INVESTMENT REPORT
2021/2022

European Investment Bank
The EU bank

Recovery as a springboard for change

Chapter 5
Investing in Europe's digital transformation

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Part III Recovery as a springboard for structural change

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Investing in Europe's digital transformation

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Investment Report 2021/2022: Recovery as a springboard for change.

About the Report

The EIB annual report on Investment and Investment Finance is a product of the EIB Economics Department. It provides a comprehensive overview of the developments and drivers of investment and its finance in the European Union. The report combines an analysis and understanding of key market trends and developments with a more in-depth thematic focus, which this year is devoted to Europe's progress towards a digital and green future in the post-COVID-19 era. The report draws extensively on the results of the annual EIB Investment Survey (EIBIS) and the EIB Municipality Survey. It complements internal EIB analysis with contributions from leading experts in the field.

About the Economics Department of the EIB

The mission of the EIB Economics Department is to provide economic analyses and studies to support the Bank in its operations and in the definition of its positioning, strategy and policy. The director of Economics Department, Debora Revoltella, heads a team of 40 economists.

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Published by the European Investment Bank.

Printed on FSC® paper.

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Acknowledgements

José Maria Alvarès, Enrico Minnella, Luca Restaldi and Nicola Vianello provided research assistance.

Chapter 5

Investing in Europe's digital transformation

Download the complete report:
www.eib.org/investment-report-2021
www.doi.org/10.2867/82061

Available as:

print:	ISBN 978-92-861-5156-9	ISSN: 2599-8269
pdf:	ISBN 978-92-861-5155-2	ISSN: 2599-8277

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Chapter 5

Investing in Europe's digital transformation

The COVID-19 crisis has accelerated the digital transformation of Europe's economy. Close to half of firms in the European Union report investing in digitalisation as a response to the pandemic — for example, by providing services online — according to the EIB Investment Survey (EIBIS). Until recently, the implementation of digital technologies was considered important for market success and was usually associated with the most innovative and modern companies. However, the pandemic has made the digital transformation an integral part of society — and integral to firms' survival. Digitalisation can transform business dynamics, work organisation, education, health and government services.

Digital firms were better able than non-digital firms to cope with the disruption unleashed by the pandemic. They were less likely to experience a strong decrease in sales since the beginning of 2020. In addition, while policy support for the private sector was widespread and did not target digital firms in particular, digital firms report more often than other firms that they used the crisis as an opportunity to accelerate digitalisation. This suggests that the crisis forced them to find more efficient ways of working with digital technologies. Overall, digital firms tend to perform better than non-digital firms. They are more productive, export more, invest more, are more innovative, grow faster and pay higher wages on average.

With digitalisation advancing fast, the European Union is facing a digital dilemma. Some EU firms are at risk of being left behind, in particular in regions where digital infrastructure is lacking. One in six EU firms consider access to digital infrastructure to be a major obstacle to investment. However, this assessment varies significantly across EU countries and regions within countries. Significant investment in digital infrastructure is needed across the European Union to support a broad-based economic recovery. Firm size also partly determines digital investment. The failure of many small EU firms to adopt digital technologies could have negative implications for Europe's long-term competitiveness. These firms need to reassess their operating environment and to invest to innovate and adapt. Digital investment will help ensure firms' survival and ability to thrive in a new, more digital environment.

Accelerating the European Union's digital transformation will also require a policy framework that fosters cutting-edge digital innovation. Digitalisation has completely transformed research, innovation and technology, intensifying the pace at which ideas spread. Digital innovation is no longer the exclusive domain of software companies, and it is crucial for an increasing variety of innovative businesses across many sectors. For example, all areas of technology are becoming data-intensive, increasingly relying upon and generating big data. A few notable examples are new battery technologies, precision agriculture, 3-D bioprinting used for medical applications and autonomous vehicles.

The European Union is lagging behind the United States and China for digital innovation and patent applications relevant to industry 4.0, but Europe's excellence in certain areas of innovation can be used to its advantage. Some of the continent's traditional sectors, such as the automotive industry, could potentially embark upon a new era of innovation thanks to digital innovation. In fact, the European Union is a global leader for patenting activities at the crossroads of digital and automotive technologies and digital and green technologies. Another sector where digitalisation could play a major role is healthcare, especially in light of the COVID-19 pandemic. Nevertheless, unlike overall healthcare innovation, patenting activity that combined digital innovation and healthcare did not pick up as an immediate response to the health crisis. The **European Green Deal** and the European Union's **Digital Strategy** constitute the cornerstone of the recovery plan for Europe. These initiatives, combined with the national recovery and resilience plans, represent a unique opportunity to transform the EU economy and make it greener, more digital and more innovative.

Introduction

The coronavirus crisis has accelerated the digital transformation of Europe's economy. Close to half of firms in the European Union report investing in digitalisation as a response to COVID-19 — for example, by providing services online — according to the EIB Investment Survey (EIBIS). Until recently, the implementation of digital technologies was considered important to market success and was usually associated with the most innovative and modern companies. However, the pandemic has made the digital transformation an integral part of society — and integral to firms' survival.

This chapter discusses the rapid digitalisation efforts of firms in the European Union during the pandemic. Digital firms were better able than non-digital firms to cope with the disruption unleashed by the COVID-19 pandemic. They were less likely to experience a decrease in sales since the beginning of 2020. Digital firms more often report that they used the crisis as an opportunity to accelerate digitalisation. This suggests that the crisis forced them to find more efficient ways of working with digital technologies. Overall, digital firms tend to perform better than non-digital firms. They are more productive, export more, invest more, are more innovative, grow faster and pay higher wages on average.

The chapter also analyses patent data to map recent patterns in cutting-edge digital innovation. Digital innovation is no longer the exclusive domain of software companies, and it is crucial for an increasing variety of innovative businesses across many sectors. The European Union is lagging behind the United States and China in digital patents. However, it is at the forefront of developments where digital innovation meets green and automotive technologies. Some of the continent's traditional sectors, such as the automotive industry, could potentially embark upon a new era of innovation thanks to major changes triggered by digital innovation. In addition, new green technologies will be key enablers of the green transition envisioned under the European Green Deal. The chapter also discusses how digital technologies have supported innovation in the healthcare domain. It concludes by highlighting the importance of developing effective public policies that incentivise investment in the digital transformation and innovation to address the COVID-19 crisis and foster the green transition.

Digitalisation during the COVID-19 crisis

Responding to the pandemic

The pandemic led to wider recognition of the importance of the digital transformation. Until recently, the implementation of digital technologies was considered important for market success and was usually associated with the most innovative and modern companies. However, the pandemic has made the digital transformation integral to firms' survival. Many of the changes associated with digitalisation are likely to stay. Investment in digitalisation is vital to preventing business disruption, organising work remotely, improving communication with customers, suppliers and employees and selling products and services online.

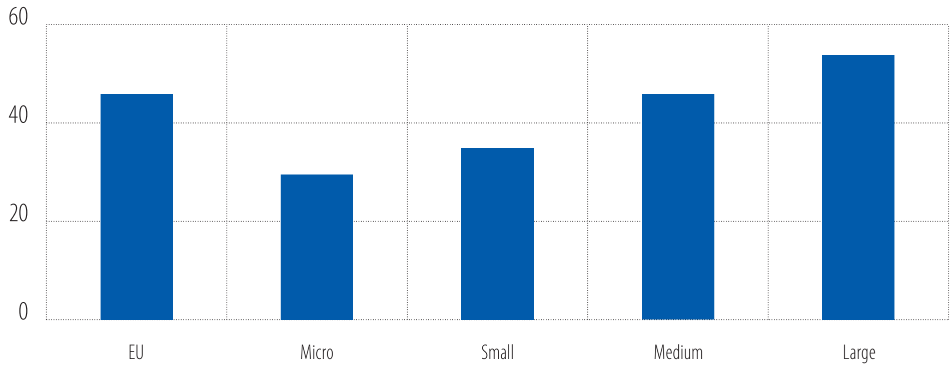
As a response to the COVID-19 crisis, many firms invested in digitalisation. In the European Union, 46% of firms report that they took action to become more digital — for example, by providing services online — according to the results of the EIBIS conducted from April to July 2021. However, significant differences exist across firm size classes, sectors and countries.[1] Micro and small firms are lagging behind medium-sized and large firms: only 30% of micro firms stated that they took steps to improve digitalisation, compared with 54% of large firms (Figure 1).[2] Furthermore, 49% of firms in the services sector report they

1 All the associations discussed in the analysis using EIBIS data — such as the link between digitalisation and firm size or firm performance — also hold in multivariate regression analysis controlling for potential factors that might confound the analysis, such as size, sector and country of the firms.

2 All figures relying on EIBIS data are weighted using value added to make the sample of firms covered by EIBIS representative of the economy.

invested in digitalisation, compared with 32% of firms in the construction sector, which reflects different dynamics across sectors during the pandemic (see Chapter 3). Comparing the different EU regions, 48% of firms in Western and Northern Europe reported taking steps or investing to become more digital, compared with 43% in Southern Europe and 37% in Central and Eastern Europe.

Figure 1
Firms that invested to become more digital as a response to COVID-19 (in %)



Source: EIB Investment Survey 2021, firms in the EU27.
Question: As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)?

