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HOW ARE DIGITAL TECHNOLOGIES CHANGING INNOVATION?

EVIDENCE FROM AGRICULTURE, THE AUTOMOTIVE INDUSTRY AND RETAIL

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How are digital technologies changing innovation? Evidence from agriculture, the automotive industry and retail

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Abstract

Digital technologies impact innovation in all sectors of the economy, including traditional ones such as agriculture, the automotive industry, and retail. Similar trends across sectors include that the Internet of Things and data are becoming key inputs for innovation, innovation cycles are accelerating, services innovation is gaining importance and collaborative innovation matters more. Sector-specific dynamics are driven by differences in opportunities such technologies offer for innovation in products, processes and business models, as well as differences in the types of data needed for innovation and the conditions for digital technology adoption. The analysis calls for revisiting innovation policy mixes to ensure these remain effective and address emerging challenges. A sectoral approach is needed when designing innovation policies in some domains, especially regarding data access and digital technology adoption policies. The current focus of innovation policies on boosting R&D to meet R&D intensity targets also requires scrutiny.

Keywords: digital technologies, digital transformation, sectoral analysis, agriculture, automotive, retail, innovation policy, R&D intensity.

JEL: D22, L62, L81, O14, O31, O33, O38, Q16

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Introduction

Digital technologies impact innovation in all sectors of the economy, including traditional ones such as agriculture, automotive, and retail sectors. Digital technologies have enabled entirely new digital products and business models, or enhanced traditional ones as exemplified by smart tractors. Innovations in automotive production processes allow for new modes of human-to-machine interactions. The characteristics of digital technologies suggests similarities in new innovation trends across sectors, similarly to other general-purpose technologies (GPTs) of the past, such as the steam engine, electricity and the Internet (David, 1990[1]; Bresnahan and Trajtenberg, 1995[2]).

Industries differ however in their products, processes and in how they engage in innovation. While end products in primary sectors such as food or mining are unchanged, the media, music and gaming industries, to name a few, have completely changed their offering over the past decades. Similarly, while the automotive sector has automated important parts of its production processes, others such as agriculture are less advanced. Understanding differences is critical to inform policy aimed at supporting those innovation systems – yet there is currently little systematic evidence about the sector-specific impacts of digital technologies on innovation.

This paper discusses how digital technologies affect innovation in the agriculture, automotive and retail sectors, and the implications for innovation policy. The analysis builds on a literature review of existing sectoral studies and industry reports, as well as information from firm websites and business news. Four expert workshops (held in June and September of 2017, April and June of 2018) and interviews (conducted between August 2018 and May 2019) with more than 60 experts, industry stakeholders and policy makers were organised. The paper also builds on three country industry case studies, regarding the digitalisation of the automotive supply chain in Germany and China, the digitalisation of agriculture in Italy, and the role of digital start-ups in traditional clusters in Austria (Kern and Wolff, 2019[3]; Pisante and Donatelli, 2019[4]; Wagner and Pöchhacker, 2019[5]).

We identify five trends for innovation in the digital age across all sectors of the economy: Innovation is increasingly data-based, enabled also by the deployment of the Internet of Things (IoT); services are at the centre of innovation; innovation cycles are accelerating; innovation processes are more collaborative; and firms invest in new organisational capabilities to better embrace digital innovation.

We also find important differences in the impacts of digital technologies across and also within sectors: First, the opportunities for innovation in products, processes and business models that digital technologies offer differ across sectors. Second, data that sectors need for innovation differ, and thus also the challenges for access and use of such data that they face. Third, the conditions for digital technology adoption and diffusion vary, as capabilities for digital technology uptake and the availability of ready-to-use digital tools for producers differ. Fourth, regulatory conditions (e.g. lack of legislation applying to new markets, different data sharing legislation across countries) may create uncertainty or barriers for innovation in some sectors.

Several policy implications emerge from the analysis. First, as the characteristics of innovation are changing in the digital age and impacts differ across sectors, developing sectoral roadmaps and strategic foresight exercises with the private sector can help define policy priorities and tailor support to their specific needs. Second, the focus of innovation policies on boosting R&D to reach R&D intensity targets (and the implementation of related instruments, such as R&D tax credits) requires scrutiny, as major innovation activities in the digital age, such as innovation in services, software and business models, are not well captured in R&D statistics. Third, adopting a sectoral approach when designing innovation policies can help support the uptake of digital innovation, specifically in some domains such as data access and digital technology adoption policies.

The paper builds on the in-depth analysis of three representative traditional industries across the primary, manufacturing and services sectors: agriculture, automotive and transportation, and retail (see the Annex). These sectors are being reshaped by digital technologies and are all characterised by involving extensive value chains, thus requiring effective diffusion processes for sectoral transformation. The paper introduces examples from other sectors, notably the health sector.

We applied the following approach to identify how sectors were affected by digital technologies. First, we developed a framework on how digital technologies – by facilitating data generation and treatment at low cost and the fluidity of data sharing – may affect innovation similarly and differently across sectors. We then validated our hypotheses based on an extensive literature review of existing sectoral studies and industry reports, information from firm websites and business news, the three above-mentioned country industry case studies developed in support of this work and the organisation of workshops and interviews with experts from the sectors.[1]

Understanding sectoral dynamics is challenging for a number of reasons. First, while the speed of innovation is accelerating economy-wise, not all actors are similarly equipped to respond to new challenges and tap into new opportunities. Caution is thus needed when analysing sectoral trends, as important differences are likely to exist also within sectors. Second, with the entry of new players in traditional sectors –mainly digital start-ups and technology firms– and the emergence of new market segments, sectoral boundaries are blurring. Third, changes are affecting multiple aspects (e.g. product, process and business model innovation) and stages of innovation (e.g. research, development, commercialisation), the prevalence of which may differ across sectors.

This paper complements available statistical evidence on sectors' digitalisation, including the OECD's Taxonomy of Digital Intensive Sectors and McKinsey Global Institute's Industry Digitization Index (Calvino et al., 2018[6]; McKinsey, 2015[7]). These provide systematic overviews of such aspects as investments on ICT equipment, number of ICT specialists over total employment or stock of robots per employee. However, as digital technologies have evolved more rapidly than has the gathering of statistical evidence, these efforts offer only partial pictures of ongoing sectoral trends.

The paper is structured as follows. Section 1 provides an overview of current digital technology applications in the agriculture, automotive and retail sectors. Section 2 analyses cross-sectoral trends in how innovation processes and outcomes are changing in the digital age. Section 3 presents what are the factors shaping sectoral-specific impacts of digital technologies on innovation. Section 4 discusses some innovation policy implications and open questions. Section 5 concludes.

1. Digital innovations in agriculture, automotive and retail

Digital technologies are integrating and transforming sectors in very different ways. This section provides an overview of trends in the agriculture, automotive and retail sectors.

1.1. Agriculture

In agriculture, intelligent and digitally connected machinery (IoT) enables the development of ‘precision farming’, i.e. systems that help farmers improve the accuracy of operations and optimise the use of inputs (water, fertilisers, pesticides, etc.) to give each plant (or animal) exactly what it needs to grow optimally. New tractors and other agricultural machinery are now equipped with a large number of sensors that capture information about crop conditions (soil conditions, irrigation, air quality, presence of pests, etc.). Drones equipped with sensors are also increasingly used for crop scouting and spraying. Their advantage is that they can cover sizeable areas (including those that are difficult to access) in relatively short time, and take high quality images, providing near real-time snapshots of the farm at a relatively low cost. Data captured by *in situ* sensors, drones and satellites allows better monitoring of crop health, assessment of soil quality and optimisation of input use, thus having positive effects on productivity.

Robots have also been introduced in farming. Although agri-robots are generally in early stages of development, they are expected to increase efficiency and allow for more automated and precise agricultural practices. Fruit-picking, harvesting and milking are examples of the repetitive and standardised tasks performed by agricultural robots. While conducting these tasks, robots also generate data of relevance to agricultural producers. For instance, Lely Industry, a manufacturer of milking robots, collects data from robots on animal health and milk quality of individual cows (Lely, 2016[8]). Such data collection can then enable the systematic use of big data analytics to optimise production processes as described next.

Moreover, large agriculture machinery producers and input suppliers, such as John Deere, are investing in enabling new data analytics based on gathering large amounts of data through the IoT from farm applications and robots, combined with other data (e.g. weather, market data), to develop ‘smart farming’ services. These consist of the use of big data analytics and AI to inform farm-management decision making (Wolfert et al., 2017[9]). Such systems can support the farmer to decide when to plant or harvest, choose the type of crop to plant depending on soil conditions and market prices, or to automatically instruct agriculture robots to perform certain tasks. Precision and smart farming is still mainly restricted to large producers, given a range of challenges to adoption of precision farming technologies, including cost of investing in new technologies, as well as the costs of learning how to use them and adapting production processes, which affect smaller producers to a greater extent.

In the agri-food supply chain, the Internet of Things (IoT) is starting to be used to trace the origins and track the location as well as transportation and storage conditions of products, improving the value chain’s transparency. Blockchain and other distributed ledger technologies (DLTs) are also expected to offer opportunities for increasing the traceability of food products from harvest to point of sale. Several large retail companies have joined the IBM Food Trust platform to apply blockchain to make food supply chains more transparent and traceable. After months of pilot projects, the platforms now offers services to SMEs and large firms to trace products and manage certifications. Retailers that are part of the network, such as Walmart, are requiring their suppliers to enter the initiative so that their products can be traced.

1.2. Automotive

In the automotive sector, rapid developments in digital technology are reshaping i) vehicle innovations (e.g. car connectivity, autonomous driving), ii) innovations in production (with smart factories or industry 4.0 applications) and iii) new business models (with the provision of after-sales services and expansion into on-demand mobility services).

First, digital technology has given rise to connected cars that generate data from the physical world, receive and process data, and connect to other cars and devices. Connected cars allow for enhanced driver safety and convenience, with services such as automatic emergency calls after an accident, real-time road hazard warnings for drivers, car repair diagnostics, systems of time-saving networked parking, and navigation systems that optimise route planning by considering real-time traffic conditions. Today, most new cars are connected and up from 35% in 2015, according to Statista (Statista, 2019[10]). European countries such as Germany, the UK and France are expected to reach nearly 100% connected car penetration by 2020 (Counterpoint Research, 2018[11]).

Developments in autonomous driving are being propelled by advances in the fields of robotics, artificial intelligence, machine learning and connectivity. There are five different levels of automation, from driver assistance to complete automation. All new car models currently offer driving assistance systems. These take over parts of the vehicle motion control and support the driver with certain tasks such as parking and speed-keeping – but the driver is still in charge of driving. From a technical viewpoint, current technology for highly automated driving in controlled environments is quite mature (VDA, 2015[12]). At full driving automation, cars drive independently and react to their environment without intervention of the driver. Such systems are currently tested in pilot projects (PSC/CAR, 2017[13]), but opinions differ greatly on when full autonomy might be achieved.

Second, the automotive industry is also a leader among sectors in developing ‘smart factories’, adopting a variety of industry 4.0 applications such as Internet-connected robotics, data analytics, and high-performance computing. For instance, Hirotec, a Japanese auto parts manufacturer, uses machine learning and data analytics to predict and prevent failures, drastically reducing the cost of the unplanned downtime (Hewlett Packard, 2017[14]). BMW has set the goal to know the real-time status of all machines producing components from all their suppliers using IoT applications (Ezell, 2016[15]). Automated guided vehicles (AGVs) are used by Audi and Daimler to transport materials between production lines and increase the efficiency of warehouse operations, and robotics are widely used to carry out repetitive tasks (Kern and Wolff, 2019[3]).

Third, firms in the automotive industry are also providing new services: new after-sales services (e.g. predictive maintenance, software updates), alternatives to car ownership (e.g. vehicle subscription services) and on-demand mobility services, including ride-hailing and car-sharing services accessed through mobile apps. Ride-hailing platforms, such as Uber, allow matching real-time requests for rides with available drivers, while car-sharing schemes, allow members to access vehicles owned by car sharing companies (e.g. Zipcar) as part of a shared fleet.

1.3. Retail

In the field of retail, digital innovations aim at enhancing the consumer experience (both in physical and online shopping) and optimising processes (logistics, warehouse management, etc.). This includes i) personalising the consumer experience using data collection and data analytics, ii) enhancing the retail services provided in physical stores, iii) improving online retail and iv) managing better the supply chain.

First, the most important innovation have been undertaken to customise the shopping experience, resulting in large investments on data collection and data analytics capabilities. Consumer data on purchasing or internet browsing, among others, give insights on consumer needs and preferences that are used to customise the shopping experience, for instance with personalised advertisements and promotions. This is a widely used practice in retail and increasingly in other sectors. For example, Sephora uses data from customers' online shopping histories, by employing beacons in their stores which send smartphone notifications when customers are close to an item they had previously added in a digital shopping cart (Pandolph, 2017[16]). Data on products (sales in different stores, prices, suppliers, etc.) are also used by retailers to take decisions on product assortment and plan shipping activities tailored to each store, reducing transportation costs and the waste of products (e.g. in the case of fresh products).

