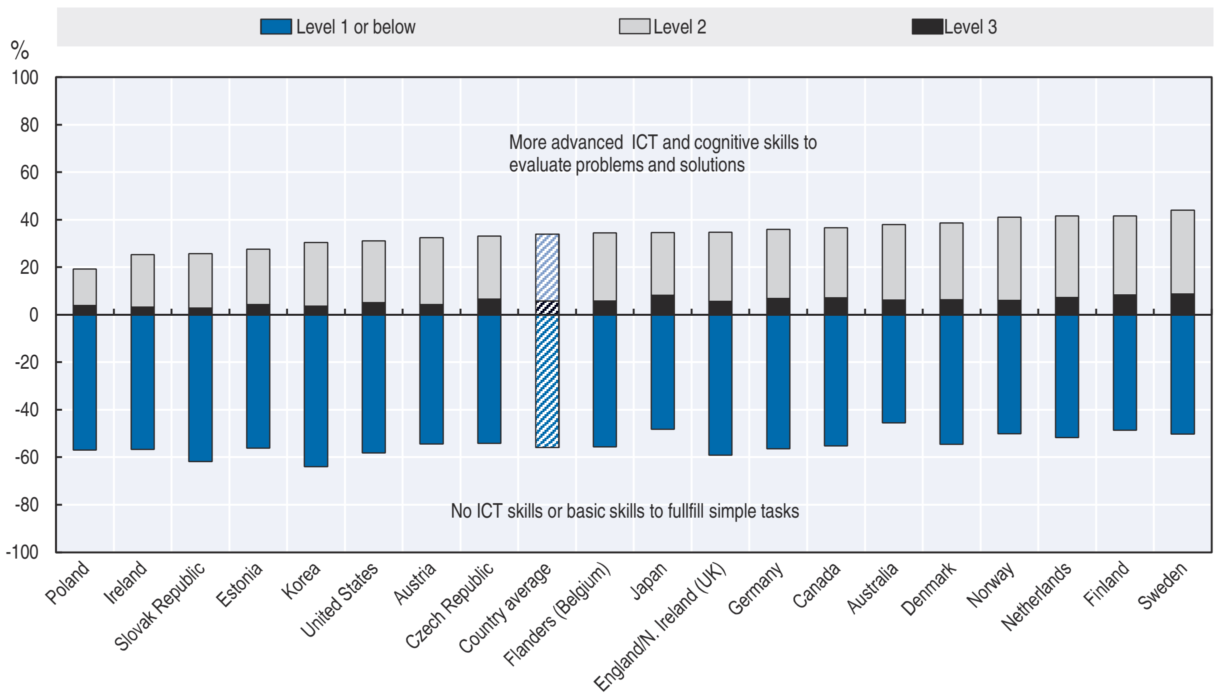
The increasing use of advanced ICTs, such as data analytics, has raised demand for new types of skills. A scarcity of specialist skills may hinder adoption of ICTs. For example, surveys point to the shortage of skilled data specialists as one of the biggest impediments to the use of data analytics in business. In the United States, since 1999, occupations for those with advanced ICT skills have been among those with the fastest growth in relative wages, suggesting (combined with other evidence) a possible shortage of such skills.

Many countries are struggling to develop the necessary skills. OECD data reveal that 7% to 27% of adults in OECD countries still have no experience in using computers, or lack the most elementary skills. Only 6% of people in the OECD[23] have the "highest level" of ICT skills. In countries such as Austria, the United States, Korea, Estonia, the Slovak Republic, Ireland and Poland, the share is 5% and below (Figure 2.8).

Evidence also strongly suggests that geography plays a role. For example, most of the big-data technologies, such as Hadoop, are so new that few experts have sufficient knowledge or the expertise to work with them, and those with high levels of skills tend to concentrate in regions such as the San Francisco Bay area in the United States. These findings call for cautious interpretation of country-level employment and skills statistics, as the latter do not always reflect (sub-) regional labour market dynamics and skill gaps.

Figure 2.8. **Level of proficiency in problem solving in technology-rich environments, 2012**

As a percentage of 16-65 year-olds



Note: Problem solving in technology-rich environments requires "computer literacy" skills (i.e. the capacity to use ICT tools and applications) and the cognitive skills required to solve problems. Level 1 or below possesses no ICT or basic skills to fulfil simple tasks; levels 2 and 3 require more advanced ICT and cognitive skills to evaluate and find solutions.

Source: OECD (2014b), *OECD Science, Technology and Industry Outlook 2014*, *http://dx.doi.org/10.1787/888933151932*, based on OECD's Programme for the International Assessment of Adult Competencies (PIAAC).

StatLink http://dx.doi.org/10.1787/888933473793

A scarcity of technical skills can often result in a lack of awareness of the productive potential of ICTs. This is particularly true for firms that face challenges in transforming their organisation. A recent study (Hammermann and Stettes, 2016) on the impact of digital change on skills and employment in Germany suggests that the "ability to plan and organise, to act autonomously", combined with firm-specific and occupation-specific working experience, are crucial for the successful digital transformation of businesses. However, surveys also show that the ability to articulate the value of digitalisation for a business' future is often missing. This translates into the lack of a business strategy for digital transformation. Kane et al. (2015), for example, find that "early-stage companies are often falling into the trap of focusing on technology" and thus only use ICTs for improving their operations, if they use ICTs at all, instead of using ICTs to transform their business. Only 52% of businesses which use ICT less intensively (early-stage adopters) say that transforming the business is part of their digital agenda.