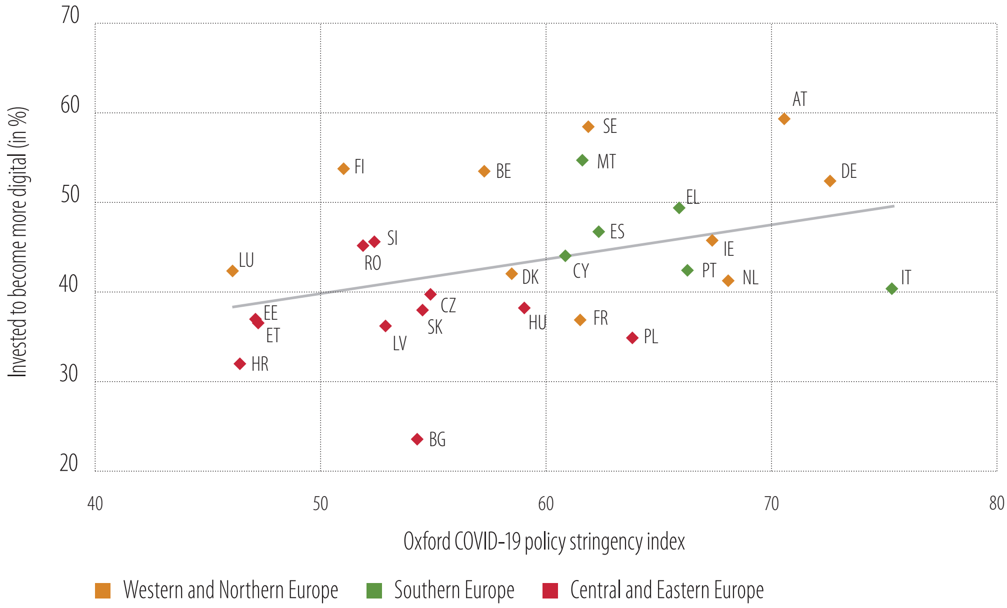
Digitalisation efforts appear to be linked to health-related measures put in place by governments during the COVID-19 pandemic, such as restrictions on movement. Throughout the pandemic, firms across the European Union were faced with different workplace closure and stay-at-home requirements. Firms were more likely to state that they invested in becoming more digital in countries with stricter measures (Figure 2).

Public policy support provided over the past three years to encourage firms to become more digital helped accelerate the digital transformation during the COVID-19 crisis. Some 15% of small and medium-sized enterprises (SMEs)[3] report having received public support — such as government grants, subsidies or subsidised finance from the public sector — to accelerate digitalisation investments over the past three years. Among the firms that benefited from this financial support, 67% report that they also took action to become more digital during the COVID-19 crisis, compared to only 38% of SMEs that did not receive previous support (Figure 3). This evidence shows that targeted incentives, when they are well designed, can make a difference in accelerating the digital transformation of the European Union.

3 See the Data Annex for more information on the EIBIS 2021 AOM survey, which covers a sample of EU SMEs in manufacturing and services.

Figure 2

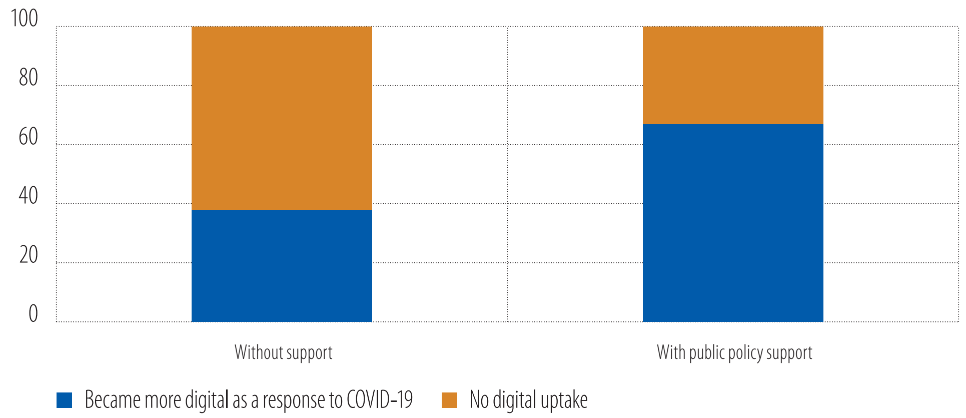
Firms that invested in becoming more digital as a response to COVID-19 and the pandemic-related policy stringency index



Source: EIBIS 2021, firms in the EU27 and Oxford COVID-19 Government Response Tracker (second quarter of 2021).
Question: As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)?

Figure 3

SMEs that invested in becoming more digital as a response to COVID-19 and received public support for digitalisation over the past three years (in %)



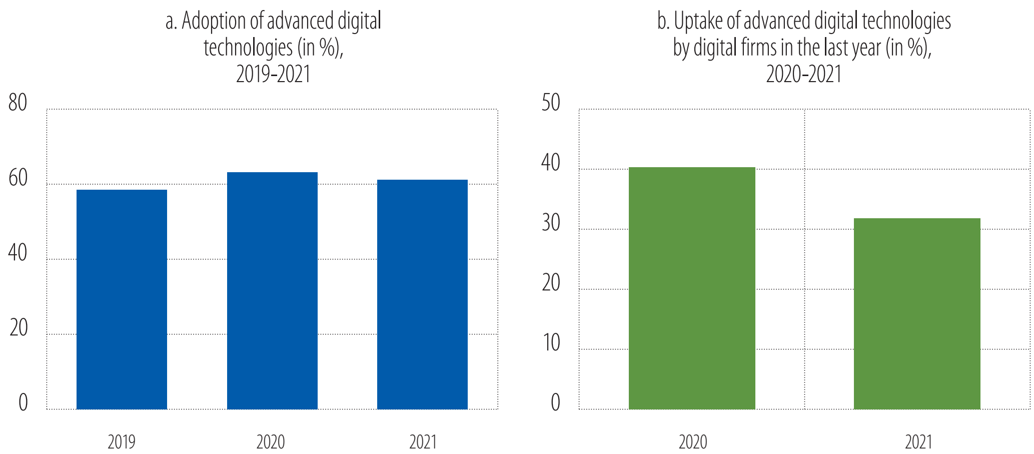
Source: EIBIS 2021 add-on module (AOM) — sample of EU SMEs in manufacturing and services (2021).
Question: As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)? In the past three years, have you received public support (e.g. government grants, subsidies, subsidised finance from the public sector) to accelerate investments in order to become more digital?

Implementation of advanced digital technologies

During the COVID-19 crisis, firms put more complex digitalisation processes on hold. In contrast to the more general digital transformation, the adoption of new advanced digital technologies is stalling. Beyond the short-term response to COVID-19, another structural element for the digital transformation of the EU economy is the implementation of advanced digital technologies such as 3-D printing, advanced robotics, the internet of things, big data analytics and artificial intelligence, drones, augmented or virtual reality, or platforms. The share of EU firms implementing advanced digital technologies in their business increased significantly from 2019 to 2020 (Figure 4a). However, this share stayed more or less constant from 2020 to 2021, reaching 61% in 2021, compared to 63% 2020 and 58% in 2019.

The share of firms that report having implemented new advanced digital technologies in their business in the past year was lower in 2020 than in 2019. Adopting advanced digital technologies is often a complex process, requiring a reorganisation of the company's business and re-training of staff. It is likely that, against the backdrop of the pandemic, firms have been delaying the most complex investment projects, focusing on their immediate needs. New, advanced and complex digital technologies appear to have been less of a priority for many firms during the COVID-19 crisis.

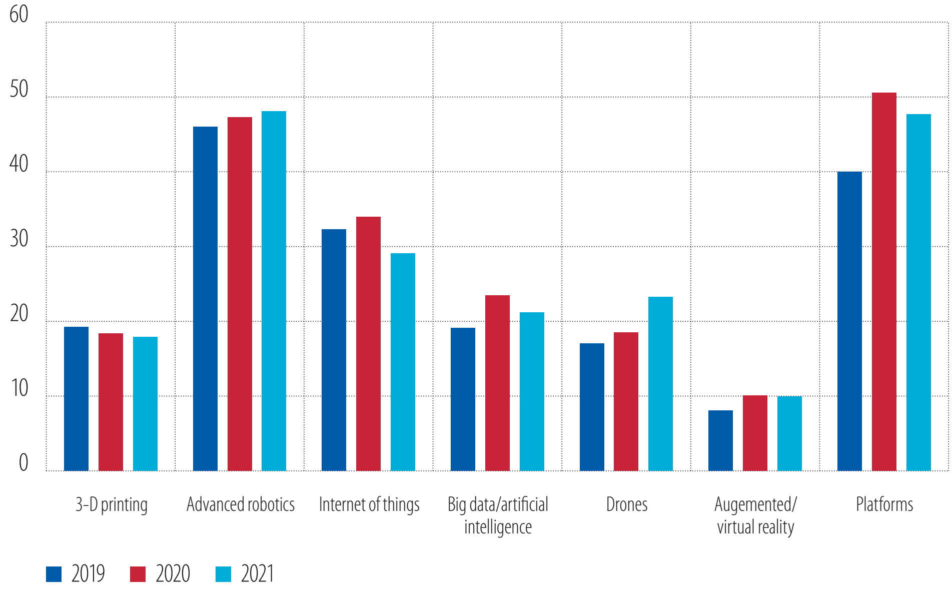
Figure 4
Adoption of advanced digital technologies



Source: *EIBIS 2019, 2020, 2021, firms in the EU27.*
Note: *A firm is identified as having adopted an "advanced digital technology" if at least one digital technology specific to its sector was implemented in parts of the business and/or if the entire business is organised around at least one digital technology. The question on whether any new digital technology was introduced in the last year was not asked in EIBIS 2019.*
Question: *Can you tell me for each of the following digital technologies if you have heard about them, not heard about them, implemented them in parts of your business, or whether your entire business is organised around them? Firms were asked to answer the question for four different digital technologies specific to their sector (see the note to Figure 5 for the definition of digital technologies).*
Question: *You just said that you implemented digital technologies in your business or organised your entire business around them. Did you introduce any of these technologies in the past year?*

Platforms and advanced robotics remain the most widespread digital technologies. The implementation of most advanced digital technologies has not changed significantly since the beginning of the pandemic. An exception is the implementation of the internet of things, which decreased slightly across all sectors, while the adoption of drones (used by firms in the construction sector) increased (Figure 5).