Second, innovations in physical stores include smart dressing rooms, digital mirrors, and automatic payment systems that allow skipping check-out lines. An example is the cashier-free AmazonGo store recently established in Seattle, enabled by the deployment of sensors, cameras and other digital technologies that allow for automatic payment of products that customers take off the shelf, without the need to scan bar codes (Amazon, 2018[17]). While other large retailers are experimenting with pilot cashier-free stores, the high cost of deployment of the needed technologies –which are still not fully mature – is a barrier to the large-scale deployment in the short to mid-term.

Third, innovations in online retail include applications for designing or personalising products (e.g. shoes or clothes) through 3D visualisations. For example, by browsing the pages of the digital IKEA catalogue on a smartphone or tablet, customers are able to choose their preferred pieces of furniture and see in their screens how they would look like in their home thanks to augmented reality technology (IKEA, 2019[18]). The automatic purchase of products may also become more common; the Amazon Dash Replenishment Service already allows connected devices (e.g. washing machines, coffee machines) to reorder products automatically (e.g. laundry detergent, coffee beans) when supplies are running low. These innovations however are at this stage mainly deployed by large retailers as experiments.

Fourth, the retail sector is also using the IoT and robotics to better manage inventories (e.g. in warehouses) and optimize processes along the supply chain. AI is also opening avenues for predictive analytics to strengthen forecasting and improve stock management. For example, Otto, a German online retailer, uses consumer data and a deep learning algorithm to predict, with 90% accuracy, what customers will buy a week before they order. This has led Otto to introduce an innovative stock management system that automatically purchases products from third-party brands (The Economist/Capgemini, 2017[19]).

2. Shared cross-sectoral trends of innovation in the digital age

This section explores how digital technologies change the characteristics of innovation processes and outcomes. We identify five trends affecting practically all economic sectors: Innovation is increasingly data-based, enabled also by the deployment of the Internet of Things (IoT); services are at the centre of innovation; innovation cycles are accelerating; innovation processes are more collaborative; and firms invest in new organisational capabilities to better embrace digital innovation.

2.1. Data are a core input for innovation

The exponential growth in the generation of diverse data (e.g. personal, business, research) and the new possibilities for exploiting such data are major enablers of data-driven innovation (OECD, 2015[20]; OECD, 2018[21]). This section discusses how data i) change R&D processes, ii) enable new business models and iii) allow optimising processes. Data generated by smart and connected devices are a unique source of innovation across each of those dimensions in practically all sectors.

First, AI-based analytics, large-scale research experiments, and new virtual simulation and prototyping techniques allow developing new products and processes in new ways. These approaches rely on data from multiple sources, including consumers (e.g. location, condition, use of smart and connected products, Internet browsing), internal business processes (e.g. testing, machine operations, storage facilities, logistics) and external sources (e.g. data from suppliers, data on market prices). For instance, machine learning techniques are being used to accelerate drug discovery and medical diagnostics.

Second, data and data analytics have enabled innovation in business models, sometimes disrupting traditional ones. Examples include smart farming services, peer-to-peer accommodation services such Airbnb, on-demand mobility services such as Uber, and platforms to search, compare and book accommodation and transportation options such as Booking.com. Customer data provide information regarding consumer preferences and needs, which firms increasingly exploit to improve and further customise their products (Deloitte, 2017[22]). This includes exploiting data to price goods and services based on a better assessment of products' price elasticity, based on factors such as day of the week, season, weather, purchasing channel and competitors' prices (McKinsey Global Institute, 2017[23]). Customisation does not only apply to the case of retail but also healthcare (precision medicine) and education (personalised learning) (Holmes et al., 2018[24]).

Third, business data are increasingly used to optimise processes within firms and supply chains. Manufacturing sectors exploit abundant real-time shop-floor data to identify patterns and relationships among discrete processes and steps in order to optimise them – e.g. in terms of waste reduction, energy savings, increased flexibility, and better asset utilisation. UPS, a multinational logistics company, uses a fleet management system enhanced by data analytics to optimise the efficiency and flexibility of delivery processes and reduce fuel consumption. In retail, companies such as Carrefour gather data from products (e.g. demand in different stores, prices) to take decisions on product assortment and delivery tailored to each store. Data are also used to predict and plan the maintenance needs of production systems. For Hirotec, a Japanese auto parts manufacturer, the use of machine learning and data analytics to predict and prevent failures has allowed addressing the problem of unplanned downtime, which costs approximately USD 1.3 million per hour (Hewlett Packard, 2017[14]).

As supply chains become more interconnected, Advanced Enterprise Resource Planning (ERP) systems are increasingly used to analyse real-time data to inform decisions and optimise end-to-end supply chain planning (Geissbauer et al., 2017[25]). Amazon, for instance, also created algorithms to automatically respond to changes in demand: when the popularity of a product increases, the system feeds information to optimise the inventory and adjust prices to maximise benefits (Reeves and Whitaker, 2018[26]).

Blockchain and other distributed ledger technologies (DLTs) – immutable, encrypted and time-stamped databases in which data are recorded, validated and replicated across a decentralised network of nodes – are expected to offer new opportunities for process innovation. Such databases enable parties that are geographically distant to record, verify and share digital or digitised assets on a peer-to-peer basis with fewer or no intermediaries, increasing transparency and trust (Nascimento, Polvora and Sousa Lourenço, 2018[27]). For instance, the start-up Provenance uses blockchain along with mobile and smart tags to track physical products and verify their claims (e.g. proof of fair payment, environmental sustainability) from the origin to the point of sale (Provenance, 2018[28]).

Finally, smart and connected devices are a rich source of innovations across all sectors. They gather and transmit data on processes, use and environmental conditions, allowing for process optimisation, predictive diagnostics and in their most advanced stages the autonomous operation of products as would be the case for self-driving cars (Table 1). Several applications are already in use as exemplified connected cars equipped with a range of new infotainment and other systems that enhance safety (e.g. automatic emergency calls after an accident, real-time road hazard warnings to drivers) and convenience for the driver (e.g. connected infotainment systems with easy-to-access personalised entertainment; systems of networked parking that reduce the time spent searching for a parking space; navigation systems that reduce travel time by optimising the route considering real-time traffic conditions). Self-driving cars, currently tested in pilot projects, will be able to drive autonomously and react to their environment without the intervention of the driver[2].

Data generated by smart and connected products are also enablers of more innovations: they open new avenues for product differentiation and customisation, and for broadening the value proposition of producers, going beyond products to offer new services (as explored in section 2.2) or data. For instance, data on driving behaviours (e.g. frequency of car use and compliance with speed limits) is of direct relevance to car insurers, while real-time data on car location can be used to better manage traffic and reduce the risks of accidents and congestion. Such data is also interesting for service station operators looking to optimise the geographic deployment of their services (McKinsey&Company, 2016[29]; Hanelt et al., 2015[30]). Some automakers are already supplying data (subject to customers' agreement) to third parties in order to offer advantages to drivers. For example, GM's OnStar AtYourService feature provides rewards and discounts around the places the customer goes the most – such as restaurants, shops and gas stations (OnStar, 2018[31]).

Table 1. Innovations based on IoT applications: industry examples

		1. Monitoring	2. Control	3. Optimisation	4. Autonomy
Description		*Sensors and external data sources enable monitoring:* *- Product's condition* *- External environment* *- Product's operation & use*	*Software embedded in the product enables :* *- Control of product functions and operations* *- Personalisation of the user experience*	*Algorithms exploit data collected to:* *- Enhance product performance* *- Allow predictive diagnostics*	*Highest level of capabilities include autonomous product operation and coordination with other products*
Examples of innovations based on IoT applications	*Agriculture*	Sensors installed in fields, equipment or drones to capture information, e.g. soil moisture, pest detection. Sensors to monitor the health of livestock. Sensors and actuators to track the trajectory and transportation conditions (e.g. temperature) of products along the supply chain.	New applications allow farmers to control farm operations from their personal devices (e.g. smart phone, tablet), e.g. remotely guided tractors, irrigation.	Precision agriculture allow for input and water use optimisation. Providers of agriculture equipment can perform remote diagnostics and in some cases remote repair of machinery.	Autonomous farm machinery/robots (harvesters, fruit-picking, tractors). Robots for the automated milking of cows. Adoption remains at early stages.
	Automotive	New cars are equipped with sensors that monitor car performance and alerts the driver in case of changing conditions (e.g. tyre pressure). Some cars are equipped with a system to automatically call emergency services after a crash.	All new car models offer driving assistance systems that take over parts of the vehicle motion control to support the driver with certain tasks (e.g. parking and lane- and speed-keeping). Some cars are equipped with a system to track and slow down the car if stolen.	Tesla's cars are connected to the manufacturer system to monitor performance & provide software upgrades. Car-sharing platforms match real-time data on the location of the user and the location of the closest available car.	At full automation, cars would be able to drive independently and react to their environment without intervention of the driver. Such systems are currently being tested in pilot projects.

Note: Capabilities are ordered from low (monitoring) to advanced (automation).
Source: Description of capabilities based on Porter and Heppelmann (2014[32]).

2.2. Services are at the centre of innovation

Digital innovation has opened new opportunities for innovation in services, particularly as opportunities to exchange with customers enable completely new forms of interaction. Manufacturing firms are consequently increasingly offering services as a complement to the goods they produce – a process known as 'servitisation' of manufacturing. This shift towards services is not only a result of new opportunities from technologies (particularly with the emergence of smart and connected products) but also results from increased pressure from new market entrants. Examples of servitisation include the following:

In the agriculture industry, agriculture machinery producers and input suppliers are becoming providers of smart agriculture services. John Deere, an agriculture machinery producer, has developed MyJohnDeere, a software platform that provides farm-management support services based on data collected from a wide range of sensors installed in its equipment, combined with historical data on weather and soil conditions and crop features, among others (Perlman, 2017[33]).

In the automotive industry, carmakers are expanding their offering by providing after-sales services, such as predictive maintenance services, regular software updates and new ownership models. Lynk & Co (an automotive brand created in 2016 by the Chinese automaker Geely and the Swedish Volvo) offers clients the possibility to share their car with other members of a network when they are not using it through an app. The brand also offers 'lifelong assurance' of vehicles – a subscription allowing clients to change cars over time to respond to changing needs (Lynk&Co, 2018[34]).

Examples of servitisation of manufacturing are also present among automotive suppliers. Michelin, a tyre company, developed EFFIFUEL, a service to help reduce fuel consumption of large truck fleets, by exploiting data regarding the use and status of the vehicle (e.g. fuel consumption, tyre pressure, temperature, speed) collected by sensors located inside vehicles (Michelin, 2018[35]).

Service sectors – including retail in particular – are also fundamentally transformed by the deployment of digital technologies, creating more opportunities innovation in the services industry than was the case in past decades. Today, retailers are investing heavily in data collection and data analytics capabilities, augmented and virtual reality, and IoT, among others, in order to enhance the consumer experience and optimise processes (Box 1).

Transportation services are also being revolutionised by digital technologies, particularly in urban areas, with the emergence of two types of platform-based on-demand mobility services, initially introduced by new market entrants and now attracting investments from carmakers and automotive suppliers. On the one hand, *car sharing* allows access to vehicles owned by car sharing companies as part of a shared fleet on an on-demand basis. Members typically pay an initial or yearly membership fee and usage fees by the mile, hour, or a combination of both. Some carmakers have already created their own car-sharing schemes, such as BMW's ReachNow and Daimler's Car2Go – these allow users to view in their apps all available vehicles around their location and book them by the hour (Stocker and Shaheen, 2017[36]). On the other hand, *ride-hailing* platforms, such as Uber, allow matching real-time requests for rides with available drivers, leading to greater utilisation of vehicles and less time driving without passengers, saving also fuel (OECD/ITF, 2016[37]).