Considering data as a new infrastructure for 21st-century production

Data are an infrastructural resource. Data represent a form of capital that can be used for a theoretically unlimited range of purposes. Physical infrastructure such as roads and bridges helps the economic benefits of some activities to "spill over", e.g. by fostering trade and social exchanges. The use of data also generates spillovers across the economy. But some of the spillovers from data are not easily observed or quantified (for example greater levels of trust induced by transparency and data-driven applications, as both are enabled by open public sector data). As a result, countries could risk under-investing in data and data analytics and may end up giving access to data for a narrower range of uses than is socially optimal. This risks undermining countries' capacity to innovate, as data and its analysis have become fundamental to innovation.

The value of data depends on the context of their use, on the use of complementary assets such as data analytics and other (meta-) data, as well as on the extent to which data can be reused. There are therefore at least three means through which the value of data can be maximised, namely by:

- enhancing the quality of data to make them a better "fit for use"
- enhancing data analytic capacities by investing in analytic software, know-how and skills as well as complementary (meta) data that help enrich existing data
- enhancing access to data to leverage their infrastructural nature (as a non-rivalrous general-purpose productive asset).

Where the social value of data is greater than their private value, benefits can come from enhancing access through e.g. open (non-discriminatory) access to public (open data) data portability or data commons.

Preserving the open Internet for global value chains

Data and digital services are increasingly traded and used across sectors and national borders. Indeed, companies increasingly divide their digital processes – hosting, storage and processing – across many countries.

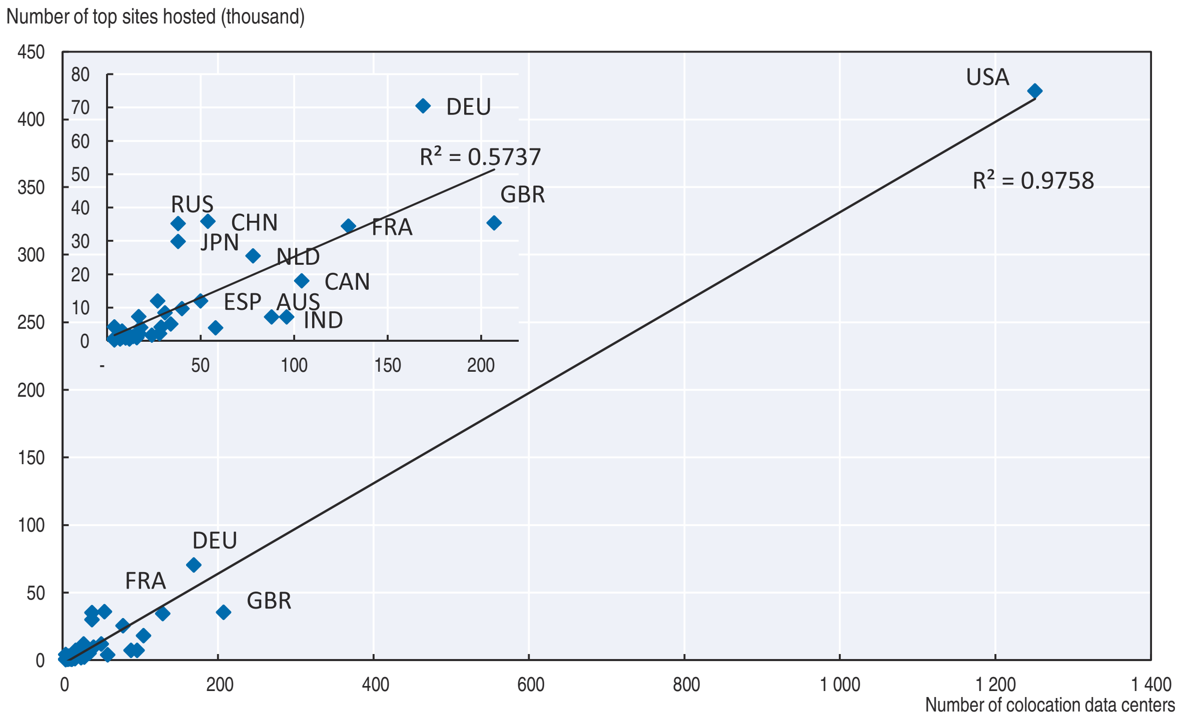
The precise distribution of digital services globally, and the magnitudes of cross-border data flows, are not known. But analysis of the world's top Internet sites suggests that digital services are disproportionately concentrated in the United States, which alone accounted for more than 50% of all top sites hosted in the OECD area in 2013 (Figure 2.9). Canada, Germany, France, Ireland, the Netherlands, Japan and the United Kingdom, as well as China, India and the Russian Federation, are catching up as they increase their contribution to global trade in ICT-intensive services.

Countries with the largest numbers of top Internet sites are also those that have the highest number of co-location data centres (data centres that are shared between users). They are also the leading locations for data-intensive services. Major exporters of digital services and top locations for data-driven services are likely to be major destinations for cross-border data flows. As a consequence, the leading OECD area importers of ICT-related services are also the major sources for trade-related data exchange. These countries thus heavily rely on cross-border data exchange.

Encouraging investments in R&D in key enabling ICTs

The digitalisation of industrial production requires investments in R&D in digital goods and services including, but not limited to, the IoT, data analytics, and computing. Countries with enhanced capacities to supply and adopt these goods and services will be in the best position to benefit from first-mover advantages coming from the digitalisation of production.