Figure 5
Adoption of specific digital technologies (in %)

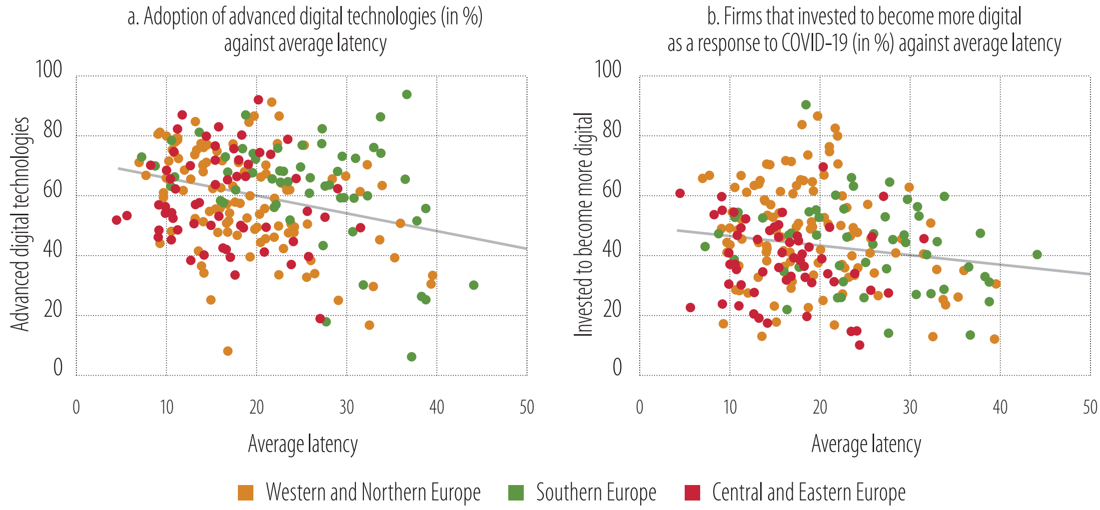


Source: *EIBIS 2019, 2020, 2021, firms in the EU27.*
Note: *"3-D printing" is also known as additive manufacturing (manufacturing, construction, infrastructure). "Robotics" is automation via advanced robotics (manufacturing). "Internet of things" refers to electronic devices that communicate with each other without human assistance (all sectors). "Big data/artificial intelligence" refers to cognitive technologies, such as big data analytics and artificial intelligence (manufacturing, services, infrastructure). "Drones" are unmanned aerial vehicles (construction). "Virtual reality" refers to augmented or virtual reality, such as presenting information integrated with real-world objects using a head-mounted display (construction, services). "Platforms" refers to a platform that connects customers with businesses or customers with other customers (services and infrastructure).*
Question: *Can you tell me for each of the following digital technologies if you have heard about them, not heard about them, implemented them in parts of your business, or whether your entire business is organised around them?*

The role of the operating environment

Digital infrastructure played a critical role during the coronavirus pandemic. Among EU firms, 16% consider access to digital infrastructure to be a major obstacle to investment, according to the latest EIBIS results. However, the assessment varies significantly across EU regions. For example, firms operating in regions with low average latency (a proxy for a good internet connection) tend to have higher rates of digital adoption (Figure 6a), and they are more likely to have invested in digitalisation as a response to COVID-19 (Figure 6b). The responses indicate that many EU regions have the potential to unlock investment in the digital transformation of businesses by making access to faster broadband more widespread. The operating environment has an impact on firms' decisions to become more digital.

Figure 6
Quality of digital infrastructure and digital adoption, by NUTS2 regions

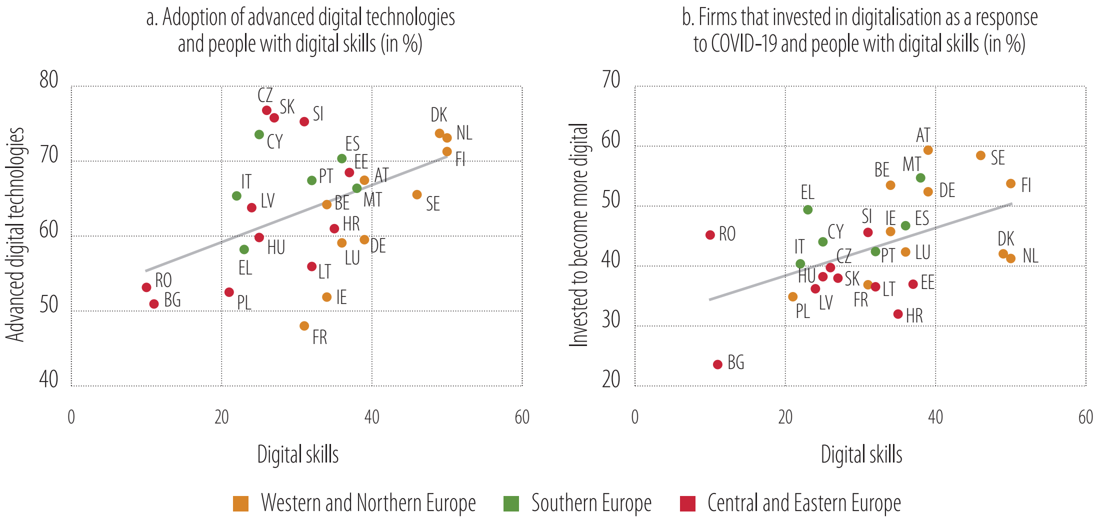


Source: *EIBIS 2021, firms in the EU27 and European Data Journalism Network (2021).*
Note: *Latency is the time it takes for data to be transferred between its original source and its destination, measured in milliseconds. Red dots: NUTS2 regions in Central and Eastern Europe, green dots: NUTS2 regions in Southern Europe, orange dots: NUTS2 regions in Western and Northern Europe. See note to Figure 4 for the definition of the adoption of advanced digital technologies. NUTS refers to the Nomenclature of Territorial Units for Statistics.*
Question: *As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)?*

The availability of people with digital skills supports the digital transformation. Firms operating in countries where a higher share of the population has above-average digital skills tend to have implemented advanced digital technologies more often (Figure 7a). They are also more likely to report having taken action on increasing their digitalisation or made investments (Figure 7b). Reaping the benefits of digitalisation will require improvements in education and training systems as well as online learning for groups that are currently excluded from the digital economy (see Chapter 4).

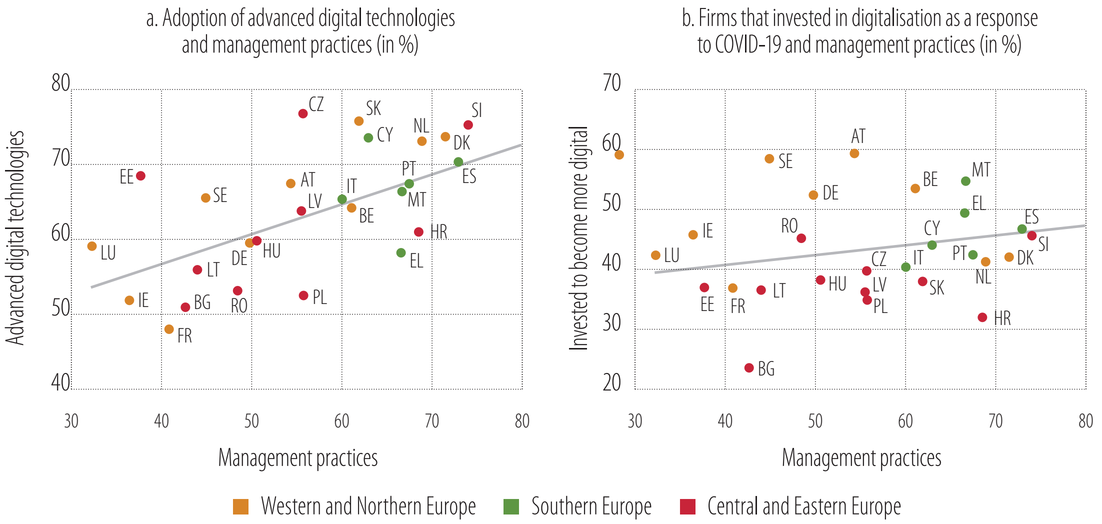
Firms that have invested in the digital transformation also tend to implement better management practices. Firms based in countries with a high share of firms saying that they use strategic business monitoring systems and key performance indicators (a proxy for management quality) are more likely to have implemented advanced digital technologies (Figure 8a). Management practices are also linked to the uptake of digitalisation during the pandemic, even though the positive correlation is less pronounced (Figure 8b). Furthermore, firms that have adopted advanced digital technologies tend to reward individual performance with higher pay, and they are more likely to have appointed a designated person responsible for defining and monitoring climate change strategies. These firms more frequently report that they have set and are monitoring targets on carbon emissions and energy consumption. These findings are in line with results from previous studies highlighting the importance of management practices for technology adoption and firm performance (Bloom et al., 2019; EIB, 2020).