Box 1. Digital innovation in retail: from selling products to providing experiences

Examples of how digital technologies change retail include the following:

- *Online apps to check product availabilities in stores*. Many stores now provide mobile apps that allow customers to access the real-time store inventory and prices, as well as the exact location of products in physical stores.
- *Automatic in-store purchases.* The AmazonGo store recently established in Seattle detects when a customer takes a product from the shelf, without a need to scan the product. Customers' Amazon accounts are automatically charged for their purchases as they walk out the store (Amazon, 2018[17]).
- *Automatic reordering of products*. The Amazon Dash Replenishment Service allows connected devices (e.g. washing machines, coffee machines) to automatically reorder products (e.g. laundry detergent, coffee beans and water filters) when supplies are running low.
- *Smart dressing rooms and virtual mirrors*. Retail stores such as Macy's and Zara have launched pilots for smart dressing rooms, where customers scan the product of their choice and order the colour and size via a mobile app or a screen in the fitting room. Items are automatically released in the fitting room. In addition, the customers receive personalised recommendations based on previous selection of items (Azur Digital, 2016[38]). Virtual mirrors enable customers to easily try clothes on virtually in the physical store by using augmented reality and a camera to capture the customer's body. These have been adopted by some clothing retailers (e.g. Van Heusen) and cosmetics retailers (e.g. MAC) (Stoylar, 2017[39]; Outform, n.d.[40]).
- *Incorporating social media feedback*. Tyrers, a UK department store, introduced a digital clothing rail, where a light above each product tells customers how popular the products are on social media, based on the number of likes, shares and comments on Facebook and Instagram (Retail Innovation, 2015[41]).
- *Personalised advertisement.* Carrefour, a French retailer, deployed iBeacons in its stores in Romania to collect data about customers' behaviours and uses machine learning algorithms to send personalised promotions to consumers as they pass by products they are likely to purchase (McKinsey Global Institute, 2017[23]).
- *Personalised product design.* Shoes of Prey, a multi-channel retail brand headquartered in Australia, offers the possibility to shoppers to design their own shoes online through their interactive 3D shoe designer that allows users to choose the fabric, details and colours of their preference (Internet Retailing, 2015[42]).

Some agriculture-related services are also enhanced by digital technologies. Farm insurance services are increasingly using advanced data-collection technologies (e.g. drones, sensors) to assess damages suffered after severe weather events, fire, etc., reducing the need for field inspections and facilitating the process of insurance claim by farmers. Some insurers are also using their data capabilities to diversify their activities, for instance by providing prevention and predictive maintenance services of greenhouses and farm equipment. Digital technologies are also facilitating the provision of agricultural extension and advisory services to farmers – services that were previously too expensive or not accessible to producers in remote areas, particularly in developing countries (Deichmann, Goyal and Mishra, 2016[43]). Machinery sharing schemes also start to be present in agriculture. *MachineryLink Sharing* and *HelloTractor* are online platforms allowing farmers to rent out their tractors and other equipment to other farmers when not using them.

Important transformations also affected other sectors such as healthcare, tourism and cultural sectors. In the healthcare sector, the expansion of wearable devices and sensors that capture patient health data in real time and transmit them to be remotely analysed already allow for more effective monitoring and management of health problems (OECD, 2017[44]). AI-powered diagnostics tools are in development to help identify diseases earlier and more accurately. In the future, precision medicine enabled by machine learning tools aims at tailoring treatments to individual patients, taking into account patient's genomic and other biological characteristics, as well as health status, previously prescribed medications and environmental and lifestyle factors, with the objective of providing safer and more effective treatments.

In the tourism and cultural sectors, augmented reality applications are for instance used to enhance the visitor experiences in historical sites or museums or allow for virtual visits. The International Centre for Cave Art, in south-west France, for instance, houses a full-scale AR replica of the Lascaux cave to help protect fragile archaeological findings while enabling visitors to explore them.

2.3. Innovation cycles are accelerating

Digital technologies offer opportunities for accelerating innovation processes, ultimately reducing R&D costs and time-to-market. Four trends can be highlighted.

First, new digitally-enabled techniques, such as virtual simulation (enabled by visualisation technologies like virtual reality and augmented reality) and 3D printing, significantly reduce the cost and time devoted to designing, prototyping and testing new products. In the automotive sector, design simulation tools allow engineers to optimise the shape and material properties of parts, considering their interaction with other parts, the easiness of manufacturing and assembly, and their response to crush-test conditions.

Second, digital innovations are often launched as beta versions when they are not in their fully-finished version. Airbnb, Spotify and Tesla regularly conduct real-life testing of their products. Tesla, for instance, installed a "public beta" of its AutoPilot software in more than 70 000 vehicles in 2016, collecting in this way data from consumers testing the software at large scale to improve the software's adaptability to different traffic scenarios (Lambert, 2016[45]). These new technological opportunities and new easy tools to interact with customers (e.g. via automatized feedback to software bugs or online surveys) have enhanced the attractiveness of test-and-learn approaches to product launches.

Third, many products allow for regular upgrades of the intangible component of products, so innovation does often not require releasing an entirely new product. Tesla's cars can receive software updates "over-the-air", similarly to IOS updates in iPhones. Users can also benefit from regular updates in the functionalities of their farm management systems, as these are developed by providers and offered through the same platform. Manufacturing sectors such as automotive, where an important part of innovation is physical, consequently have parallel innovation cycles running at different speeds for the intangible and tangible components of their products.

Fourth, digital technologies increase the flexibility of manufacturing, enabling the production of small series at low cost (i.e. similar to the cost of mass production) and thus higher personalisation of products to respond to customers' requirements and serve niche markets. Production responds to orders, which automatically pass through the production planning process to the machine control. The machine then reconfigures itself to process individual orders. 3D printing can represent a significant enabler technology within this context. Smart products can also be personalised through software rather than hardware (e.g. pay-per-function) (Wagner and Pöchhacker, 2019[5]; Stolwijk and Punter, 2019[46]).

In addition, e-commerce and the expansion of platforms as product marketplaces (e.g. eBay, Amazon, Etsy, Alibaba) allow for easily reaching consumers regardless of their location, but also raise competition pressures, as the rate of introduction of new products and functionalities by other players is also accelerating.

2.4. Innovation is more collaborative

Firms engage in collaborative innovation to remain competitive in a context of fast-paced technological developments and disruptive innovation for two main reasons:

- **Gain access and exposure to a richer pool of expertise**: Innovation in the digital era often requires skills that go beyond traditional sectoral competence strengths, notably but not only in the field of data analytics. By engaging with external actors (e.g. start-ups, universities), firms search for opportunities to access complementary skills, spur creativity, and channel R&D efforts towards areas that would not have been explored. For instance, automakers increasingly seek collaborations with start-ups with strong capabilities in software engineering and data analytics to complement theirs in mechanical and electronic engineering.
- **Share the risks and costs of uncertain investments in digital innovation**: Firms are often confronted with a variety of potential research and technology development paths, the mastery of which requires large-scale investments with very uncertain outcomes. For example, carmakers may have to take strategic decisions as to whether to focus investments in the fields of connectivity, autonomous driving, electric cars or smart mobility. Such uncertainty encourages the diversification of investments, but becoming frontrunners in all those areas in isolation remains challenging. Collaboration with others allows firms to expand into different areas while sharing costs.

The types of engagements can take several forms and in particular include the following:

(1) Business incubation

Company-sponsored incubators and accelerators are tools used by firms to engage with innovative start-ups at early stages of development. Incubation programmes offer support to a limited number of selected start-ups for a few years by providing them with office space, access to business support resources and services (e.g. business skills training, access to networks) and in some cases also with equity investment. Companies setting those incubating programmes benefit from accessing new R&D capabilities, gathering closer insights on the potential of new developments, and having a way of attracting new talent. Popular locations for industry incubators are innovation hotspots, such as Silicon Valley, Berlin, London or Tel Aviv (Brigl et al., 2014[47]). Accelerators provide start-ups in more mature development stages access to a short-term business development programme. They require lower engagement and cost for companies compared to incubators, and enable them to quickly screen a large number of start-ups and be in contact with promising ventures in domains that are adjacent to their core business area.

Walmart's *Store N. 8* in an example of technology-startup incubator in the retail sector. Located in Silicon Valley, it aims at identifying new technology developments for the retail industry, such as virtual and augmented reality and drone product delivery. An example in the automotive sector is the Volkswagen's *Future Mobility Incubator* in Dresden.

Examples of accelerator programmes include the following. In agriculture, the Terra Food+Ag Accelerator programme, founded by Rabobank (a financial services firm specialising in food and agribusiness) and RocketSpace (a technology company), supports around 20 selected start-ups with an 8-week curriculum of workshops and mentoring followed by an 8-week pilot testing with corporate collaborators. The program concludes with a demo day in San Francisco (TERRA, 2018[48]). In retail, John Lewis in partnership with Waitrose launched in the UK the *JLAB*, a retail tech accelerator that offers 5 to 10 companies with disruptive retail tech ideas the opportunity to participate in a 12-week programme, through which they receive business development support from senior level mentors, gain access to industry knowledge and expertise as well as free workspace. Start-ups that participate in the programme apply for funding of up to £100,000 (approx. USD 126,000) in exchange for equity (JLAB, 2017[49]). Target is also actively engaged in two accelerator programmes: the *Techstars Retail* (a 3-month accelerator programme launched by in partnership with Techstars) and *Target Takeoff* (Techstars, 2017[50]; Target Corporation, 2018[51]). Examples in the automotive sector include Ford's *Techstars Mobility Accelerators* and Honda's *Xcelerator programme* (Techstars, 2017[52]; Honda Innovations, 2018[53]). *Startup Autobahn* is a joint initiative that connects corporate partners with late-stage start-ups (Startup Autohahn, 2018[54]).

(2) Strategic partnerships with firms and research institutions

Strategic partnerships with other firms – whether this be competitors or technology firms and digital start-ups – and research institutions are also gaining momentum among firms in traditional sectors. The goal of such partnerships is to join efforts to foster joint value creation, expand market potential and combine strengths in a way that allows closing skills or competence gaps. This often involves the creation of a new legal entity, or sharing a range of infrastructures, investments or assets, notably data.

Partnerships with large digital technology firms are expanding across sectors. In the agriculture sector, partnerships have been set up between traditional players and agriculture technology firms to extend smart farming services to farmers. Some examples include John Deere's partnership with Sentera, a global provider of precision agriculture software and drones (Sentera, 2017[55]); and Climate Corporation's partnership with Ceres Imaging, TerrAvion and Agribotix, providers of aerial imagery technologies, to provide higher resolution imagery to farmers (Climate Corporation, 2017[56]). Partnerships have also been set up with telecom companies. For example, CLASS, an agricultural machinery producer, collaborated with Deutsche Telekom to develop a 'Farming 4.0' project (Deutsche Telekom, 2014[57]); and Dacom, a high-tech company that develops smart farming solutions, partnered with Orange Business Services, which provides machine-to-machine communications infrastructure (Orange, 2014[58]).

Car manufacturers are teaming up with digital technology companies to develop connected and autonomous cars. For instance, Toyota is partnering with Microsoft to develop new internet-connected vehicle services (Lienert, 2016[59]). Ford has also partnered with Microsoft to use its HoloLens mixed reality headsets to improve the car design process: they allow for rapid prototyping in a virtual environment, and make it easier for designers and engineers to experiment and test changes (Etherington, 2017[60]).

In retail, collaborations between traditional retailers and digital technology firms primarily aim at enhancing the customer's experience. For example, Walmart collaborates with Google to enable voice shopping through Google Assistant (Perez, 2017[61]). Rebecca Minkoff, a fashion retailer, partnered with eBay and Magento to create a digitally connected store, with digital walls (that allow, for instance, to request assistance from an employee) and smart fitting rooms to improve the in-store experience of customers, while collecting data about customer preferences and trends (World Economic Forum, 2017[62]).

Collaborations with digital start-ups have also boomed. Firms in traditional sectors see opportunities for start-ups to function as "digital accelerators", as they often enjoy greater flexibility in developing new disruptive technologies (Lund, Manyika and Robinson, 2016[63]). In turn, digital start-ups have natural incentives to collaborate with large players to have access to funding, sectoral expertise or capabilities, new markets and important assets (e.g. corporate's data). For example, in 2017 Ford announced a USD 1 billion investment in Argo AI, a technology start-up with strong competences in robotics and AI, to accelerate the development of self-driving cars (Forbes, 2017[64]).

Partnerships with universities or public research centres with data analytics capacities have also been sought. In the agriculture sector, Origin Enterprises (an agri-services firm) established a digital research partnership with University College Dublin, an institution with strong multidisciplinary research teams in the fields of advanced data analytics, sensing technologies, modelling and agriculture science (Origin Enterprises, 2016[65]). There are also multiple examples in the automotive sector: Toyota Research Institute is investing in research collaborations with Stanford University, the Massachusetts Institute of Technology (MIT) and the University of Michigan (Toyota Research Institute, 2018[66]). Bosch, a major automotive supplier, has established a research alliance with the University of Amsterdam (the Delta Lab) focused on deep learning (Bosch, 2017[67]). Michelin, a producer of tyres, established a joint laboratory called FACTOLAB with universities and research institutes in Clermont-Ferrant (France) to develop technological components for the industry 4.0, focusing on human-machine cooperation (Michelin, 2018[68]).

There are also initiatives led by the public sector to foster collaborative innovation. For example, firms aiming to engage in data-driven innovation can reach out for support from organisations such as Digital Catapult in the UK and CSIRO's Data61 in Australia. Digital Catapult provides pit-stops to sign-post potential market information opportunities between large and emerging companies. (Digital Catapult, 2019[69]). CSIRO's Data 61 conducts frontier research, often in collaboration with firms, to foster data-driven innovation across sectors, capitalising on the combination of expertise in data science and domain-specific areas (Data61, 2018[70]).