Figure 2.9. **Top locations by number of co-location data centres and top sites hosted, 2013**

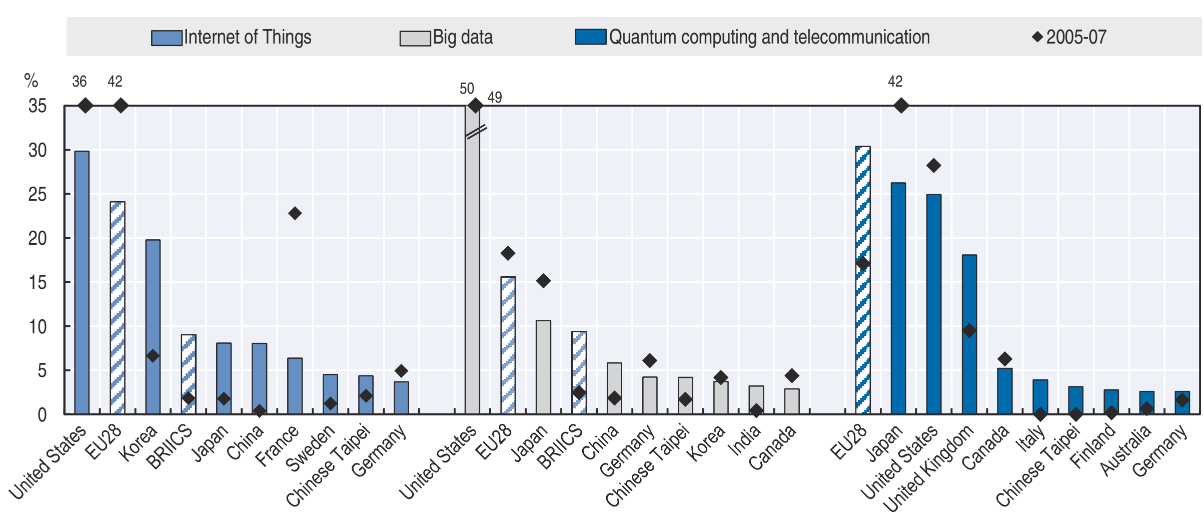


Sources: Based on Pingdom (2013), "The top 100 web hosting countries", *http://royal.pingdom.com/2013/03/14/web-hosting-countries-2013/* (accessed 19 May 2015) and *www.datacentermap.com* (accessed 27 May 2014).

StatLink http://dx.doi.org/10.1787/888933473803

Figure 2.10. **Top players in IoT, big data and quantum computing technologies, 2005-07 and 2010-12**

Share of IP5 patent families filed at USPTO and EPO, selected ICT technologies



Source: OECD (2015c), *OECD Science, Technology and Industry Scoreboard 2015*, *http://dx.doi.org/10.1787/sti_scoreboard-2015-en*, based on IPO (2014), "Eight great technologies: the patent landscapes", *www.gov.uk/government/uploads/system/uploads/attachment_data/file/360986/Eight_Great_Technologies.pdf* (accessed June 2015).

StatLink http://dx.doi.org/10.1787/888933473815

Data on international patent filings provide evidence that inventive activity in technologies related to the digitalisation of industrial production is rapidly increasing. Since 2007, the number of patent filings related to the IoT, big-data analytics, and quantum computing and telecommunication has grown at two digit rates. In 2012, the latest year for which data are available, growth reached more than 40%. But the supply of DDI-related technologies is concentrated in only a few economies, with the United States leading in terms of the number of filed patents, followed by Canada, France, Germany, Korea, Japan and the United Kingdom, as well as China (Figure 2.10).

Addressing liability, transparency, and ownership issues

Data analytics leads to new ways of decision making, through low-cost and rapid experiments, often based on correlations, as well as through the use of AI in autonomous machines and systems. This can lead to accelerated decision making and higher productivity.

But data-driven and AI-enabled decision making can also produce mistakes. This might be because of poor-quality data, errors from the inappropriate use of data and analytics, or unexpected changes in the environment from which data are collected. Recent financial losses caused by unforeseen behaviour in algorithmic trading systems, such as Knight Capital Group's loss of USD 440 million in 2012, illustrate this last point.

The risk of erroneous decisions raises questions of how to assign liability between decision makers and the providers of data and ICTs. The issue is exacerbated by challenges linked to the concept of data ownership. In contrast to other intangibles, data typically involve complex assignments of different rights across different stakeholders. Where data are considered personal, the concept of ownership is problematic, since most privacy regimes grant explicit control rights to the data subject to the data not being restricted (see for example the Individual Participation Principle of the *OECD Guidelines Governing the Protection of Privacy and Transborder Flows of Personal Data*). For example, data generated from smart meters are considered personal data when they convey information about individual electricity consumption, which challenges any exclusive property right the smart meter owner might claim on the data.

As data analytics and AI-enabled applications become more pervasive, users need to be aware of the limitations of both, or these applications may cause social and economic harm. This is especially true when the incentives for users of these applications to minimise risks to third parties is low. This can happen when analysis of personal data primarily benefits the customer of the application user and not the individuals from whom the data has been collected.

Rethinking policy and regulatory frameworks: from privacy to intellectual property (IP) protection, competition and taxation

Big-data analytics, cloud computing and the IoT could raise serious concerns relating to privacy, IPRs, consumer protection, competition and taxation. Aspects of existing regulatory frameworks may be ill-suited to deal with the new challenges. Further consideration should be given to evaluating opportunities and challenges entailed by existing regulatory frameworks in the transition to digital industrial production.