Figure 7
Digital adoption and share of population with high digital skills



Source: *EIBIS 2021, firms in the EU27 and Eurostat.*
Note: *See note to Figure 4 for the definition of the adoption of advanced digital technologies.*
Question: *As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)?*

Figure 8
Digital adoption and management practices



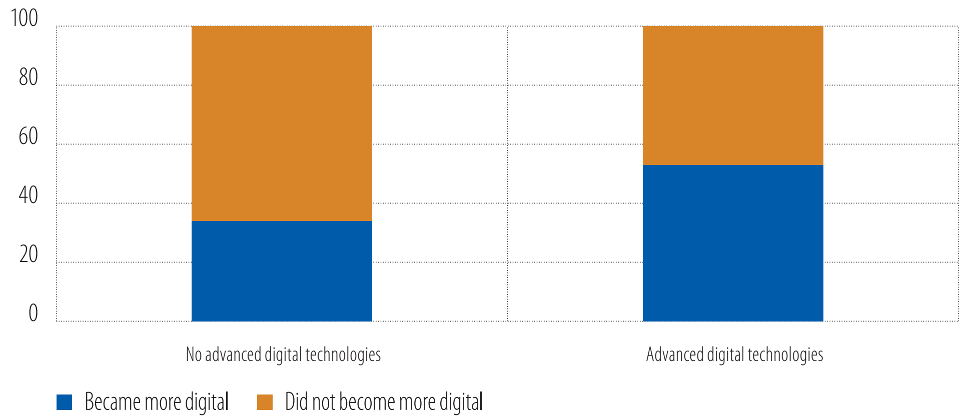
Source: *EIBIS 2021, firms in the EU27.*
Note: *See note to Figure 4 for the definition of the adoption of advanced digital technologies.*
Questions: *In 2020, did you company use a strategical business monitoring system? As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)?*

The digital divide revisited

Firms that already implemented advanced digital technologies are more likely to report that they invested in increasing digitalisation activities in response to COVID-19. The finding suggests that the coronavirus pandemic has not been the driving factor pushing firms to catch up, but instead has further deepened the digital divide. Leading firms pushed ahead while lagging firms fell even further behind (Rückert et al., 2021). Nevertheless, 34% of firms have used the crisis as an opportunity to begin to invest in their digital transformation, compared with 53% of firms that had already adopted advanced digital technologies and invested in becoming more digital (Figure 9). At country level, the share of firms that made digital investments during the COVID-19 crisis is positively associated with the implementation of advanced digital technologies in the same country.

Figure 9

Firms that invested in digitalisation as a response to COVID-19 (in %)



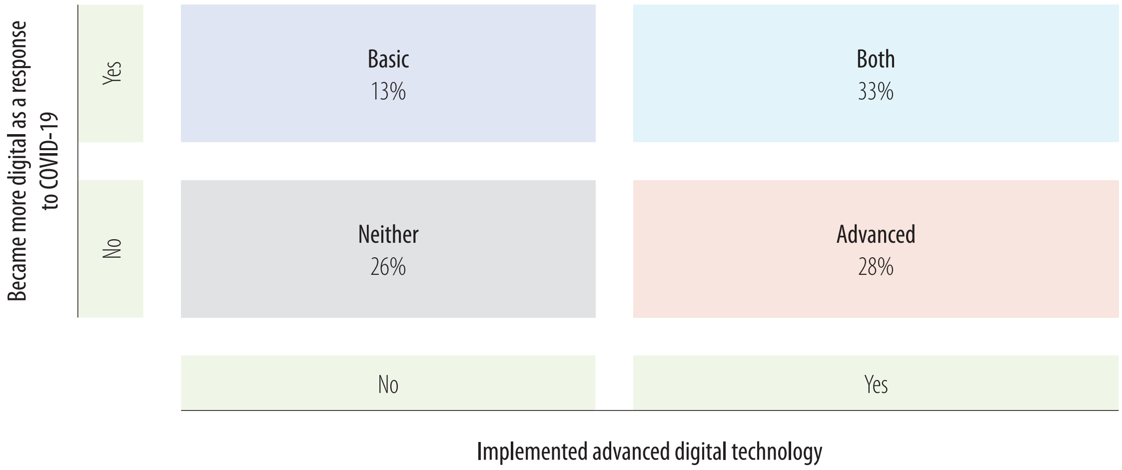
Source: EIBIS 2021, firms in the EU27.
Question: As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)? See note to Figure 4 for the definition of the adoption of advanced digital technologies.

Firms are grouped into four different profiles to identify where they fall in the digital divide. The four categories are based on the combination of firms' current implementation of advanced digital technologies, and the action they took to become more digital as a response to COVID-19: neither, basic, advanced and both. Figure 10 positions firms on the digital divide grid according to these categories and displays the share of EU firms in each category.

A substantial share of EU firms did not invest in digitalisation, despite the impact the pandemic had on the economy. Of EU firms, 26% have not invested in digital transformation: they are in the "neither" category, at the bottom of the corporate digital divide. The large share of firms not investing in digitalisation is worrying and could have serious repercussions on firms' competitiveness during the economic recovery. Firms that fall in the "neither" category may need stronger or specific policy support to prevent them from falling behind.

On the upside, a non-negligible share of firms has used the COVID-19 pandemic to embark on their digitalisation journey. These companies have not implemented any advanced digital technology in their business yet but have taken action to become more digital as a response to COVID-19 — for example, by providing services online — and are categorised as "basic" digital.

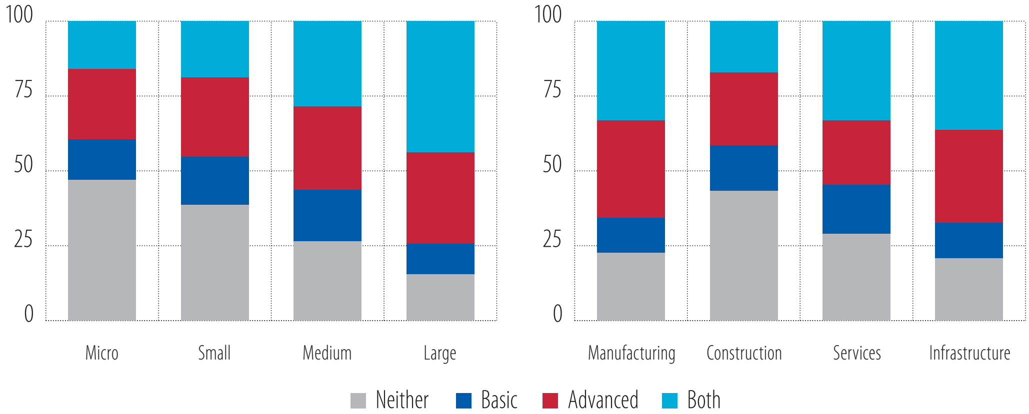
Figure 10
Corporate digital divide profiles



At the other end of the spectrum, 61% of firms have already adopted advanced digital technologies. Among firms that have implemented advanced digital technologies in their business, some firms have not invested in increasing digitalisation activities during the pandemic. These firms are categorised as "advanced." Finally, firms that use digital technologies and that have also invested further in digitalisation as a response to the pandemic are categorised as "both" because they have fully embraced the digital transformation. To understand which companies are falling behind and which are leading, the remainder of this section will examine firms on each side of the divide, and explore the impact of the COVID-19 crisis on their business.

Firm size plays a key role in the corporate digital divide. Larger firms are much more likely to be on the right (or digital) side of the corporate digital divide. They are more likely to be in the "both" category and less likely to be "neither" (Figure 11a). By contrast, smaller firms tend to be stuck on the wrong (or non-digital) side of the digital divide grid. This lack of investment in digital technologies by small EU firms is an area of concern because small firms are more prevalent in the European Union than in the United States. Furthermore, small firms are on average more digital in the United States (EIB, 2021a). This disparity is likely to be a major disadvantage for accelerating the digital transformation in Europe (Revoltella, Rückert and Weiss, 2020). Some differences exist in the corporate digital divide profiles across sectors. For example, the construction sector has a lower share of firms that invest in digital transformation (Figure 11b). Nevertheless, the effect of size on digitalisation activities is particularly strong. Box A highlights the differences between the European Union and the United States in firm digitalisation profiles.

Figure 11
Corporate digital divide profiles (in %)**, by size and sector**



Source: EIBIS 2021, firms in the EU27.
Question: As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)? See Figure 10 for the definition of corporate digital divide profiles.

Box A
Digitalisation in the European Union and the United States[4]

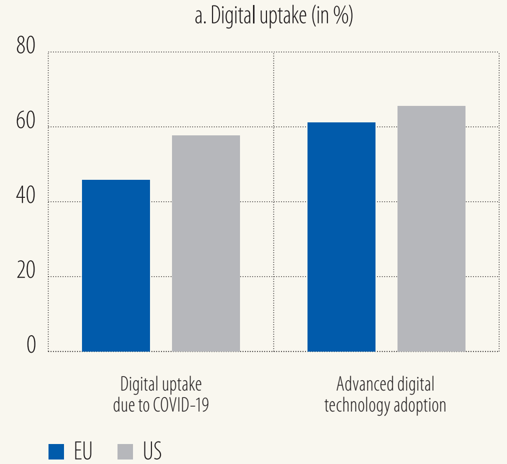
The European Union lags behind the United States in digitalisation. 46% of EU firms report having taken action to become more digital during the COVID-19 crisis, compared with 58% of US firms (Figure A1.a). Furthermore, the share of firms adopting advanced digital technologies is higher in the United States (66%) than in the European Union (61%). 42% of US firms fall into the "both" group, compared with 33% in the European Union. Only 18% of US firms have neither implemented advanced digital technologies nor invested in digitalisation as a response to the pandemic, compared with 26% of firms in the European Union (Figure A1.b). This higher share of EU firms that have not invested in the digital transformation compared to the United States is worrisome as it could have long-term negative consequences for the economy.