(3) Corporate venture capital investments and acquisitions

Many companies are establishing venture business units. Venture investments are an attractive option for firms in traditional sectors as they can be a rich source of information on emerging technologies with potential to reshape and disrupt their industry. To provide an example, Alliance Ventures, a fund launched in 2018 by Renault, Nissan and Mitsubishi, aims to pursue strategic investments in start-ups developing disruptive technologies and business models in the fields of new mobility, autonomous systems, connectivity and AI.

Another approach consists in acquiring technology firms and digital start-ups. In 2017, firms worldwide spent around USD 22 billion on mergers and acquisitions (M&A) related to AI and machine learning, up from less than USD 1 billion in 2015, according to PitchBook, a data provider (The Economist, 2018[71]). An example in the field of autonomous driving is General Motors' acquisition of Cruise Automation, a San Francisco-based developer of autonomous vehicle technology in 2016 (Vlasic and Isaac, 2016[72]). Monsanto's acquisition in 2013 of the Climate Corporation, a provider of weather insurance to farmers based on data, is an early example of this trend in the agriculture sector; another is the acquisition of Observant, an Australian start-up provider of in-field hardware and cloud-based applications for precision farm water management, by Jain Irrigation Systems, a large Indian-headquartered precision irrigation company (Observant, 2017[73]). In retail, an example is Walmart's acquisition of Jet, an online fast-growing and innovative e-commerce company (Walmart, 2016[74]; Grill-Goodman, n.d.[75]).

New players in the automotive, retail and agriculture sector are also using acquisitions to expand into new activities and gain access to markets and data. For instance, Samsung Electronics (a South Korean multinational electronics company) recently acquired Harman Industries Inc., a US electronics equipment maker and leader in connected car technology, in order to expand its presence in the market for connected technologies, reducing in this way its reliance on a slowing smartphone market (PWC, 2017[76]). In retail, an illustrative example is Amazon's acquisition of Whole Foods, which allows it to access consumer data of affluent shoppers to explore their shopping habits, preferences, and correlations between purchases of products (Petro, 2017[77]).

(4) Industry platforms and standards for digital innovation

Industry platforms can be defined as products, services or technologies that provide the foundation upon which different actors can innovate by developing complementary products, services or technologies using digital tools (Gawer and Cusumano, 2014[78]). A platform can serve in this way as the (de facto) industry standard, making development processes more efficient and less costly, enabling rapid innovation and accelerating time-to-market for new products.

Platforms can bring important value to producers. First, producers do not have to build the basis technology offered by the platform. Second, the rate of innovation may increase as the risk and cost associated with incremental innovations based on a basis technology is much lower. However, the long-term implications of such platforms on market competition are ambiguous: the more applications there are in a platform, the more valuable the platform becomes. This explains why a number of firms have opened up IP rights for the exploitation by others. For instance, in 2013 John Deere opened its software platform MyJohnDeere to third parties (e.g. input suppliers, software companies) to develop applications and software that connect through the platform. (Perlman, 2017[33]; Deere & Company, 2017[79]). This increases opportunities for start-ups, individual innovators and smaller firms to enter the market and offer their services. Nevertheless, platform owners hold certain essential assets (e.g. proprietary standards, data collected) and they might use them to keep control over key aspects of the market.

In agriculture, farming data platforms have been established, based on which new applications and services can be developed. These are often created by large agriculture suppliers and are thus proprietary, but some have been created by cooperatives of farmers to exchange data among their members in order to inform farm decisions. An example is the French InVivo's SMAG, which provides farm management applications based on shared data from members of the cooperative (InVivo, 2018[80]). An example of an international initiative for sharing farming and food supply chain data is FIspace, an open software platform created by a consortia of universities and firms with the support of EU funding that allows business-to-business collaboration and data exchange to develop new applications and services, while preserving data privacy and security (FIspace, 2013[81]).

In the automotive sector, examples include the Automotive Grade Linux, a collaborative open source project to accelerate the development and adoption of a Linux-based, open software platform for automotive applications (Automotive Grade Linux, 2016[82]); the Open Automotive Alliance (OOA), founded by Alphabet in 2014 to develop the infotainment system software Android Auto that allows connecting Android smartphones to car dashboards; and the SmartDeviceLink Consortium, created in 2016 by Ford and Toyota, an open source platform for smartphone app development for vehicles that aims to become the industry standard (OOA, n.d.[83]; SDL, 2018[84]).

(5) Crowdsourcing platforms and hackathons

Crowdsourcing platforms are tools used by firms to source ideas from outside the organisation (either the general public or a pool of accredited experts) to solve a specific problem or challenge, or find new product or design ideas. Typically, firms present their challenge online and innovators (be it designers, scientists, start-ups, experts) can present their proposals within a given timeline. Selected solutions can then be adopted by the firm, while the innovator receives the agreed reward (e.g. fixed monetary reward, ownership of IP rights). This approach has several advantages. First, it facilitates access to a wide range of capabilities and skills that may not be available in-house, and fosters knowledge flows across scientific or sectoral communities. Second, it lowers the cost and time devoted to develop a solution or innovation, as search and transaction costs decline (e.g. compared to setting a formal partnership agreement with another firm). Finally, they allow firms to be aware of latest technological developments and trends.

Such initiatives are often conducted through intermediary platforms, such as Innocentive, IdeaConnection, Innoget, Hypios or NineSigma, which organise online competitions for different organisations. These benefit from network effects – as they are able to reach to a wider range of experts across the world. Some intermediary platforms are sector-specific, such as Allfoodexperts (Allfoodexperts, 2018[85]). In some cases, initiatives are established by firms themselves. Fiat Mio, the BMW Customer Innovation Lab and Peugeot's design contest are examples in automotive; others include Dell's IdeaStorm, IBM's InnovationJam and Proctle&Gamble's Connect+Develop. In food processing, General Mills has created the G-WIN platform to crowdsource innovative ideas, from packaging to new production technologies (General Mills, 2018[86]).

Exploiting the potential of such platforms also comes with challenges. The most relevant is for firms to clearly define their challenge, so that experts from different fields and countries are able to provide suitable solutions. Firms also need to strengthen their capacity to interact with external innovators that are loosely connected to the firm, and have a clear definition of the conditions and rewards for winning ideas (Hossain and Lassen, 2017[87]).

Hackathons are another method for sourcing external ideas to foster data-driven innovation. These are often 24-48 hour events where participants are provided with data with which they have to create an innovative product, often an app. Winners are typically compensated with opportunities for incubating the idea.

2.5. Firms invest in new organisational capabilities and practices

To fully embrace digital innovation, firms are investing in new skills and are adjusting their organisational structures to become more agile and spur in-house creativity.

Firms in traditional sectors invest in a workforce with digital capabilities in order to master new innovation domains, and often other competencies to operate new business models. Companies undertake different strategies in order to build these new capabilities: (1) Retraining their workforce; (2) Recruiting digital talent (e.g. software engineers, data analysts); and (3) Accessing external resources by engaging with other actors, such as start-ups, universities and other firms, exploiting synergies while progressively enhancing in-house capabilities. While retraining is the most desirable long-term approach, it has limitations where entirely new skills sets are needed to innovate in the short term.

Firms in traditional sectors however have faced two main challenges in recruiting digital talent:

First, attracting and retaining digital talent is difficult given the high demand and relatively short supply of such talent, which is also often more attracted by tech firms. Traditional players have adopted strategies to address this challenge. Audi has intensified partnerships with universities and sponsored research and doctoral projects to access new talent pools, Daimler uses hackathons, and others undertake efforts to create start-up like environments within their organisations (e.g. creating semi-independent digital innovation labs) to offer a more attractive working environment for data scientists (Strack, Dyrchs and Kotsis, 2017[88]).

Second, to exploit the potential of digital talent, it is crucial to connect their skills to traditional competencies and sectoral expertise. In retail, data scientists have to acquire or work collaboratively with experts in e-commerce, market trends and consumer behaviours to make the best use of data. Similarly, data scientists joining manufacturing firms may have to expand their capabilities in the area of Industry 4.0 or IoT (Ringel et al., 2018[89]).

Many companies are currently being restructured following what is known as the ‘agile’ techniques to make it easier for disruptive innovations to be adopted in traditional companies. These arrangements have also proven to be important to attract data scientists. These techniques consist of establishing small, cross-functional teams composed of cross-trained individuals that manage a specific process from start to end with less hierarchical command structures. Such structures contrast with traditional firms organised around siloed departments that undertake discrete and highly specialised tasks. They foster interactions across team members with different (digital and traditional) skills, provide more decision-making power to lower levels of hierarchies, and are expected to spur experimentation, as small teams can implement new ideas more easily without compromising the functioning of the entire organisation, encouraging a test-and-learn approach.

A popular way of building alternative structures has been the creation of own (digital) innovation labs, also called innovation hubs or garages, where specific teams are tasked to experiment with and test new ideas for the development of new products, services, business models or customer experiences. These labs encourage workers to think ‘outside the box’ and adopt an entrepreneurial mentality. To simulate a start-up-like environments, these labs are often separated from corporate offices. Some are located in high-tech clusters such as Silicon Valley to benefit from spillovers and facilitate new collaborations. They typically have multidisciplinary teams including data scientists, software developers, researchers and designers (Internet Retailing, 2015[42]). Examples in retail include Tesco Labs, Argos

Digital Hub, M&S Digital Labs, ShopDirect UX Lab and Nordstrom Innovation Lab. Examples in the automotive sector include the Volkswagen Automotive Innovation Lab and Ford Research. In the agriculture sector, several DuPont Innovation Centres have been established worldwide.

Other efforts to foster a corporate culture that is supportive of digital innovation include hiring a Chief Digital Officer to lead this process, and adopting digital strategies that allow for experimentation and regular adjustments (in contrast with traditional 5-year strategic plans), leveraging on real-time feedback gained from data on effectiveness of initiatives (World Economic Forum, 2016[90]). Firms also set up initiatives to stimulate in-house creativity. The Renault Creative People initiative encourages employees to propose innovative ideas and prototypes the best proposals; and Renault's Cooperative Laboratory for Innovation stimulates collaboration among product, design and engineering departments (Groupe Renault, 2018[91]).

3. Differences in impacts of digital technologies on innovation across sectors

Aside from shared cross-sectoral trends, there are also important sector-specific dynamics. Some differences in adoption can be observed based on traditional statistical indicators of adoption (Calvino et al., 2018[6]). However, due to challenges in data collection (e.g. lack of access to comparable and representative data across countries on the development and adoption of frontier technologies; constraints to capture within-sector heterogeneity), these efforts offer only partial pictures of ongoing developments across sectors. This section uncovers the underlying factors behind these differences across sectors, and identifies four key dimensions: 1) the opportunities for innovation that digital technologies offer in each sector; 2) the types of data needed for innovation and the challenges faced with regard to their exploitation; 3) the conditions for digital technology adoption and diffusion; and 4) regulatory frameworks applying to each sector (e.g. lack of legislation applying to new markets, different data sharing legislation across countries). This section also highlights the prevalence of within-sector heterogeneities.

3.1. Digital technology opportunities for innovation: present and future

Digital technologies may offer different opportunities for sectors to 1) digitalise final products; 2) digitalise business processes; and 3) create new digitally enabled business models.

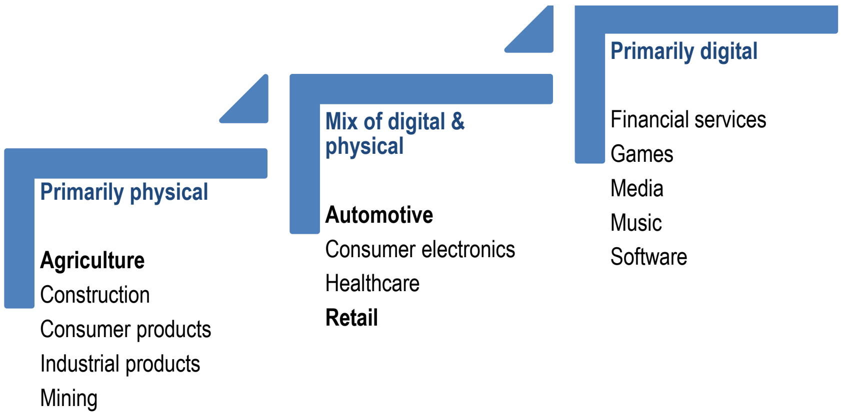
(1) Digitalising final products and services

Digital technologies have the potential to create new or expand existing goods and services with digital features – yet possibilities in this regard depend on the characteristics of specific sectors' end products. Some products can be offered fully digitally. This includes the media, music and gaming industries (Figure 1).

Many industries have a mix of digital and physical components in their final products, with the digital ones often becoming progressively more important. The automotive industry is an example: vehicles increasingly integrate digital features, such as advanced infotainment systems and other functionalities enabled by connectivity and data analytics, and these are becoming key considerations in consumers' purchasing decisions.