Comprehensive data collection enabled by the IoT may lead to loss of privacy, with advances in data analytics making it possible to sometimes infer sensitive information, including from non-personal data (e.g. metadata). The misuse of this possibility can affect core social values and principles, such as individual autonomy, equality and free speech. Meanwhile the applicability of core principles on which privacy protection relies (e.g. the definition of personal data and the role of consent) is being challenged by the huge volume, velocity, and variety of the data being collected almost everywhere.

Data-driven innovation also raises challenges for competition authorities. These include challenges in:

- Defining the relevant market – the use of data enables the creation of multi-sided markets. Typical examples include online platforms such as Facebook and Uber. However, the traditional approach to market definition generally focuses on one side of the market.
- Assessing the degree of market concentration (this relies on the analysis of market prices, however, a large share of data-driven products are provided either for "free" in exchange for access to personal data, and/or in addition to an offer of a bundle of premium services).
- Assessing potential consumer detriments due to privacy violation – competition authorities tend to direct specific privacy issues to the privacy protection authorities, which however have no authority over competition issues (see OECD [2015b]).

Furthermore, data and ICT use across borders can make it difficult for tax authorities to determine where tax-relevant activities are carried out and where value is created (OECD, 2015a). Inherent in this is the difficulty in measuring the monetary value of data, determining data ownership, and acquiring a clear picture of the global distribution and interconnectedness of data-driven services.

Finally, the convergence of production infrastructure with ICTs, and the increasing role of software, give IPR, and in particular copyright, a strategic role as a point of control in future production. Recent OECD (2015d) work already showed that, among the different types of IPRs, copyright's performance excels in terms of the magnitude of investment it attracts, the growth rate of that investment, and the associated job growth. Copyright's economic importance appears to be growing. In particular, in much of the world copyright protects a significant amount of software investment.

The increasing role of IPRs for the future of manufacturing also comes with challenges. Concerns have been raised that the control of strategic IPRs on which whole ecosystems rely today could favour anti-competitive behaviour. This remains true despite the increasing use of open-source software (OSS) applications, which have eased some of the constraints that IT infrastructure users faced in the past (see OECD [2015b]). For example, some have expressed concerns that the patent US 7650331 B1 on MapReduce[24] awarded to Google could put at risk companies that rely on the open-source implementations of MapReduce such as Hadoop and CouchDB. But given that Hadoop is widely used today, including by large companies such as IBM, Oracle and others, as well as by Google, many consider that Google "obtained the patent for 'defensive' purposes" (Paul, 2010).[25] By granting a licence to (open-source) Apache Hadoop under the Apache Contributor License Agreement (CLA), Google has officially eased fears of legal action against the Hadoop and CouchDB projects (Metz, 2010).

Another area related to ICT-enabled production systems where IPRs might play a role are APIs. Copyright protection for APIs could help to deter counterfeit applications. Not only does copyright protection provide incentives for investment and innovation in applications, it also promotes cybersecurity since counterfeit applications may be used to introduce malware in production systems. However, some experts have raised concerns that copyrighting APIs could also adversely affect the creation and adoption of new applications, and that control of IPRs related to APIs could lead to anti-competitive behaviour.[26] Trends towards more closed APIs are therefore raising concerns among some actors that rely on open APIs for their innovative services.

Policy considerations

Based on the discussion in the previous section a number of policy considerations can be derived. These policy considerations can be clustered around three objectives: first, promoting investments in ICT and data, including investments in complementary organisational change; second, supporting the development of skills and competences for the digitalisation of production; and, third, addressing emerging risks and uncertainties, related either to the use of new digital technologies or to inefficiencies in current regulatory frameworks.

Promoting investments in and use of ICT and data

- **Governments aiming to promote the supply of key ICTs should consider supporting investments in R&D in enabling technologies** such as big-data analytics, cloud and high-performance computing, and the IoT, as well as in security- and privacy-enhancing technologies. Through its 2014 national digital economy strategy, Canada, for example, foresees investments worth CAD 15 million over three years to support leading-edge research in, and the commercialisation of, quantum technologies. And France intends to invest EUR 150 million to support R&D in five technologies identified as strategic: the IoT, super and cloud computing, big-data analytics, and security.
- **Governments should consider using demand-side policies to encourage the investments in and adoption of key enabling ICTs, especially by SMEs.** This can be done through activities such as awareness raising, training, mentoring and voucher schemes (Box 2.11). These measures should also aim at fostering investments in complementary forms of knowledge-based capital (KBC), including in particular organisational change (see OECD [2016b]). Demand-side policies should also be complementary to (existing) ICT supply-side policies (e.g. R&D programmes and national broadband strategies). In Germany, for example, policies supporting investments in R&D related to industrial ICT applications, IT security research, microelectronics and digital services, are complemented with demand-side policies such as awareness raising and training (e.g. through two big-data solution centres established in Berlin and Dresden). Furthermore, the German government has gathered more than 260 examples of the successful implementation of "Industry 4.0" in an interactive online map.[27]
- **Governments should develop an innovation policy mix that encourages investments in data** (its collection, curation, reuse and linkage) that have positive spillovers across industries, while addressing the low appropriation of returns to data sharing. This is particularly relevant for data with social value that is larger than private value. To address the appropriation challenge, the combination of IPR, licences and alternative incentive mechanisms such as data citations, data donation or philanthropy, need to be considered further. One example of where alternative incentive mechanisms have been effective is in science and research. Researchers wishing to be acknowledged for their work can release data sets through mechanisms similar to those already in place for citations of academic articles. However, data citation is still not a widely accepted concept in the academic community.