If policymakers want to close the gap in adoption rates between EU and US firms, they need to help European firms grow to a sufficient size. It is clear that large firms tend to be more digital in the European Union and in the United States. The larger EU share of "neither" compared to the United States is observed in particular for micro and small firms, suggesting that the overall difference in the digital divide between the European Union and the United States is driven by the greater preponderance of small businesses in the European economy (Figure A2).

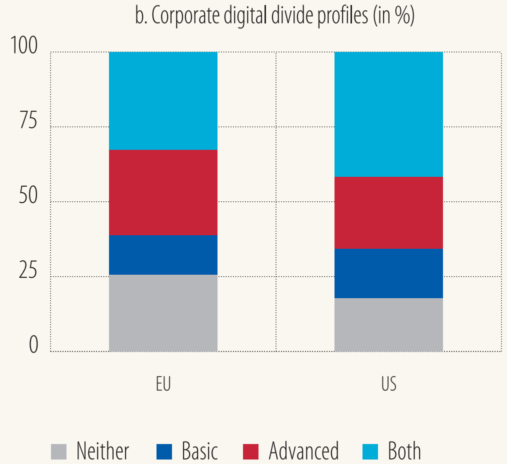
A lack of available finance and digital infrastructure are more often reported as major obstacles to investment by small non-digital firms. 24% of small EU non-digital firms (the "neither" category in the corporate digital divide profiles) mention a lack of available finance as major obstacle, compared with 10% in the United States (Figure A3). Similarly, 15% of EU small firms report that securing access to infrastructure is an obstacle compared with 3% for US small firms. In addition, being unable to find workers with the right skills is also more often mentioned as an obstacle for small EU companies than for large EU firms, unlike in the United States.

4 Data for US firms in EIBIS wave 6 were not available when this chapter was prepared. The comparison with EU firms was added in this box.

Figure A.1
Digitalisation activities in the European Union and the United States

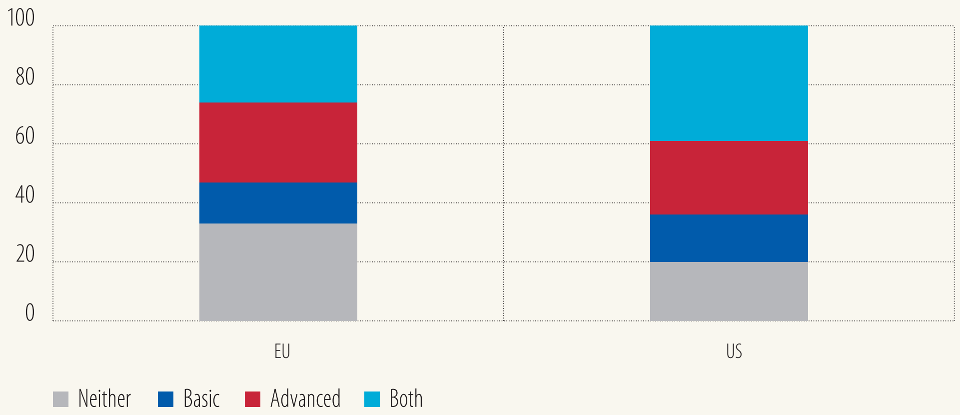


Source: *EIBIS 2021.*
Note: *See Figure 4 for the definition of digital adoption.*
Question: *As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)?*



Source: *EIBIS 2021.*
Note: *See Figure 10 for the definition of corporate digital divide profiles.*

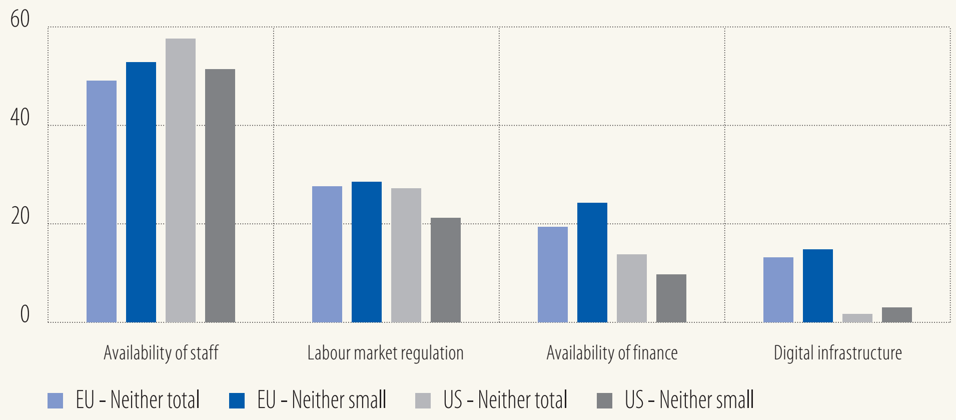
Figure A.2
Employment (in %)**, by corporate digital divide profile**



Source: *EIBIS 2021, Eurostat and OECD Structural Business Statistics, and US Census Bureau.*
Note: *See Figure 10 for the definition of corporate digital divide profiles.*

Figure A.3

Major obstacles to investment (in %) **for firms in the bottom category ("neither") of the corporate digital divide profiles, by firm size**

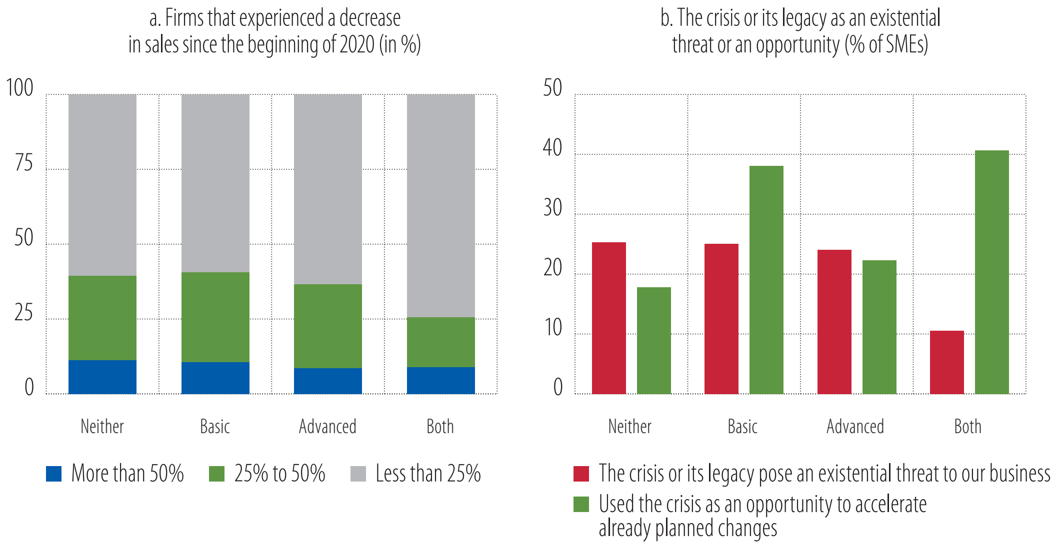


Source: *EIBIS 2021.*
Note: *See Figure 10 for the definition of corporate digital divide profiles. Small: 5-50 employees.*
Question: *Thinking about your investment activities, to what extent is each of the following a major obstacle?*

Firms that have embraced digital technologies were better able to cope with the disruptions created by the pandemic. Firms adapted by enabling remote working arrangements, implementing smart factories, using 3-D printing to produce in house product components or parts affected by supply chain disruptions, and taking advantage of big data analytics and artificial intelligence to reschedule and plan activities to adapt to the COVID-19 crisis. The more digitally advanced firms were less likely than non-digital firms to have experienced a strong decrease in sales since the beginning of 2020 (Figure 12a). They were also the least likely to consider that the crisis or its legacy posed an existential threat to their business (Figure 12b). Furthermore, the crisis forced firms to find more efficient ways of working with digital technologies. Smaller businesses that improved their digitalisation as a reponse to the pandemic report more often that they used the crisis to accelerate changes they had already planned to make (38% of "basic" and 41% of "both", compared with 18% of "neither" and 22% of "advanced").

Larger firms are more likely to have invested in becoming more digital during the COVID-19 crisis. Comparing the probability of firms falling into the "neither" vs. "basic" categories can provide insight into which firms decided to start investing in digitalisation as a response to COVID-19. The estimates in Table 1 confirm once again that firm size matters. In particular, firms with more than 50 employees are much more likely to start investing in the digital transformation. Similarly, the probability of falling into the "both" category vs. remaining "advanced" highlights the firms that are likely to forge ahead during the pandemic among those that have already implemented digital technologies. Again, small firms belong to the problematic category. Even when they are already digitally active, they are significantly less likely to have increased their digital investments.