Other end products remain mainly physical, such as food and consumer products – but even those may, to a lesser extent, be progressively enhanced by digital features. In agriculture, digital technologies may foster the product value by offering IoT-based tracking systems that allow consumers to trace the origins and processing stages of the food they purchase.

Figure 1. Opportunities to digitalise end products



(2) Digitalising processes

The extent to which sectors' business processes are affected by digitalisation may also be different, depending on the nature of the activities and the characteristics of production (e.g. whether it involves the assembly of physical products, if the sector is characterised by long supply chains, etc.). In particular, digital technologies offer opportunities for digitalisation (and automation) of production processes; for interconnecting supply chains; and for improving interactions with the final consumer. The relevance of these opportunities varies by sector.

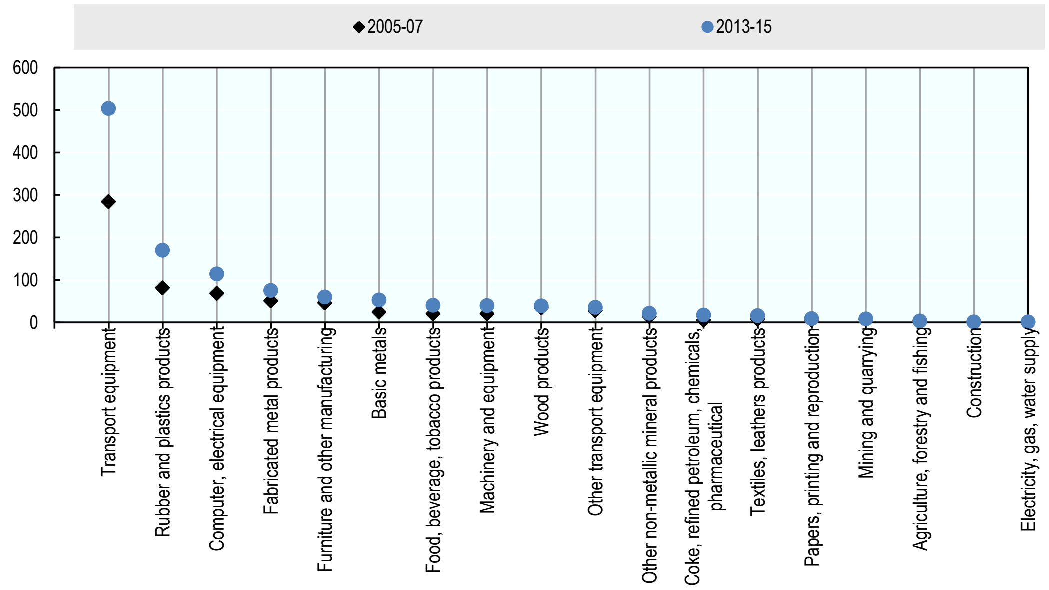
Some sectors have highly automated production processes. The automotive industry is leader in the adoption of more advanced industrial robots, as shown by its high rate of robot density compared to other industries (IFR, 2017[92]) (Figure 2). While robots have begun to be present in other sectors (e.g. the use of fruit picking, harvesting and milking robots in agriculture, and robots used in retail warehouses to optimise space and drive cost savings), not all activities equally lend themselves to automation.

Digital technologies also offer opportunities to interconnect supply chains, increase transparency and agility, and facilitate end-to-end management of the production and distribution processes. Yet connected supply chains are advancing at different speeds both across and within sectors. For instance, while big retailers have largely digitalised their supply chain activities, a long tail of small and medium-sized retailers lags behind (McKinsey Global Institute, 2016[93]). Developments are also unequal within the automotive sector (Kern and Wolff, 2019[3]). In the construction sector, digital design tools (Building Information Modelling) are used to communicate the technical details of materials and building designs between architects, contractors pursuing the construction and building owners, facilitating the transmission of key information for the construction and maitenance of buildings (Lehne and Preston, 2018[94]).

Some sectors also have more potential for using digital technologies to improve interactions with final customers. For instance, traditional retailers enter e-commerce to connect with consumers through new channels. The sector is also increasingly gathering data from end-consumers to personalise their offerings. This trend is less visible in sectors such as agriculture, even if a growing number of producers use digital technologies to directly connect to consumers, avoiding intermediaries.

Figure 2. Robots stock per employee, by sector

Number of robots per 10 000 employees – Averages for selected OECD countries in two periods



Note: Sector-specific values are simple averages over the years (2005-07 and 2013-15) and across OECD countries for which sectoral data are available for both periods. Data on transport equipment have the largest country coverage, with data for 27 countries. Sector labels are based on the sector's ISIC rev.4, 2-digit classification.
Source: Calculations based on De Backer et al. (2018[95]).

(3) Creating digitally enabled business models and markets

New markets or market segments enabled by digital technologies and adjacent to traditional sectors have been created over recent years. E-commerce, car-sharing services and financial technology (fintech) services are well-known examples. While new business models are emerging across the economy, the scale and disruption potential of these trends vary across sectors. In some cases the new models may largely displace traditional ones (e.g. online hotel searching platforms taking over an important segment of activity of traditional travel agencies), while in others they may co-exist and expand the product or service offering (e.g. brick-and-mortar existing simultaneously with online retail stores).

3.2. Data needs and challenges for innovation

Data have become a key input for innovation, as explored in section 2. However, the type of data needed differs across sectors and often across specific sectoral applications. The availability and access challenges as well as data quality and the ease of integration of multiple databases also differ. Table 2 presents some of the differences across the agriculture, automotive and retail sectors regarding the type of data needed for innovation purposes, and the opportunities and challenges related to those data types. A common challenge cutting across all sectors is the need for capabilities to exploit these data for the specific sectoral applications. Specific conditions also apply to other sectors. In healthcare, the high sensitivity of data needed (personal patient data) requires ensuring data security and privacy, and access to data is often restricted. In addition, countries do not follow common standards in their collection practices, making it difficult to aggregate and exploit data [see Auffray et al., (2016[96])]. There are also differences within countries in data collection practices applied by different hospitals, social security, private insurance companies, etc.

Table 2. Data needs and challenges differ by sector

	DATA NEEDS	MAIN DATA USE CHALLENGES
Agriculture		
Precision agriculture	*Personal data*: - *Business data*: Aggregated sensor data from many farms / large-scale exploitation (captured by sensors on the fields or mounted on machinery or drones; satellite imagery) *Public & research data*: Satellite data (GIS, meteorological data, satellite imagery on crops)	- Low levels of digital technology adoption and high cost of uptake, particularly among small farms - Data sharing (resistance by farmers to share with large platform providers) requires building trusted data analytics services need to be build - Data quality & integration & transparency in data analytics required
Product traceability in food supply chain	*Personal data*: - *Business data*: Sensor data collected by all members of the supply chain (incl. information on product's origin, processing stages and actors involved, transportation and storage conditions) *Public & research data*: -	- Engagement of the whole supply chain is required, but there are important differences in capacities for digital technology uptake across actors - Need for a clear definition of the type and amount of information to be shared - Data quality and integration
Automotive industry		
Connected cars	*Personal data*: - *Business data*: Historical data on cars performance (for predictive maintenance services) *Public & research data*: GIS, real-time traffic information	- Skills to exploit data - Data integration - Data privacy (risks e.g. usage-based insurance contracts) - Road safety (risk of cyber attacks)
Optimisation of value chain processes	*Personal data*: - *Business data*: Internal production and business processing data (for internal process optimisation); data on partners' processes (for value chain optimisation); real-time demand data *Public & research data*: -	- Skills to exploit data - Data quality and integration (data often siloed in different departments)
Retail		
Personalisation of consumer experience	*Personal data*: Customers & transactions data; personal data on social media and searching websites *Business data*: - *Public & research data*: -	- Skills to exploit data - Data integration - Personal data privacy (risk e.g. of price discrimination) and ethics in data exploitation - Data sharing conditions need to be developed
Optimisation of processes & inventory	*Personal data*: - *Business data*: Real-time in-store data (e.g. product stock, purchases); real-time online demand; data on inventory and internal processes *Public & research data*: -	- Skills to exploit data - Requires full digitalisation of processes

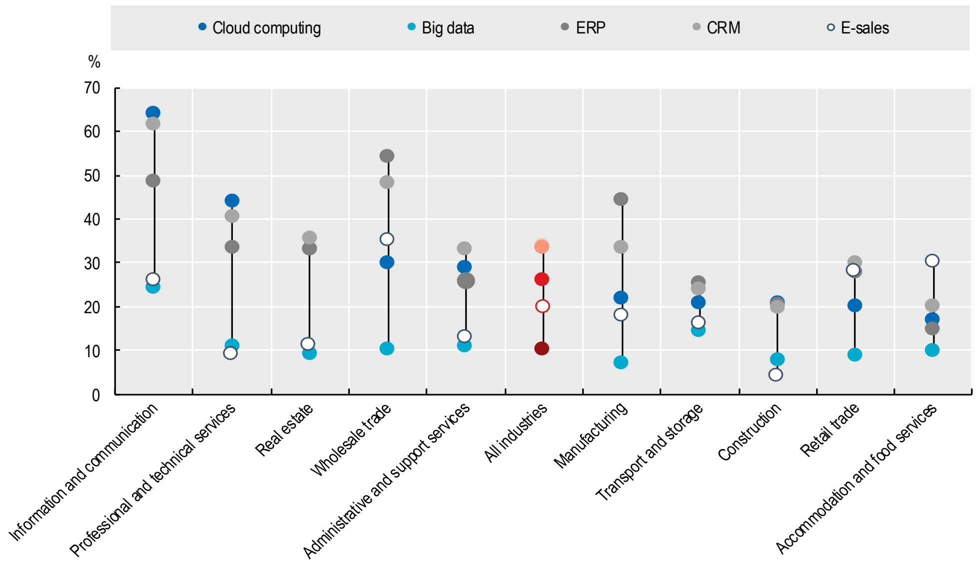
Source: Expert interviews; McKinsey Global Institute (2016[97]).

3.3. Digital technology adoption and diffusion trends

The level of digital technology adoption varies across sectors (Calvino et al., 2018[6]). Industry estimates show that sectors such as automotive and financial services are currently leading AI adoption while others are falling behind, such as the tourism and construction sectors (McKinsey Global Institute, 2017[23]). Data from business surveys in Europe shows that there is significant difference across industries in the adoption of sophisticated digital tools, such as big data analytics, enterprise resource planning (ERP) and customers relations management (CRM) technologies (Figure 3)

Figure 3. ICT uptake by industry, EU28, 2018

As percentage of enterprises with ten or more persons employed in each industry



Source: (OECD, 2019[98]), based on Eurostat, Digital Economy and Society Statistics, January 2019.

Differences in adoption rates stem from variances in sectors' capabilities and incentives to adopt new technologies (Andrews, Nicoletti and Timiliotis, 2018[99]). Key factors influencing adoption include: 1) capabilities to uptake new digital technologies; 2) specific sectoral characteristics and structures; 3) consumer demands and attitudes towards change; and 4) the presence of market disruptors. These challenges are well-known obstacles to the adoption and diffusion of innovation with the exception of the final factor, specific to the disruptive nature of digital technologies for traditional sectors.

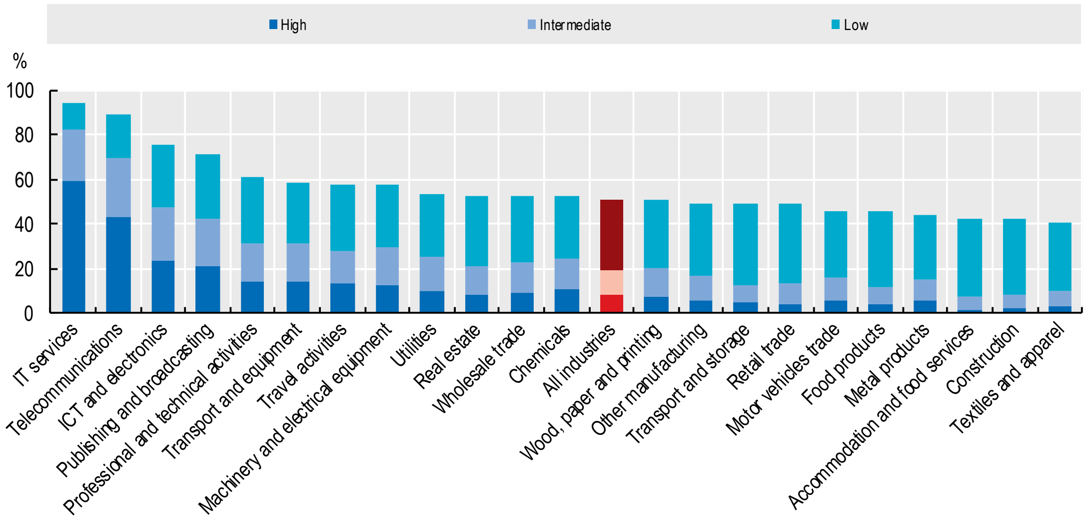
(1) Skills to uptake new digital technologies

Skills are important for digital technology adoption, and these differ significantly across sectors. Capacities needed for digital technology adoption include skills at both the individual level (e.g. ICT skills, data expertise or previous related knowledge) and the organisational level. The latter go beyond "digital" skills and include among others the capacity to fine-tune organisational structures, adjust processes, redefine strategies and tasks, and manage emerging risks. Managers' capacities to steer those changes and an organisational culture supportive of innovation and digital transformation are also critical for successful digital technology uptake.