- **Promoting open standards, including in APIs and data formats, can be key.** Standards based on pro-competitive and technologically open reference models could be promoted to boost the interoperability and reuse of data and digital services, and to reduce technological lock-ins, while enhancing competition among service providers (see OECD [2015a], Chapter 2). For example, the Information Economy Strategy of the United Kingdom aims at "ensuring that key building block standards are deployed – to enable businesses to easily build innovative systems which remain open to further new ideas". The government in the United Kingdom is therefore working through ETSI, BSI and other bodies in the standards field, to bring together a range of stakeholders to align programmes, to build on existing knowledge and to put the United Kingdom in the best position to influence future standards at an international level. The German government, as another example, is promoting standards to ensure interlinking between traditional industries and the ICT sector (Box 2.11).

Box 2.11. Selected government initiatives promoting ICT adoption by SMEs

Many governments have initiatives to promote ICT adoption by SMEs, some as part of their national digital strategies, others through separate strategies and programmes. These initiatives are often motivated by the recognition that insufficient knowledge and financial resources, but also barriers to organisational change, often inhibit the effective use of ICTs. In particular, smaller firms, which too often do not have internal IT departments or in-house know-how, are affected as they lack the financial and other resources needed to invest in ICTs or to engage with external ICT services firms. Most initiatives targeting SMEs focus on: awareness raising and training, often with a focus on enhancing ICT-related, and sometimes also organisational, know-how; financial support; and, social networking.

In Canada, for example, the Business Development Bank of Canada (BDC) realigned its existing support to SMEs in 2011 to focus on ICT adoption. Its support is designed around three stages:

- awareness raising, in particular via e-books and articles, success stories and testimonials, and free ICT assessment of a company's technology situation in relation to other Canadian SMEs
- financial support for consulting services to help SMEs tailor ICT solutions to their business, and to address financial challenges more specifically
- loans to purchase hardware, software and consulting services (with a budget of CAD 200 million).

Interest in and use of these offerings has been greater than expected. In the first 18 months of the initiative's existence, from October 2011 to May 2013, the BDC SmartTech website had almost 220 000 visitors; the two e-books were downloaded over 10 000 times; and BDC undertook more than 35 000 online web assessments, around 900 ICT assessments, and over 300 consulting mandates. In addition, BDC averaged 130 ICT loans per month. However, the BDC only serves a small and specific segment of the SME market in Canada, and many other firms would benefit from these services.

Another example is the initiative "Mittelstand-Digital" (EN "SMEs digital") of Germany's Federal Ministry of Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie, BMWi). This initiative aims to show SMEs and skilled crafts people the importance of using software for business processes, and give support for digitalising these businesses. The initiative builds on three pillars, including:

Box 2.11. **Selected government initiatives promoting ICT adoption by SMEs** *(cont.)*

- **German Mittelstand 4.0 – digital production and work processes**, which aims to support SMEs and skilled crafts people in digitalising business processes and deploying Industry 4.0 applications via competence centres. Among others, focus is put on raising awareness of opportunities and challenges, enhancing technological and organisational competences, and providing opportunities for demonstration and testing.
- **Simply intuitive – usability for SMEs**, which aims at providing development and testing support mechanisms for SMEs to increase quality and usability of business and production software in SMEs. This pillar is motivated by the recognition that software for SMEs has mostly ignored aspects of usability, which, however, has become an important aspect of end-user software.
- **e-standards – standardising business processes, securing success**, which aims at developing a common language for SMEs and different fields of business so as to facilitate data exchange. This pillar is motivated by the finding that SMEs face considerable initial costs if they want to use and implement e-standards.

The initiative "Mittelstand-Digital" so far shows that trust is important for SMEs. Unbiased, official information produced by the federal government has found broad acceptance, while information provided by commercial IT consultants is seen rather sceptically. Creating networks between stakeholders, where entrepreneurs can learn from each other, has helped to create acceptance among SMEs.

In Korea, as another example, 17 creative economy and innovation centres have been created nationwide to promote digital innovation. A significant number of centres focus on digital innovation in production. Local governments and big Korean corporations (e.g. SKT, Hyundai-Kia, GS, Doosan, LG, Samsung and Lotte) jointly operate the regional centres. The tasks of these centres include: supporting start-ups and SMEs in each speciality area, organising the partnership or ecological relations between the relevant big corporations and regional enterprises, arranging funds for them to overcome financial difficulties, encouraging managerial and technological innovation and advisory services (called mentoring), promoting communication and co-operative work among participants, and exploring new markets at home and overseas.

Source: OECD (2016b), "Stimulating digital innovation for growth and inclusiveness: The role of policies for the successful diffusion of ICT", *http://dx.doi.org/10.1787/5jlwqvhg3l31-en*.