Figure 12
Impact of the COVID-19 crisis on the business



Source: *EIBIS 2021, firms in the EU27.*
Note: *See Figure 10 for the definition of corporate digital divide profiles.*
Base: *All firms that responded that sales decreased since the beginning of 2020.*
Question: *By how much has your sales or turnover decreased since the beginning of 2020?*

Source: *EIBIS 2021 AOM — sample of EU SMEs in manufacturing and services (2021).*
Note: *See Figure 10 for the definition of corporate digital divide profiles.*
Question: *The current coronavirus pandemic has led to a large number of changes. Which of the following statements best reflect the position of your own company?*

Fluctuations in sales during the crisis are also linked to whether a firm decided to start investing in digitalisation. Among firms that had not adopted advanced digital technologies ("neither" and "basic"), those that experienced an increase or decrease in sales from 2019 to 2020 were more likely to have subsequently invested in increased digitalisation than firms that reported no change in sales. Firms that were negatively affected by the COVID-19 crisis and experienced a drop in sales were more likely to have then invested than those not reporting a change, but to a lesser extent than firms that saw a positive impact. However, the impact of COVID-19 on sales was not associated with the continued digitalisation efforts of firms that had already implemented advanced digital technologies.

The digital divide between firms in the European Union may continue to grow over time. Looking ahead to the next three years, the top investment priorities for more digital advanced firms are expanding capacity and developing new products, processes or services. For non-digital firms, on the other hand, replacing capacity (including existing buildings, machinery, equipment and IT) is more often mentioned as the investment priority (Figure 13a). About 20% of non-digital firms report that they do not have any investment plans. Furthermore, firms that have adopted advanced digital technologies are more optimistic about business prospects specific to their industry and the overall economic climate over the next 12 months (Figure 13b). At the same time, they are less likely to expect the political and regulatory climate to deteriorate. This suggests that less digital firms consider that they are in a more difficult investment situation in the short term, which leaves them with a less positive long-term outlook. Ultimately, there is a risk that the digital divide will be exacerbated by the pandemic (Rückert et al., 2021).

Table 1

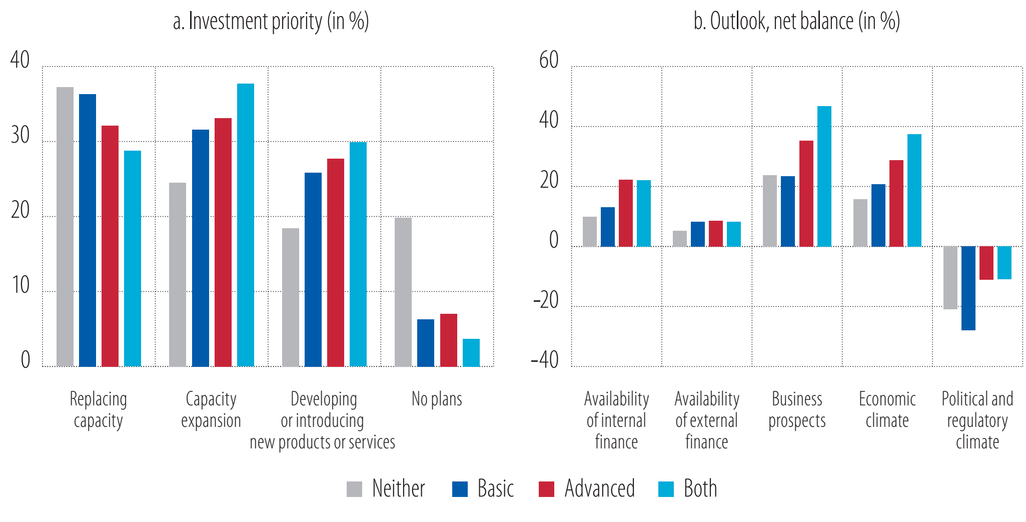
Probability of investing in digitalisation as a response to COVID-19

	Basic vs. neither	Both vs. advanced
Omitted category: micro		
Small	0.069***	0.020
	(0.025)	(0.032)
Medium	0.173***	0.128***
	(0.031)	(0.032)
Large	0.179***	0.219***
	(0.044)	(0.034)
Omitted category: COVID-19 had no impact on sales		
Increased sales or turnover	0.108**	0.003
	(0.044)	(0.041)
Decreased sales or turnover	0.080**	0.044
	(0.034)	(0.034)
Observations	5 560	6 135

Source: EIBIS 2021, firms in the EU27.
*Note: Marginal effects in a probit model. The coefficients can be interpreted as marginal effects on the probability of being "basic" or "both". *** p<0.01, ** p<0.05, * p<0.1. The regression also controls for country groups and sector.*

Figure 13

Investment priority over the next three years and short-term outlook



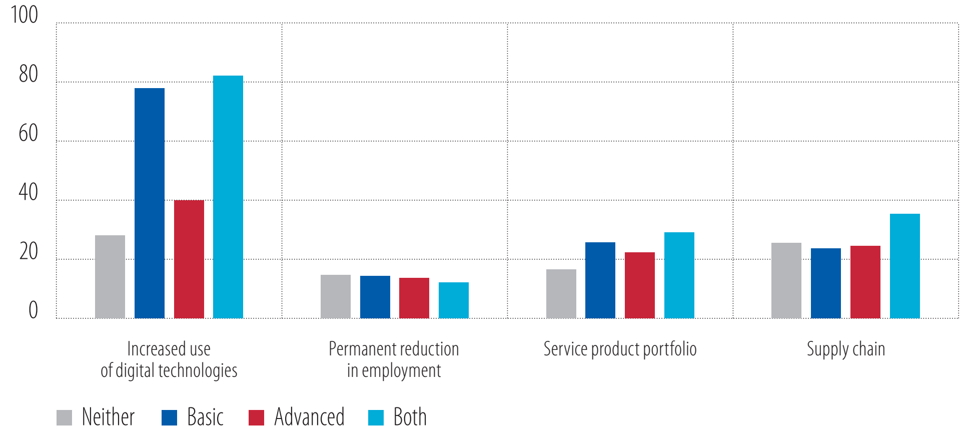
Source: EIBIS 2021, firms in the EU27.
Note: See Figure 10 for the definition of corporate digital divide profiles.
Question: Looking ahead to the next three years, which of the following is your investment priority?

Source: EIBIS 2021, firms in the EU27.
Note: See Figure 10 for the definition of corporate digital divide profiles.
Question: Do you think that each of the following will improve, stay the same or get worse over the next 12 months?

Firms that invested in becoming more digital during the pandemic believe that the business environment created by the pandemic will require enhanced digitalisation. In particular, the firms with "basic" and "both" digital divide profiles are much more likely to expect COVID-19 to increase the use of digital technologies in the long term (Figure 14). In addition, firms with the most advanced level of digitalisation are more likely to expect COVID-19 to affect their service and product portfolio as well as the supply chain. By contrast, the long-term expected impact of COVID-19 on employment is not associated with firms' digitalisation status.[5]

Figure 14

Expected long-term impact of COVID-19 (in %)



Source: EIBIS 2021, firms in the EU27.
Note: See Figure 10 for the definition of corporate digital divide profiles.
Question: Do you expect the coronavirus outbreak to have a long-term impact on any of the following?

Digital transformation and firm performance

Digitalisation, productivity and competitiveness

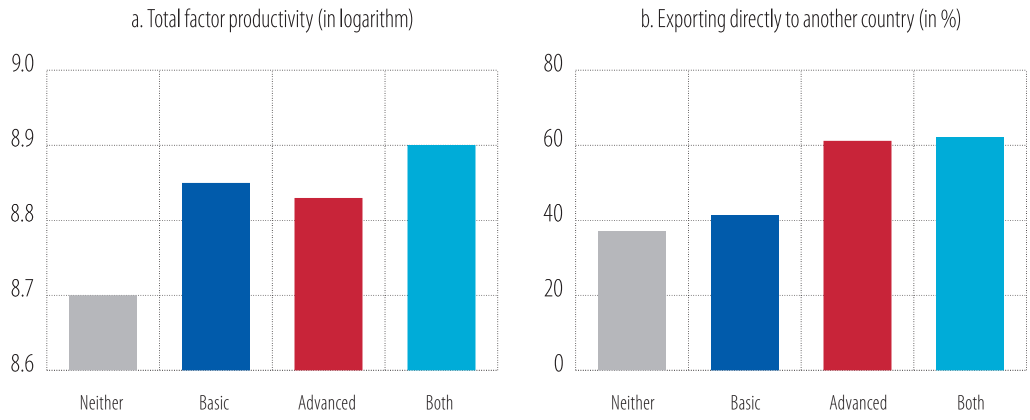
Digital firms tend to be more productive. Non-digital firms that started investing in their digital transformation during the pandemic and do not use advanced digital technologies have lower total factor productivity (Figure 15a).[6] These results support previous empirical evidence on the positive effect of digital adoption — including the use of platform technologies in the services sector — on productivity (Falk and Hagsten, 2015; Bailin Rivares et al., 2019; Gal et al., 2019). The pandemic has led to major changes in the nature and organisation of work, with implications for productivity, employment, wages and investment (Revoltella, Maurin and Pál, 2020).

Firms that have adopted advanced digital technologies are more likely to export goods and services to another country (Figure 15b). This is in line with studies stressing that exporters tend to be more productive (Melitz and Redding, 2021). Investing in digital technologies therefore appears to be especially relevant to firms wanting to compete in international markets (DeStefano and Timmis, 2021). Exporting products or services also improved firms' resilience during the COVID-19 crisis and recovery, as export-led sectors tend to bounce back faster than non-export-led ones (McKinsey, 2020).

5 See Chapter 4 of this report for an in-depth discussion of the impact of the COVID-19 crisis on labour markets in Europe.

6 Total factor productivity (TFP) is the portion of output not explained by the amount of inputs used in production. It reflects the overall efficiency with which labour and capital inputs are used together in the production process.