Figure 4 illustrates differences across sectors in availability of internal ICT capabilities. While in IT services and telecommunications, 40% to 80% of enterprises possess at least intermediate ICT capabilities, in transportation and equipment shares are below 30% and in retail and construction shares are below 10% (OECD, 2019[98]).

Figure 4. Enterprises with internal ICT capabilities, by industry, EU28, 2018

As percentage of enterprises with ten or more persons employed in each industry



Source: (OECD, 2019[98]), based on Eurostat, Digital Economy and Society Statistics, January 2019.

Some sectors may also have more limited resources to build internal digital capabilities, invest in digital technologies, and promote a culture of innovation. In agriculture, investments to deploy precision farming technologies or automate certain tasks are not affordable by family farms or small-scale exploitations, in a context of tight revenue models and high market competition that generate pressures for low food prices.

Disparities in terms of capacities and resources to take up new digital technologies contribute to increasing productivity gaps across firms and sectors. This may lead to "dual economy" situations in the middle to long term, where innovative, technologically advanced and highly productive sectors or firms coexist with traditional, low-productive ones that benefit little from new technologies (Planes-Satorra and Paunov, 2017[100]). The McKinsey Global Institute (2017[23]) suggests that sectors leading AI adoption today are also expected to invest more in AI in the future, leading to widening gaps over time.

(2) Sectoral structures

Sectoral characteristics also influence the pace of digital technology adoption, and particularly on how rapidly digital technologies permeate the activities of different types of actors (including SMEs, large firms, start-ups) within the sector:

- *The distribution of firm size and sectoral fragmentation* – Sectors characterised by firms of relatively large size may transition towards digital differently from sectors with a smaller average firm size. Large firms are usually early adopters of new technologies mainly due to higher resources to invest in new technologies and a higher technical expertise of workers (Zhu, Kraemer and Xu, 2006[101]; Rogers, 2003[102]). Small firms may, in addition of having fewer resources, be more risk-averse, as failed investments could jeopardise their own survival. Yet large firms can also suffer from inertia, rigid hierarchical structures, and legacy systems that may hamper their transformation. Technology diffusion may also be slower in highly fragmented sectors, such as agriculture (with large numbers of individual farms) or health (with large numbers of hospitals and individual practitioners).

- *Access to relevant infrastructure* – The diffusion of digital technology strongly relies on access to critical infrastructure, such as broadband Internet connection and research infrastructures (e.g. R&D facilities, high performance computer centres). This may be a challenge for sectors and firms located in more remote or rural areas.
- *Complexity of supply chains* – Connections among firms along the supply chains also influence uptake dynamics. Firms integrated in global value chains may be more exposed to and have higher incentives to adopt digital technologies: suppliers may adjust more rapidly upon requests from upstream producers to adopt new practices, and receive support to implement them. For instance, Toyota supports its suppliers in implementing their new production systems (Kern and Wolff, 2019[3]).
- *Level of public investments* – The public sector is the main (direct or indirect) provider of some services, such as education and healthcare. Thus the level of digital technology adoption largely depends on the capacity of the public sector to invest in those areas. Differing capacities to invest in and adopt those technologies may lead to cross-country differences in adoption rates.

(3) Consumer demands and attitudes towards change

Changes in consumer demands are also driving the digital transformation of sectors, shaping differences in developments and applications. In the field of transportation, consumer attitudes towards car ownership and use are changing, with the lower propensity of younger generations (especially in urban areas) to own cars and their preference for on-demand schemes. Consumers highly value the in-vehicle experience, with demands for higher customisation, user-friendly interfaces and seamless connectivity between cars and smart phones. In retail, consumers show increasing preference for personalised shopping experiences, online shopping and the quick delivery of products purchased on line. In agriculture, digital technologies can help reduce the use of inputs such as fertilisers, pesticides and water, reducing the impacts of agriculture on environmental degradation.

Attitudes towards change may also differ across sectors, depending on the awareness of opportunities offered by digital technologies, absorption capacities, and the state of development of sector-specific digital technology applications. Low levels of technology adoption may also be a reflection of consumers’ resistance to change, which differs across products. For instance, there may be more resistance to accepting robots for personal care services than for new transportation services.

(4) Presence of market disruptors

The emergence of new market players (i.e. digital start-ups or tech firms that enter existing markets or create new activities adjacent to traditional sectors) is pushing incumbents to innovate. However, such pressures seem to be more critical in some sectors than others. In the automotive industry, the presence of new players such as Alphabet (investing in the development of self-driving cars) and Zipcar (offering car-sharing services that transform the concept of mobility and potentially discourage car ownership) has pushed carmakers to embrace new digital innovations. In agriculture, big machinery producers and input providers are heavily investing in developing software platforms for smart farming services and building strong capabilities in this area, so as to ensure they keep an advantaged position in the emerging smart farming market.

Some sectors are especially affected by the emergence of new platforms that transform the competitive landscape – be they platform marketplaces, platforms for the provision of on-demand services, etc. For example, two types of platforms are reshaping the tourism industry. On the one hand, platforms to search, compare and book accommodation and transportation options (e.g. Booking.com) lower the search and transaction costs of self-organising trips, significantly disrupting traditional travel agencies. For instance, between 2000 and 2014, online hotel booking revenue in the US increased from USD 14 billion to USD 150 billion, while the number of travel agents halved (McKinsey, 2015[7]). On the other hand, peer-to-peer accommodation services platforms (e.g. Airbnb), whereby private owners can easily rent their spare rooms or properties, puts competitive pressure on the hotel industry.

Impacts of market entry on innovation incentives may differ not only across sectors but also across firms. Some studies find that entry of new advanced players spurs innovation of incumbent firms at the technology frontier – as innovation is seen as the appropriate means to face the threat – while it discourages the innovation of laggards (Aghion et al., 2009[103]; Czarnitzki, Etro and Kraft, 2014[104]). The regulatory environment can also influence dynamics by determining what is allowed in terms of disruption.

3.4. Regulatory frameworks

Regulatory frameworks can significantly shape the impacts of digital transformation on innovation across sectors, particularly in highly regulated sectors such as healthcare, agriculture and transportation, for example in the following cases:

- *Regulatory uncertainty* – As technology evolves rapidly, regulatory frameworks are often not able to quickly adjust to new technological conditions and challenges. This can open regulatory breaches and create uncertainty for innovators and users. For example, Uber and Airbnb raised new challenges for regulators on a number of dimensions (e.g. the debate regarding fair competition with taxi drivers or with the hospitality sector). Uncertainty regarding future regulatory reforms concerning new technologies and innovative business models can limit investments in such areas. At the same time, very tight regulation can also inhibit new models from emerging.
- *Regulatory barriers* – The exploitation of data for innovation purposes raises concerns linked to data privacy and security, but also ethical considerations that require regulatory action, e.g. the need for transparency of algorithms to avoid biases and discriminatory decision making. Consumer protection laws (and particularly product liability laws) ensure that all potential product defects are evaluated before entering the market, which affect some manufacturing sectors (e.g. automakers innovating in the area of automated driving) than others. Job security concerns may also lead to regulatory action.
- *Fragmented regulatory frameworks* – Differences across countries in regulations with implications for digital innovation, e.g. in the fields of cybersecurity and data protection, and regulations affecting sector-specific domains such as health, can also lead to different rates of innovation. Mistrust in the capacity of systems to enforce laws protecting data privacy may also limit the capacity to use data for innovation in some sectors and countries more than others.

4. Innovation policy implications

The new context and features of innovation require revising policy support to innovation (OECD, 2019[105]). Differences in the impacts of the digital transformation in different sectors requires taking a sectoral approach when designing innovation policies in some domains, and also raise questions regarding the relevance of traditionally used instruments.

4.1. A shared vision for the future of priority sectors

The following approaches can help designing effective and tailored policy support to sectors operating in a highly uncertain and complex digital technology environment:

- **Roadmaps or sectoral plans for key strategic sectors in the country, in collaboration with industry stakeholders, partners from the science and research community and civil society.** These plans set out long-term visions for sectors, describe the current challenges and opportunities facing them, and define the actions needed to address them. For instance, the six sector-specific Industry Growth Centres in Australia have developed such Sector Competiveness Plans with a specific focus on changes brought by digital technologies (Australian Government, 2017[106]). Sector Deals in the UK follow a similar approach (GOV.UK, 2017[107]). Examples in the automotive sector include the Austrian Research, Development & Innovation Roadmap for Automated Vehicles (Affenzeller et al., 2016[108]) and the Dutch HTSM Roadmap Automotive 2018-25 (Wouters et al., 2017[109]).
- **Foresight exercises to explore long-term policy challenges linked to the digital transformation**. Such exercises involve developing different scenarios used to promote dialogue among stakeholders and jointly identify long-term policy challenges, as well as regulatory barriers and enablers for the diffusion of digital technologies. CSIRO's Data61 in partnership with the Department of Industry, Innovation and Science have developed foresight scenarios to explore how digital innovation might transform Australia in the next decade (Quezada et al., 2017[110]).
- **Mapping of policy instruments that support innovation in different sectors in the digital age to identify gaps and new areas for policy action**, and ensure policy coherence and efficiency. The Digital Roadmap Austria, for instance, maps existing and planned strategies of relevance for the country's digital transformation, as well as their interactions (Federal Chancellery and Ministry of Science, 2016[111]). A similar approach could be followed at sectoral level.

4.2. R&D investment targets in the digital age

R&D expenditures are a major driver of innovation, and most OECD countries have set reaching a higher R&D intensity target (i.e. domestic gross expenditure in R&D relative to GDP) as the main objective of their innovation policies. A variety of policy instruments – notably R&D tax credits, grants for business R&D, etc.– have consequently been implemented.

The fundamental changes to innovation brought by digital technologies, however, raise the question whether this policy target should remain as prominent. In particular, the following major innovation activities might not be captured in R&D investment statistics[3]:

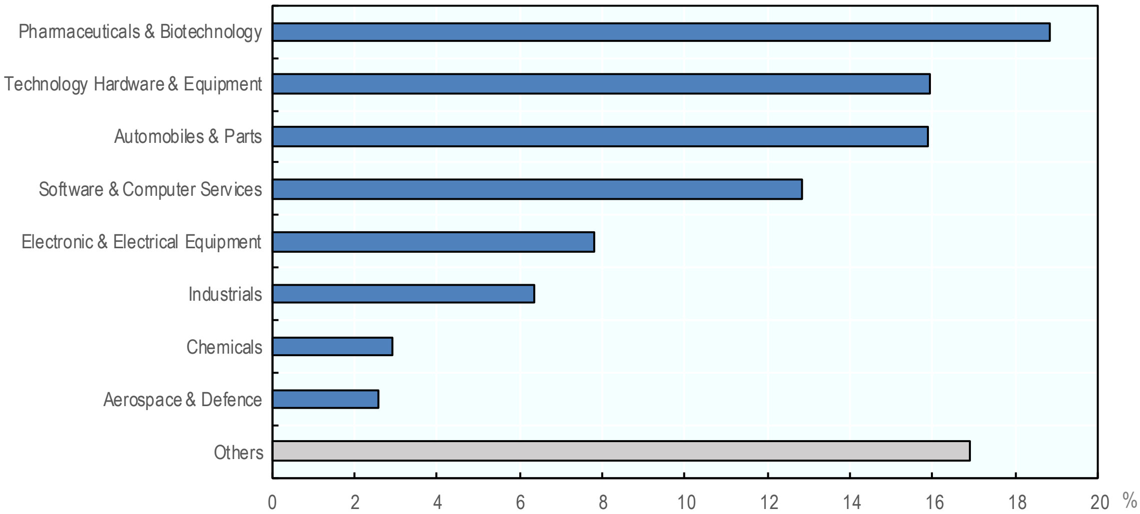
- *Data and software development innovation activities* – Software development is often a source of new or improved business processes or products (e.g. computer games, logistical systems), and data is increasingly used to explore customer preferences that are key to improve the customisation of services. Such developments are often at the roots of services innovation. However, as outlined in the Frascati Manual, only some of these activities are considered R&D[4].
- *Innovation in business processes* – Innovation in the digital age often comes in the form of new or improved production processes, organisational structures, services or delivery methods. If these arise mainly from data and software applications then they would not be captured. Digital technologies are, for instance, enabling innovations that improve efficiency of interactions with suppliers and customers.
- *Business model innovation* – Digital technologies have also spurred organisational and business model innovation (e.g. platform-based on-demand services). These oftentimes result from new combinations of existing technologies and processes but do not necessarily involve traditional R&D investments.
- *The role of capabilities for innovation* – Digital inventions require capabilities if they are to be adopted across firms in traditional sectors. The gap between available and needed capabilities in sectors that were not digital from the onset may slow down adoption in spite of relevant and important R&D investments.