Supporting the development of skills and competences for the digitalisation of production

- National education systems, in collaboration with business and trade unions, need to support the development of ICT-related skills, starting with basic ICT skills, and including data specialist skills. Related educational needs extend beyond ICT to include science, technology, engineering and mathematics (STEM). This calls for measures to: promote digital literacy in schools; further develop vocational and on-the-job training; and interlink educational areas, e.g. through the establishment of strategic alliances between universities and businesses as well as interdisciplinary competence centres. Examples include two big-data solution centres established in Berlin and Dresden in the context of Germany's national digital economy strategy (Digital Agenda 2014-17).
- **Technical skills alone are not enough.** Technical skills need to be complemented with know-how on domain-specific issues (including know-how about the entire production

process) as well as "soft skills" such as communication, self-direction, creative thinking and problem solving. OECD (2016d) shows that demand for such non-technical skills will continue to grow as the diffusion of digital technologies and new business models change how work is performed. These skills are particularly important to address the effects of technologies that are disrupting existing industries. Those with low skills are more likely to be displaced, so improving their non-technical skills will help them to adapt to new occupations and new workplaces. Businesses and their social partners also have important roles to play, as illustrated by the best-practice examples published by the German government on how to implement training and develop qualifications in companies.[28]

Addressing emerging risks and uncertainties

- **Governments may need to act if regulatory uncertainties prevent the adoption of ICTs.** This is especially the case if regulations that have been designed for the pre-digitalised world were to inadvertently shield incumbents from competition that digitalisation could bring, thereby thwarting digital innovation (see OECD [2017a]). For the IoT, for example, removing regulatory barriers to entry into the mobile communication market would allow the so-called 'million-device users', such as some vehicle manufacturers, to become independent of the mobile network, strengthening competition (see OECD [2016a]). To take another example, in the automobile and mobility services industry, existing taxi regulations may slow the diffusion of mobility services (including ride sharing) applications, and may require review and reforms to permit application-based ride services to continue. Similarly, already available technical solutions for self-driving trucks cannot often be deployed because of existing regulatory frameworks.
- **Governments should support a culture of digital risk management**, as promoted by the 2015 OECD Recommendation on *Digital Security Risk Management for Economic and Social Prosperity*. Otherwise, stakeholders will continue to adopt a traditional security approach that not only falls short of appropriately protecting assets in the current digital environment, but is also likely to stifle innovation and growth (see OECD [2016c]). The usual barriers to a culture of digital risk management in businesses, and in particular SMEs, are a lack of know-how related to digital risk management and the misunderstanding that digital security is a (technical) IT management issue, rather than a business management issue. To respond to this challenge, governments have prioritised awareness raising, training and education on digital risk management. The French national digital security strategy, for example, foresees that the French state secretariat in charge of digital technology, along with the ministries concerned, should co-ordinate, with the support of the Agence nationale de la sécurité des systèmes d'information (National Cybersecurity Agency, ANSSI), the establishment of a cybersecurity awareness-raising programme for professionals in France.
- **Barriers to Internet openness, legitimate or otherwise, can limit the effects of digitalisation and may require policy attention.** Frequently encountered barriers include technical means, such as IP package filtering, which is used among other things to optimise the flow of data for specific purposes, and "data localisation" efforts, such as territorial routing or legal obligations to locate servers in local markets. The limiting effects of barriers to Internet openness are particularly severe in economies where deployment of data-driven services is poor due to failures in ICT infrastructure markets. However, as highlighted in OECD (2016e), openness also presents challenges, as some

actors may take advantage of it when conducting malicious activities. Barriers to Internet openness coming from business practices or government policies may thus have a legal basis, such as the protection of privacy and IPRs, as well as a security rationale. Governments looking to promote trade in digital services should take the OECD 2011 *Council Recommendation on Principles for Internet Policy Making* into consideration. These principles aim to preserve the fundamental openness of the Internet and the free flow of information.

- **Obstacles to the reuse, sharing and linkage of data should be examined.** These obstacles can include technical barriers, such as constraints on the machine readability of data across platforms. Legal barriers can also prevent data reuse, sharing and linkage. For example the "data hostage clauses" found in many terms-of-service agreements can be a legal barrier, in particular when this provision is "used to extract additional fees from the customer or to prevent the customer from moving to another provider" (Becker, 2012).[29] Non-discriminatory access to data (or "access on equal terms"), including data commons or open data, as well as data portability, should be explored to support the production of goods with public and social benefits without requiring governments or businesses to pick winners (whether users or applications) (Box 2.12).
- **Coherent data governance frameworks should be developed.** Access to data should not necessarily be free or unregulated: a balance is needed between data openness (and the consequent social benefits of greater access and reuse of data), and the legitimate concerns of those whose privacy and IPRs may be negatively affected. This calls for a whole-of-government approach in the application and enforcement of data governance and IPR frameworks. So far no commonly agreed data governance framework exists that would support the reuse, sharing and linkage of data across sectors. Issues that would need to be addressed by such a framework could include, among others, questions related to accountability, data ownership, data curation and the repurposed reuse of data. In the context of business-to-business (B2B) transactions, these questions could potentially be, and often are, addressed by bilateral contractual arrangements. However, even then standards and best practices are needed to reduce exposure to digital risks in supply chains.
- **Governments may seek to promote the responsible use of personal data to prevent violations of privacy.** Efforts to promote privacy-enhancing technologies and the empowerment of individuals through greater transparency of data processing, and through data portability, via such initiatives as midata (United Kingdom) and MesInfos (France) should be further considered. Governments may need to increase the effectiveness (i.e. resourcing and technical expertise) of privacy enforcement authorities. Data protection regulations should aim to offer a high level of privacy protection and be easily implementable, with the goal of widespread adoption.
- **Governments may need to assess market concentration and competition barriers** using up-to-date definitions of the relevant market and taking into consideration potential consumer detriment due to privacy violations. It may be necessary to foster dialogue between regulatory authorities (in particular in the area of competition, privacy and consumer protection) as highlighted in OECD (2015a, Chapter 2).
- **Further thinking is needed on the attribution of responsibility and liability for inappropriate data-driven decisions.** Governments may have to assess whether existing regulations and legislation fully address the challenge of attributing responsibility and liability for damaging data-based decisions (as between decision makers and providers of data and data analytics). Multi-stakeholder dialogue at national and international

level may help through the exchange of best practices and helping to develop compatible approaches to addressing these challenges.