Figure 15
Total factor productivity and export performance



Source: *EIBIS 2021, firms in the EU27.*
Note: *The figure shows the median total factor productivity. See Figure 10 for the definition of corporate digital divide profiles.*

Source: *EIBIS 2021, firms in the EU27.*
Note: *See Figure 10 for the definition of corporate digital divide profiles.*
Question: *In the previous financial year, has your company directly exported goods and services to another country?*

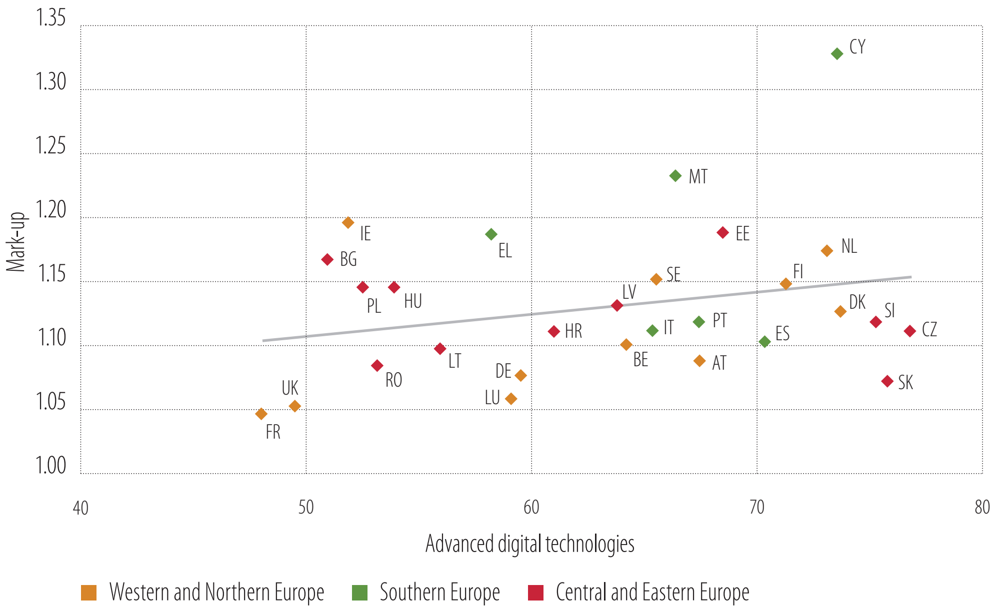
Firms that have implemented advanced digital technologies tend to charge higher mark-ups. While digital technologies can lead to more competition (Crémer et al., 2019), firms that adopt advanced digital technologies are often in a relatively privileged market situation, with above-average mark-ups (Figure 16 and Table 2). This supports previous empirical evidence showing that digital technologies often come with (i) network effects; (ii) economies of scope in data collection and analysis; and thanks to this information, (iii) a high and increasing level of price and product differentiation leading to a concentration of market power (Brynjolfsson and McAfee, 2011; Calligaris, Criscuolo and Marcolin, 2018).

Table 2
Mark-ups and corporate digital profiles

Dependent variable	Mark-up (in log)
Digital profiles *(omitted category: neither)*	
Basic	0.013
	(0.030)
Advanced	0.049*
	(0.027)
Both	0.047*
	(0.027)
Controlling for firm size, sector, country	
Sample size	9 220
*Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1*	

Source: *EIBIS 2021, firms in the EU27.*
Note: *See Figure 10 for the definition of corporate digital divide profiles. Mark-up calculations are based on the approach of De Loecker et al. (2020).*

Figure 16
Average mark-ups and adoption of advanced digital technologies



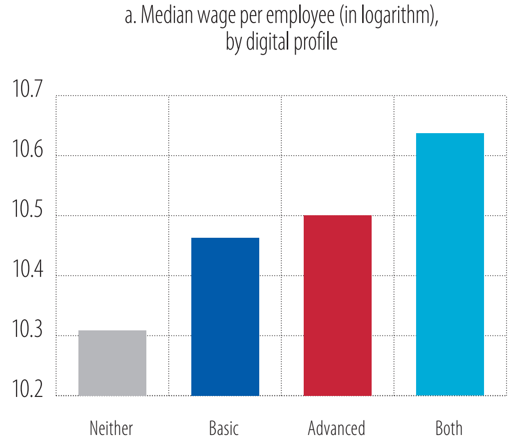
Source: *EIBIS 2021, firms in the EU27.*
Note: *See Figure 10 for the definition of corporate digital divide profiles. Mark-up calculations are based on the approach of De Loecker et al. (2020).*

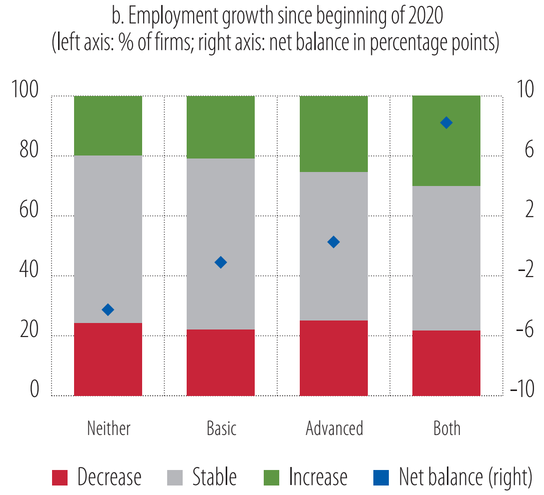
Digitalisation and the demand for skills

Digital firms pay higher wages on average. Many economists argue that digital technologies — such as artificial intelligence, machine learning and industrial robots — have an impact on employment, wages, the demand for skills and job polarisation because of automation and skill biased technological change (Acemoglu and Autor, 2011; Autor, 2015; EIB, 2018; Frank et al., 2019; Acemoglu and Restrepo, 2020). The higher demand for skilled workers is reflected in the higher average wages paid by digital firms (Figure 17a). The digital transformation often goes hand in hand with the automation of routine jobs. This automation often comes at the expense of demand for low and medium-skilled jobs. On the other hand, to use digital technologies, firms need to have a pool of qualified personnel with the right skills. While digitalisation can disrupt employment and tasks, the jobs created by digital firms often appear to be relatively well paid.

The most advanced digital firms were able to increase staff numbers compared to before the pandemic. On average, firms that adopted advanced digital technologies and invested in becoming more digital during the coronavirus pandemic have increased the number of workers they employ since the beginning of 2020 (Figure 17b). The share of non-digital firms that downsized after the COVID-19 outbreak was also higher than the share of non-digital firms with positive employment growth. The net balance of employment was negative for non-digital firms.

Figure 17
Wages and employment change





Source: EIBIS 2021, firms in the EU27.
Note: The figure shows the median wage per employee (in log). Wage per employee is defined as the wage bill divided by the number of employees. See Figure 10 for the definition of corporate digital divide profiles.
Question: How much did the company spend on wages in the previous financial year?

Source: EIBIS 2021, firms in the EU27.
Note: See Figure 10 for the definition of corporate digital divide profiles.
Question: How many people does your company employ either full or part-time at all its locations, including yourself? How many people did your company employ either full or part-time at all its locations, at the beginning of 2020?

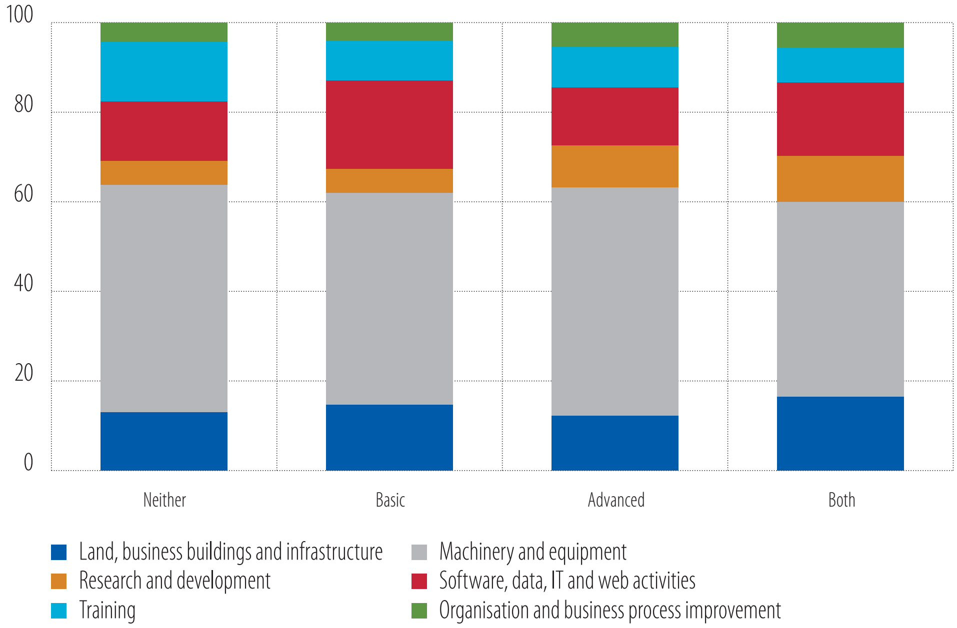
Digitalisation and innovation

Digital firms tend to invest more, especially in R&D. More advanced digital firms have higher investment intensity (defined as investment spending over turnover). This higher investment intensity can be explained by the higher productivity of digital firms and the stronger demand for their goods and services. Firms that have adopted advanced digital technologies tend to allocate a larger share of their investment activities to R&D (Figure 18). Firms that invested in digitalisation during the pandemic report having spent a large share of their investment on software, data, IT infrastructure and website activities in 2020.