Turning to the evidence, the ideal comparison would be of R&D investment in digital innovations with traditional innovations. This, however, is difficult to do in practice as the most granular data generally available are at company and not innovation project level. We consequently look at business R&D investments in the “born digital” sectors as a way of understanding the R&D investments associated with digital innovation. This is but an imperfect proxy, as the investment behaviour of those firms is very different and notably involve much less business model innovation, data gathering and adoption of software to implement innovations. These sectors also do not display the same skills and adoption dynamics.

Industries directly relating to digital technologies are among the most R&D-intensive sectors: Technology hardware and equipment producers account for 16% of business R&D at global level in 2017, and software and computer services account for 13% of total R&D. The pharmaceuticals and biotechnology (19%) and the automotive sector (16%) are also top industry investors in R&D (Figure 5). Overall, these four sectors account for 63% of the total R&D investments of the top 2,500 world investors (Hernández et al., 2018[112]).

Figure 5. Global Industrial R&D investments by sector, 2017

2500 World's top R&D investors



Note: Worldwide industrial investments in R&D in 2017 are estimated at EUR 736.4 billion. Industrials comprise General Industrials and Industrial Engineering.
Source: The 2018 EU Industrial R&D Investment Scoreboard

Leading digital technology firms (e.g. Alphabet, Microsoft, Huawei, Intel, Apple, etc.) have risen to the top of world top R&D investors, together with a number of automakers (e.g. Volkswagen, Daimler, Toyota, Ford, BMW, GM) and pharmaceutical companies (e.g. Roche, Johnson & Johnson, Novartis) (Table 3). Figure 6 shows that R&D investments of the top firms in ICT sectors (software and computer services sector and technology hardware and equipment, respectively) significantly increased over the past 5 years, placing themselves at the top of the world ranking. For instance, Facebook went from being the 295th firm worldwide in terms of R&D investment in 2011 to the 15th in 2017. Part of those increases are driven by the acquisition of tech firms.

While this preliminary analysis indicates that R&D investments are important for those leading digital firms, a number of open questions will require further investigation in view of understanding how digital innovation can best be supported and what role R&D activities play:

- What is the importance of R&D investments for firms conducting digital innovation in different sectors (beyond leading digital firms explored here)? What is the role of R&D investment for the wider diffusion of such technologies across sectors?
- Are R&D intensity measures the best indicator of innovativeness potential of firms in the digital age? What could be alternative or complementary indicators?

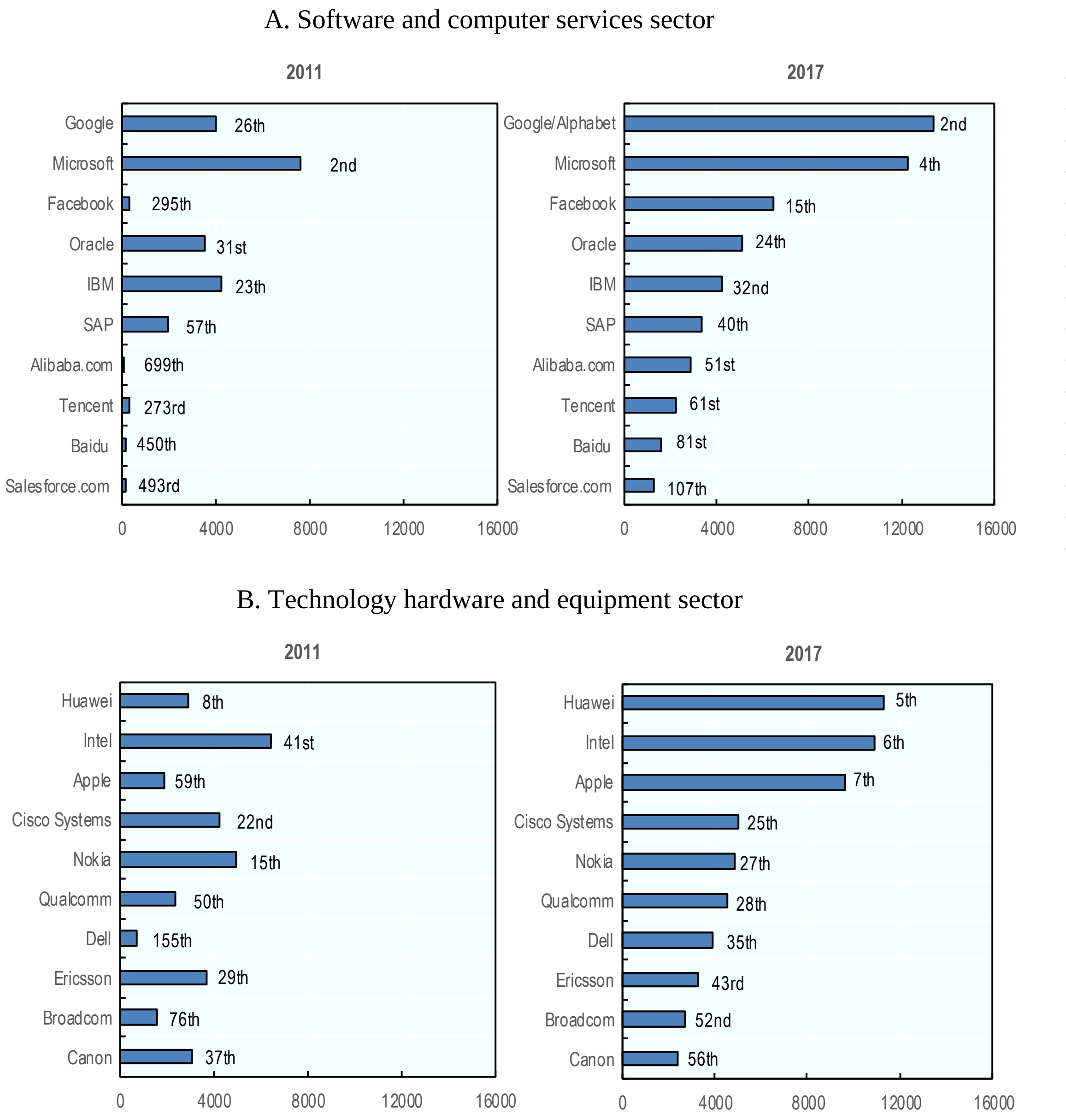
Table 3. World's top 25 companies by their total R&D investment, 2017[5]

World rank	Company	Country	Industry	R&D 2017/18 (EUR million)	R&D one-year growth (%)	R&D intensity (%)
1	SAMSUNG	South Korea	Electronic & Electrical Equipment	13436.7	11.5	7.2
2	**ALPHABET**	US	Software & Computer Services	13387.8	18.4	14.5
3	VOLKSWAGEN	Germany	Automobiles & Parts	13135.0	-3.9	5.7
4	**MICROSOFT**	US	Software & Computer Services	12278.8	13.0	13.3
5	**HUAWEI**	China	Technology Hardware & Equipment	11334.1	16.6	14.7
6	**INTEL**	US	Technology Hardware & Equipment	10921.4	2.8	20.9
7	**APPLE**	US	Technology Hardware & Equipment	9656.5	15.3	5.1
8	ROCHE	Switzerland	Pharmaceuticals & Biotechnology	8884.5	4.8	19.5
9	JOHNSON & JOHNSON	US	Pharmaceuticals & Biotechnology	8800.1	16.0	13.8
10	DAIMLER	Germany	Automobiles & Parts	8663.0	15.0	5.3
11	MERCK US	US	Pharmaceuticals & Biotechnology	8474.1	48.7	25.3
12	TOYOTA MOTOR	Japan	Automobiles & Parts	7859.6	2.6	3.6
13	NOVARTIS	Switzerland	Pharmaceuticals & Biotechnology	7330.9	-2.3	17.5
14	FORD MOTOR	US	Automobiles & Parts	6670.6	9.6	5.1
15	**FACEBOOK**	US	Software & Computer Services	6465.4	31.0	19.1
16	PFIZER	US	Pharmaceuticals & Biotechnology	6167.8	-4.9	14.1
17	BMW	Germany	Automobiles & Parts	6108.0	18.3	6.2
18	GENERAL MOTORS	US	Automobiles & Parts	6086.9	-9.9	5.0
19	ROBERT BOSCH	Germany	Automobiles & Parts	5934.0	0.4	7.6
20	SIEMENS	Germany	Electronic & Electrical Equipment	5538.0	9.5	6.7
21	SANOFI	France	Pharmaceuticals & Biotechnology	5450.0	5.7	15.5
22	HONDA MOTOR	Japan	Automobiles & Parts	5396.8	10.7	4.8
23	BAYER	Germany	Pharmaceuticals & Biotechnology	5162.0	8.1	11.2
24	**ORACLE**	US	Software & Computer Services	5078.8	-1.1	15.3
25	**CISCO SYSTEMS**	US	Technology Hardware & Equipment	5052.1	-3.8	12.6

Note: R&D intensity is measured as the R&D investment per sales ratio. Data based on R&D as reported in companies' most recent accounts. Companies in bold are those in software and computer science and technology hardware and equipment industries.
Source: The 2018 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DF RTD.

Figure 6. R&D investments and ranking of firms in ICT sectors, 2011 and 2017

Top 10 world investors, in million EUR, current prices



Note: As of 2015, part of Google's R&D investments were channelled through its subsidiary Alphabet.
Source: The 2018 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DF RTD.

4.3. Approaches across specific policy fields in support of sectoral digital innovation

(1) Access to data for innovation, taking into account data diversity

With the core role data play in innovation across those sectors, innovation policy needs to also concern itself with policy approaches in this domain. Given that, as discussed in section 3.2, the types of data needed for innovation and conditions to access such data differ across sectors, policy approaches will also not be the same. Practical steps vary when it comes to ensuring the broadest possible access to data and knowledge to favour innovation, while respecting constraints arising from data's diversity, trust (privacy, ethics, etc.), economics (incentives to produce the data, competition, intellectual property), and different national frameworks regarding data protection (OECD, 2015[113]; OECD, 2019[114]).

With regards to transportation, some governments establish open access to data generated by public services (e.g. urban transportation, etc.) in order to promote data-driven innovation. For instance, the open data portal in the United Kingdom (data.gov.uk) publishes data from the central government, local authorities and other public bodies that cover transport. The online platform TransportAPI, which provides real-time country-wide information on departures and timetables as well as journey planning services covering all modes of transportation, was created using such data (TransportAPI, 2018[115])

Regarding private sector data, different criteria for access may be considered. Data that are core to firms' business could be (and in some countries are) treated as trade secrets. In the case of data generated by the core activity of a firm (e.g. data on the manufacturing and use of its products), opening access might hand critical information to competitors, which would be to the detriment of the firm. It could also allow competitors with higher data-processing skills to establish themselves as intermediaries between themselves and their customers, which may not always be conducive to innovation in these sectors. SMEs in particular may be challenged by large firms' uses of big data. Collaborative data sharing platforms are being created in different sectors to share data among different players for innovation purposes while keeping the control over them. The JoinData cooperative in the Netherlands is an example in the agriculture sector.

(2) Support of adoption and diffusion across sectors

Government can implement various instruments to support digital technology adoption tailored to the specific needs of the sector and/or type of actor, such as:

- **Awareness-rising and capacity-building schemes tailored to specific sectoral needs and developments**. Such schemes aim at informing about opportunities offered by digital technologies and take different forms, such as information sessions, the publication of materials for diffusion, or the diffusion of success stories (e.g. virtual maps in France, Germany and Japan). The Digital Extension Centre in Chile provides expert assessment of firm capabilities and needs targeted at SMEs in the agriculture sector (Bravo, 2019[116]). Innovation vouchers (i.e. repayable grants provided to SMEs to purchase services from universities) are also often used to help those firms adopt digital technologies.
- **Demonstration and testing facilities, adapted to the technology needs of the targeted sector/firms**. The SME 4.0 Competence Centres in Germany offer SMEs access to demonstration of specific industry 4.0 technologies and applications, often tailored to specific sectors. Most of these demonstration facilities are located at universities (BMWI, 2019[117]). The MADE programme in Denmark also

organises industrial visits to firms excelling in a particular area and willing to share their experiences, as well as open labs where participants can try out state-of-the-art solutions (MADE, 2019[118]).