Box 2.12. **Improving agricultural performance with open data: The case of US Department of Agriculture (USDA)**

As farming is becoming increasingly data-driven, farmers need data to be competitive. For entry-level farmers, who may not own historical data, lack of data could become a competitive disadvantage.

To address this challenge, the USDA has made its data openly available. These include data on food supply, economic demand, and remote sensing that are made available as part of the USDA's National Agricultural Statistical Service (NASS) and its Economic Research Service (ERS). Many data sets span the past 100 years and are provided through APIs. NASS offers, for example, a CropScape API that provides direct access to a raster image dataset containing an agriculture-specific land cover classification published annually at the end of the growing season, as well as a VegScape API that provides direct access to a raster image dataset on crop condition vegetation, published on biweekly timescales throughout the year. USDA also provides ERS data on farm financial and crop production practices, including data on production practices and costs (such as fertiliser, pesticide, labour, tillage and seeds) and on financial information for farm businesses, as well as a variety of financial and demographic information (such as age, education, occupation, off-farm income) for farm operators and their households.

To promote the reuse of its data, USDA, in collaboration with Microsoft, initiated the Innovation Challenge, a competition (hackathon) to develop data-driven software applications to explore how climate change could affect the resilience of food systems in the United States. USD 63 000 in prizes were offered for applications that use the USDA data and provide actionable insights to farmers, agricultural businesses, scientists, or consumers across the United States. One winning application, FarmPlenty Local Crop Trends, helps farmers find the best crops by browsing nearby crops, trends, and prices: "Using this information, a farmer can better understand what crops are becoming more popular or unpopular in the region and anticipate changes in prices and demand."[1]

1. See *http://devpost.com/software/farmplenty-local-crop-trends* (accessed 15 January 2017).

- **Also needed is careful examination of the appropriateness of fully automated decision making, transparency requirements and required human intervention in areas where the potential harm of decisions could be significant.** Policy makers should consider that transparency requirements may need to extend to the processes and algorithms underlying automated decisions. These transparency requirements may conflict with existing IPRs and the processes and algorithms at the core of certain business operations. More studies are needed to determine how best to assess the appropriateness of algorithms without violating existing IPRs.
- **Governments may need to encourage improved measurement to help better assess the economic value of data, and to prevent base erosion and profit shifting.** Such base erosion and profit shifting occur through aggressive tax planning by firms seeking to artificially reduce taxable income or shift profits to low-tax jurisdictions by taking advantage of the intangible nature of data, and with that the ease of moving data across jurisdictions (see OECD [2015a], Chapter 2).

Notes

1. Advanced ICTs, such as ERP software, are thought to enhance firm competitiveness by synchronising internal business processes and by providing real-time data for management decision making, thereby reducing structural barriers between departments and allowing for greater collaboration and innovation (for the quantification of the beneficial effects of ERP investments on firm performance see Hitt and Zhou, 2002).
2. Rolls-Royce uses big data to reduce downtime for its engines. Its on-board analytics transmit only data that deviates from normal, so its employees monitor engines while they are in operation. As a result, they can intervene to address any issues before they become big problems that might result in a disruption of service. This approach also supports Rolls' "Power by the Hour," contracts for services. This allows Rolls-Royce to sell engines as a service, not a product (see also Michelin's "kilometre by the hour" offering).
3. This represents an average annual (year-on-year) growth of 1.7%. This potential arises from the sum of the expected additional value-added for mechanical (EUR 23 billion at an expected year-on-year growth of 2.21%), electrical (EUR 13 billion, +2.21%), automotive (EUR 15 billion, +1.53%), chemical (EUR 12 billion, +2.21%), agriculture (EUR 3 billion, 1.17%) and ICT sectors (EUR 14 billion, 1.17%).
4. Figure 2.3 is highly stylised, and does not show many of the complex relationships and feedback loops between these technologies.
5. However, these estimates cannot be generalised, for a number of reasons. First, the estimated effects of DDI vary by sector and are subject to complementary factors such as the availability of skills and competences, and the availability and quality (i.e. relevance and timeliness) of the data used. More importantly, these studies often suffer from selection biases. For example, it is unclear whether the firms adopting DDI became more productive due to DDI, or whether they were more productive in the first place. Furthermore, these studies rarely control for the possibility that some firms may have seen a reduction in productivity due to DDI, and so may have discontinued their investment in it.
6. This estimate uses value-added by industry data from the US Bureau of Economic Analysis. It is part of the *GDP by Industry* database (*www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=51&isuri=1&5114=a&5102=1*).
7. The Fort Hays State study employed a mathematical estimation tool. It studied 1 445 fields with a total of 135 755 acres in three states.
8. Cloud computing can be classified into three different service models according to the resources it provides: infrastructure-as-a-service (IaaS) provides users with managed and scalable raw resources such as storage and computing resources; PaaS provides computational resources (full software stack) via a platform on which applications and services can be developed and hosted; and SaaS offers applications running on a cloud infrastructure. Sometimes clouds are also classified into private, public, and hybrid, according to their ownership and management control.
9. As a result of its simulation, Ford, for example, introduced an aluminium chassis that reduced costs and increased profitability. By some accounts, Ford is making a 50% profit on new F-150 trucks.
10. A report of a stakeholder organisation states that in 2020 benefits of the IoT could be up to USD 2 trillion, whereas USD 1 trillion could be based on cost reductions (e.g. by using smart meters where the estimation is that already 1.1 billion devices could be in use by 2022) and another USD 1 trillion could come from improved services such as remote monitoring of chronically ill patients. These figures are outnumbered by an analysis which predicts that for the car industry alone annual global savings of over USD 5.6 trillion could be achieved by cars based on advanced connectivity technology (semi-autonomous and completely autonomous cars).
11. Driverless cars such as those developed by Google, are based on the collection of data from all the sensors connected to the car (including video cameras and radar systems), which are combined with data from Google Maps and Google Street View (for data on landmarks, traffic signs and lights).
12. A firm that invests USD 1 million on a large-scale enterprise software installation faces a one-time expense that cannot be recovered once spent.
13. See *www.mckinsey.com/industries/high-tech/our-insights/disruptive-trends-that-will-transform-the-auto-industry* (accessed 15 January 2017).
14. While Internet firms among the top 250 ICT firms generated on average more than USD 1 million in annual revenues per employee in 2012 and more than USD 800 000 in 2013, the other top ICT firms generated around USD 200 000 (IT services firms) to USD 500 000 (software firms) (OECD, 2015b).

15. As Mayer-Schönberger and Cukier (2013) explain: "To datafy a phenomenon is to put it in a quantified format so it can be tabulated and analyzed".
16. Infotainment is a portmanteau for information and entertainment. "Typical tasks that can be performed with an in-vehicle infotainment system include managing and playing audio content, utilizing navigation for driving, delivering rear-seat entertainment such as movies, games and social networking, listening to incoming and sending outgoing SMS text messages, making phone calls, and accessing Internet-enabled or smartphone-enabled content such as traffic conditions, sports scores and weather forecasts." (Beal, 2016).
17. Daimler is still seen as one of the leading automobile firms in terms of (semi-) autonomous cars. At the Consumer Electronics Show in Las Vegas in January 2015, Daimler presented its Mercedes F 015, which drove itself onto the showroom floor.
18. "Contract farming can be defined as an agricultural production carried out according to an agreement between a buyer and farmers, which establishes conditions for the production and marketing of a farm product or products. Typically, the farmer commits to providing agreed quantities of a specific agricultural product." (FAO, 2012).
19. For 2030, it is estimated that 8 billion people and maybe 25 billion active "smart" devices will be interconnected and interwoven by one single huge information network, leading to the emergence of an intelligent "superorganism" in which the Internet represents the "global digital nervous system" (Radermacher and Beyers, 2007; O'Reilly, 2014).
20. For example, workers in Amazon's warehouses in the United Kingdom are reported to walk between 11 and 24 kilometres per day (O'Connor, 2013).
21. Before the system can function, it has to model the position of all goods in the warehouse and the most efficient paths and distribution.
22. As Perkins (2003) explains: "Central to the idea of lock-in is that technologies and technological systems follow specific paths that are difficult and costly to escape. Consequently, they tend to persist for extended periods, even in the face of competition from potentially superior substitutes. Thus, lock-in is said to account for the continued use of a range of supposedly inferior technologies, ranging from the QWERTY keyboard to the internal combustion engine."
23. In 2013, ICT investment in the OECD area represented 13.5% of total fixed investment or 2.7% of GDP, with over two-thirds of ICT investment being devoted to software and databases.
24. MapReduce is a programming framework for processing large data sets in a distributed fashion presented in a paper by Dean and Ghemawat (2004). In 2006, the open-source implementation of MapReduce, called Hadoop, emerged. Initially funded by Yahoo, Hadoop is now provided as an open-source solution (under the Apache License) and has become the engine behind many of today's big-data processing platforms. Beside Yahoo, Hadoop is ushering in many data-driven goods and services offered by Internet firms such as Amazon, eBay, Facebook, and LinkedIn.
25. As Paul (2010) explains: "Many companies in technical fields attempt to collect as many broad patents as they can so that they will have ammunition with which to retaliate when they are faced with patent infringement lawsuits." For more on IP strategies see OECD (2015d).
26. The debate on the ability of legal entities to copyright APIs has gained significant momentum after a recent petition by the Electronic Frontier Foundation (EFF, 2014) to the US Supreme Court in November 2014 (see Brief of Amici Curiae Computer Scientists in Support of Petitioner, Google Inc. versus Oracle America, Inc., Supreme Court of the US, No. 14-410, November 7, 2014). The petition follows a court finding earlier in May 2012 that Google had infringed on Oracle's copyright on Java APIs in Android, "but the jury could not agree on whether it constituted fair use" (Duckett, 2014).
27. See *www.plattform-i40.de/I40/Navigation/DE/In-der-Praxis/Karte/karte.html* (accessed 16 January 2017).
28. See *www.plattform-i40.de/I40/Redaktion/DE/Downloads/Publikation/digitale-transformation-im-betrieb-aus-und-weiterbildung.pdf* (accessed 16 January 2017).
29. As Becker (2012) explains: "Data hostage clauses are employed when a contract between a cloud provider and customer is improperly terminated by the customer in order to allow the cloud provider to hold on to a customer's data until the customer has paid a termination fee or compensated the cloud provider for lost business through liquidated damages. In some cases, however, this data hostage provision may be used to extract additional fees from the customer or to prevent the customer from moving to another provider."

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