- **Intermediary institutions with specific sectoral expertise to connect suppliers and potential users of new digital technologies**. Intermediary institutions (i.e. independent entities that act as catalysts of innovation projects by connecting potential partners) help connect different actors in the innovation ecosystem with field and digital technology expertise, often with the organisation of matchmaking events, the launch of open innovation calls, and the provision of shared facilities and expertise. Digital Catapult in the UK is an example of intermediary that particularly focuses on manufacturing sectors and creative industries, helping firms in those sectors connect with digital start-ups to collaborate in new areas (Digital Catapult, 2019[69]). In Germany, the 72 Fraunhofer Institutes located across the country conduct applied research to support industry innovation, each focusing on different fields of applied science or sectors.

(3) Sectors' experimentation with specific digital innovation applications

Countries should support experimentation with new digital technology developments and applications. These can take different forms:

- **Test beds and living labs**. Test beds are controlled environments (often a physical location, e.g. a specific hospital unit, a clearly delimited area in a city) in which new technology developments can be securely tested in real-world conditions. These can spur innovation by facilitating experimentation with new digital technology applications such as autonomous driving or new medical devices. For instance, Finland has established test beds for self-driving cars – physical locations equipped with needed infrastructure (e.g. access to 5G mobile network) where car manufacturers can test their innovations in a safe environment and collaborate with each other (Team Finland, 2017[119]). Other countries with testing grounds for self-driving vehicles include Austria (ALP.Lab, DigiTrans), Germany (A9 Digitale Autobahn) and Sweden (AstraZero) (MBMWF, MBVIT and BMDW, 2018[120]). In the United Kingdom, a Test Beds Programme was introduced in 2016 by the National Health Service (NHS) in partnership with industry to allow testing innovations (e.g. combinations of new digital devices such as sensors, monitors, wearables with data analysis) and new approaches to health service delivery facilitated by digital technologies in specific hospitals and groups of patients. Successful innovations are then scaled-up to the entire health system (NHS England, 2018[121]).

  Living labs are "user-centred, open innovation ecosystems, integrating research and innovation processes in real life communities and settings" (ENoLL, 2018[122]). They are localised areas of experimentation within urban environments, in which stakeholders collaboratively develop new technology-enabled solutions. In Antwerp (Belgium), a "City of Things" is being developed through installation of a dense network of smart sensors and wireless gateways in buildings, streets and objects. Collected data can be used by companies to build innovative smart city applications (Department of Economics, Science and Innovation, 2017[123]).

- **Regulatory sandboxes to foster innovation in highly regulated sectors**. Regulatory sandboxes provide flexibility for firms to test new products or business models with reduced regulatory requirements, while preserving some safeguards (e.g. to ensure appropriate consumer protection). Sandboxes help identify and better respond to regulatory breaches, and enhance regulatory flexibility. They are particularly relevant in highly regulated industries, including transport (ITF, 2015[124]) but also energy (OECD/IEA, 2047[125]), health (OECD, 2017[126]) and financial services (OECD, 2018[127]). Most regulatory sandboxes have been developed for the fintech and energy sectors. In the energy sector, the British Office of Gas and Energy Markets created their Innovation Link service, a "one stop shop" offering rapid advice on energy regulation to businesses. When regulatory barriers prevent launching a product or service that would benefit consumers, a regulatory sandbox can be granted to enable a trial (Ofgem, 2018[128]).

(4) Collaboration across sectors and interdisciplinary innovation

Innovation in the digital age is often the result of new combinations of existing technologies and competences applied in new areas. Fostering cross-fertilisation and collaboration across traditional and digital technology sectors and between industry and research is therefore critical. Support instruments include the following:

- **Spaces for collaboration and co-creation**. Some countries have created spaces for multidisciplinary teams of public researchers and businesses to work together to address specific technology challenges. For instance, the Smart Industry Fieldlabs in the Netherlands are public-private partnerships that create physical or digital spaces for member companies and research institutions to jointly develop, test and implement new smart industry technological solutions. The 15 fieldlabs in South Holland are part of a regional network that contributes to cross-sector cooperation for innovation (Stolwijk and Punter, 2019[46]).
- **Cross-disciplinary university programmes and industrial PhDs.** Many universities currently offer interdisciplinary undergraduate degrees with a digital component (e.g. MIT undergraduate degrees on computer science and biology, and on computer science, economics and data science), as well as industrial PhD programmes, where PhD students conduct a research project jointly supervised by a university and a private firm, and often students need to attend some mandatory business courses (e.g. in the case of the Industrial PhD Programme managed by the Innovation Fund Demark) (MIT, 2018[129]; University of Copenhagen, 2019[130]). Companies are also more strongly engaging with universities to access talent in different fields. Siemens for instance organises hackathons together with universities, where students are asked to develop new business models based on unused patents owned by the company. Such instruments can foster innovation in specific sectors building on competences that were traditionally not at the core of their skills sets.

5. Conclusions

Digital technologies are changing innovation practices and outcomes. Five trends are found to be affecting practically all sectors of the economy in similar ways: Innovation is increasingly data-based, enabled also by the deployment of the Internet of Things (IoT); services are at the centre of innovation; innovation cycles are accelerating; innovation processes are more collaborative; and firms invest in new organisational capabilities to better embrace digital innovation. Sector-specific dynamics are also observed, due to differences in digital technology uptake capacities, data needs and infrastructure access conditions, among others.

Several policy implications emerge from the analysis. First, as the characteristics of innovation are changing in the digital age and impacts differ across sectors, developing sectoral roadmaps and strategic foresight exercises with the private sector can help define policy priorities and tailor support to their specific needs. Second, the focus of innovation policies on boosting R&D investments to meet R&D intensity targets (and the implementation of related instruments, such as R&D tax credits) requires scrutiny, as major innovation activities in the digital age, such as innovation in services, software and business models, are not well captured in R&D statistics. Third, adopting a sectoral approach when designing innovation policies can help support the uptake of digital innovation, specifically in some domains such as data access and digital technology adoption policies.

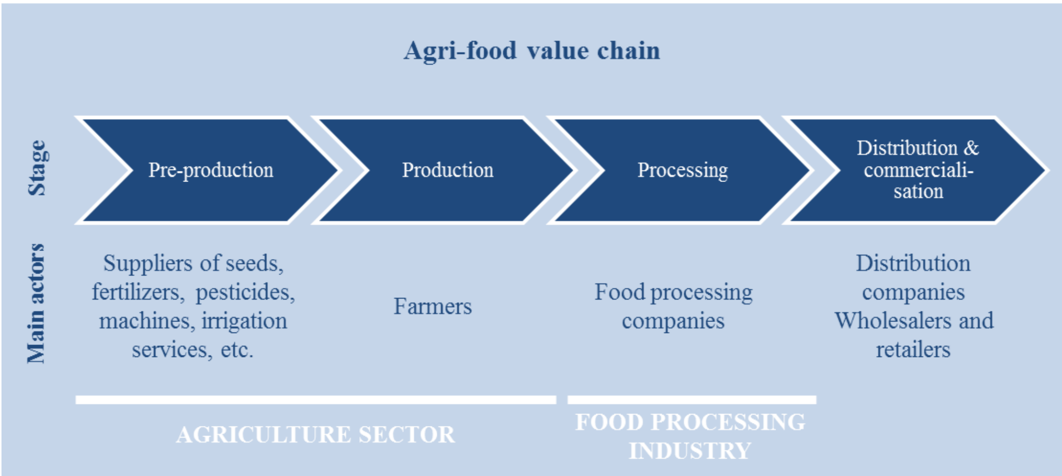
This paper is a first step in understanding how innovation in the digital age changes across different sectors. In focusing on those current changes, the paper does not provide an exhaustive coverage of impacts across all different actors within the selected sectors. Developments of large and leading players are given higher priority, complemented with perspectives from middle-size companies and industry associations representing SMEs on selected technology developments. An important priority for policy research in this field involves producing a heatmap of which changes are taking place, taking into account differences across technologies in their uptake and development across firms, regions and countries. Understanding more what developments take place in which sectors, and where progress is slow can inform policy better in identifying where to act.

Annex. Definition of sectors covered in the paper

Agriculture sector

The agriculture sector comprises the production, processing, distribution and commercialisation of food. This paper analyses the impacts of digital transformation on innovation in the production stage of the agriculture value chain (Figure 7) (relating to the activities of the ISIC Rev.4 classification under Section A, Division 01, except for Group 017). The main actors traditionally involved in these activities are the producers (i.e. farmers), the manufacturers of agricultural equipment (e.g. tractors), the suppliers of seeds, fertilizers and other inputs and services. The paper also broadly covers the impacts of digital technologies on the food processing industry (Section C, Division 10), particularly regarding management of the agriculture supply chain.

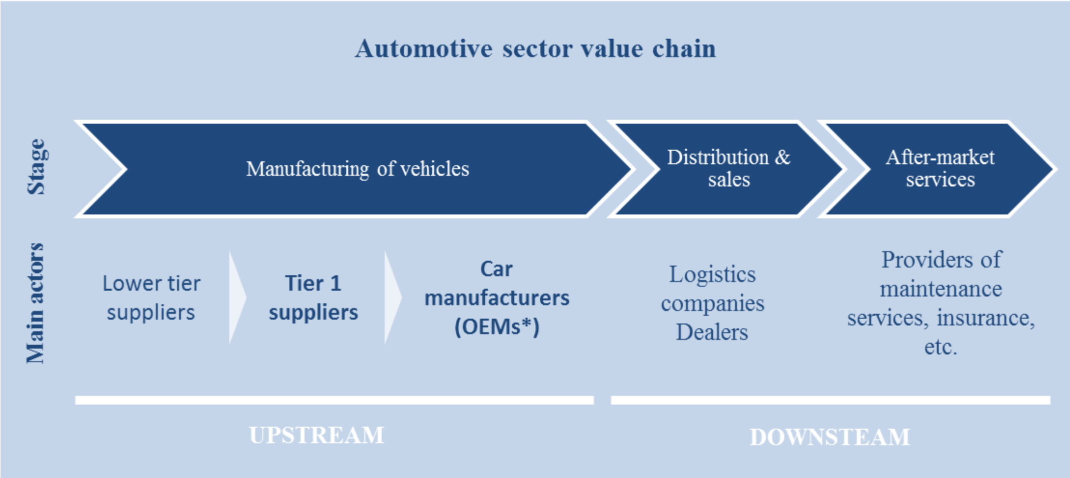
Figure 7. Agriculture value chain: stages and main actors



Automotive and transportation sectors

Value chains in the automotive sector comprise the manufacturing, distribution and commercialisation of vehicles, as well as after-sales activities. This paper explores the impacts of digital transformation on the innovation activities of large car manufacturers (or automotive original equipment manufacturers, OEMs) and first tier suppliers (i.e. direct suppliers of components and parts to OEMs) (Figure 8) (corresponding to the activities of the ISIC Rev.4 classification under Section C, Division 29). The paper also covers the road passenger transportation services in urban areas (corresponding to the activities under Section H, Division 49, Class 4922 of the ISIC Rev.4 classification).

Figure 8. Automotive value chain: stages and main actors



Retail

The retail sector involves the process of selling consumer goods or services to ultimate consumers, both online and at physical stores (corresponding to the Section G, Division 47 of the ISIC Rev. 4 classification). These also include the processes of transportation of products from warehouses to stores and to consumers' place by retailers. This paper analyses the impacts of digital transformation on the innovation activities of large retailers.

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[1] The four workshops were the following: *Innovation and the digital economy: what role for innovation policies?*, Paris, 14 June 2017; *The impacts of digital transformation on innovation across sectors*, London, 21-22 September 2017, organised jointly with Innovate UK and Digital Catapult; *Digital Health Innovations*, The Hague and Eindhoven, 11-13 April 2018, organised jointly with the Dutch Ministry of Economic Affairs and Climate Policy; *How to leverage the potential of the digital transformation for innovation?*, Paris, 20 June 2018.

[2] See OECD (2018[135]) on the metrics to assess the effects of IoT in different policy areas.

[3] The Frascati Manual specifies that R&D activities must meet five criteria: (i) novel; (ii) creative; (iii) address an uncertain outcome; (iv) systematic; and (v) transferable and/or reproducible. R&D comprises basic research, applied research, and experimental development (OECD, 2015[134]).

[4] "The nature of software development is such that it is difficult to identify its R&D component, if any. Software development is an integral part of many projects that in themselves have no element of R&D. The software development component of such projects, however, may be classified as R&D if it leads to an advance in the area of computer software. Such advances are generally incremental rather than revolutionary. Therefore, an upgrade, addition or change to an existing program or system may be classified as R&D if it embodies scientific and/or technological advances that result in an increase in the stock of knowledge. The use of software for a new application or purpose does not by itself constitute an advance (OECD, 2015, p. 65[134]).

[5] R&D figures may in some case be under- or over-stated, as is the case of Amazon. The firm includes most R&D investments under the heading 'technology and content' – a total of USD 22.6 billion in 2017, 41% more than in 2016. It is estimated that a significant part of this constitutes R&D, which would place the company in the 3rd or 4th position of the global R&D business ranking (Hernández et al., 2018[112]).