Digital firms tend to invest more in innovation. The share of active innovators — either incremental or leading (such as firms that invest in R&D and introduce products, processes and services new to the company or to their market) — is higher among digital firms (Figure 19). At the same time, non-digital firms are less likely to invest in innovation, meaning they do not conduct any R&D and do not develop new products, processes or services. However, the correlation between investment in digitalisation and the wide range of firm performance metrics considered in this chapter – such as productivity, employment growth, average wage per employee or innovation activities – does not necessarily imply causation.

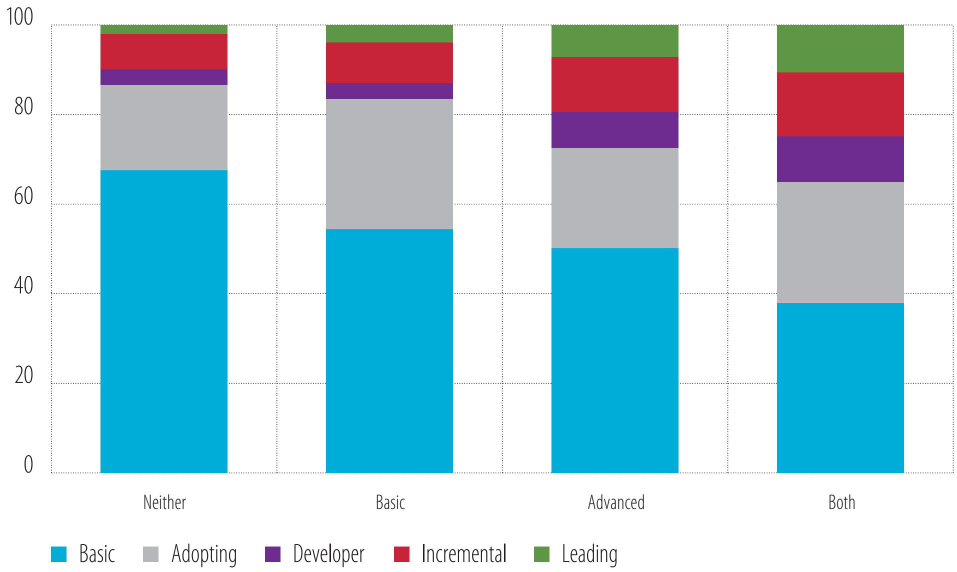
Higher innovativeness is associated with the use of big data analytics, artificial intelligence and 3-D printing. To make the most of these technologies, firms have to collect and analyse large amounts of information. Big data analytics or artificial intelligence can enable the innovation process (Haskel and Westlake, 2017; Cockburn et al., 2018). 3-D printers also improve the innovation process.

Figure 18
Composition of investment (in %)



Source: *EIBIS 2021, firms in the EU27.*
Note: *See explanation above Figure 10 for the definition of corporate digital divide profiles.*
Question: *In the previous financial year, how much did your business invest in each of the following with the intention of maintaining or increasing your company's future earnings?*

Figure 19
Innovation profiles (in %)



Source: *EIBIS 2021, firms in the EU27.*
Note: *See Veugelers et al. (2019) for the definition of innovation profiles and Figure 10 for the definition of corporate digital divide profiles.*

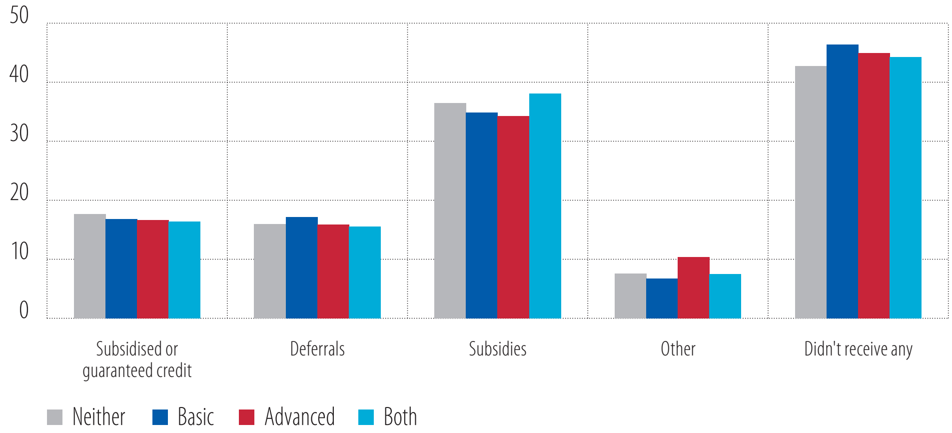
Policy support and barriers

Policy support during the COVID-19 crisis

Government support for firms was widespread during the crisis. As the support was general and not targeted at specific sectors, there is no significant difference in the share of firms receiving support in each digital divide profile. The support also took many forms, such as access to subsidised or guaranteed credit, deferral of payments (tax, rent or mortgage, or interest payments) or subsidies to help with wage costs or government grants (Figure 20). Nevertheless, the COVID-19-related support enabled firms to preserve their investment plans, including in digital, regardless of fluctuations in sales (see Chapter 3).

Figure 20

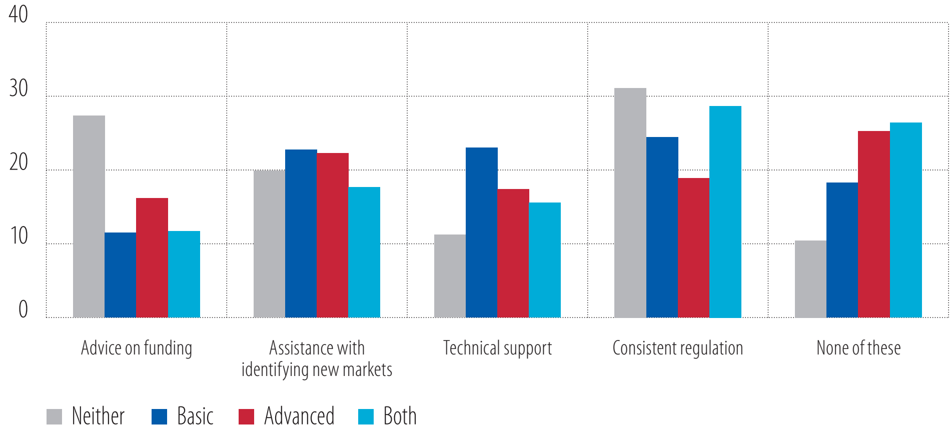
Firms that received financial support (in %)



Source: *EIBIS 2021, firms in the EU27.*
Note: *See Figure 10 for the definition of corporate digital divide profiles.*
Question: *Since the start of the pandemic, have you received any financial support in response to COVID-19? This can include finance from a bank or other finance provider, or government-backed finance.*

Non-digital firms say that advice on funding and consistent regulation would be the best way to support their digital investments (Figure 21). The types of support that firms would like to receive differ among the corporate digital profiles. The add-on module (AOM) to EIBIS 2021 asked SMEs in the services and manufactoring sectors which type of support would incentivise them to invest in digital technologies. Firms clearly signalled that consistent regulation would be welcome, and firms that started digitalisation activities in reponse to the COVID-19 crisis said they would like technical support and help in identifying new markets. This suggests that policy support focusing on facilitating access to finance for SMEs will not necessarily accelerate the digital transformation in the European Union. Technical support, market expertise and predictable regulation are also required.

Figure 21
Policy support SMEs considered most useful (in %)

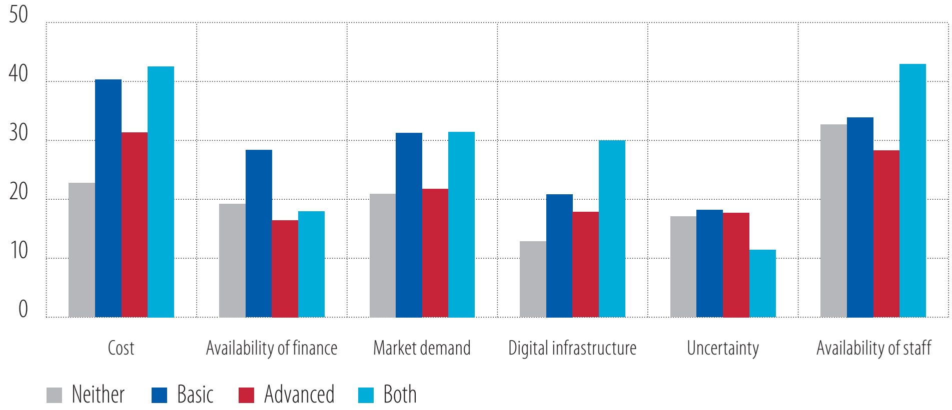


Source: EIBIS 2021 AOM — sample of EU SMEs in manufacturing and services (2021).
Note: See Figure 10 for the definition of corporate digital divide profiles.
Question: When thinking about investments in digital technologies, which of the following would you find most helpful?

Barriers to the digital transformation

Finding staff with the right skills and the cost of investments are the most significant obstacles to the digital transformation. More than one in three EU firms consider an absence of workers with the right skills to be a major barrier. Access to digital infrastructure is less frequently cited, on average, but there are significant differences across digital divide profiles. Firms that took steps to become more digital as a response to the pandemic are more likely to report that a lack of access to digital infrastructure constrains their investment in digital technologies (Figure 22).

Figure 22
Major obstacles SMEs face when investing in digital technologies (in %)

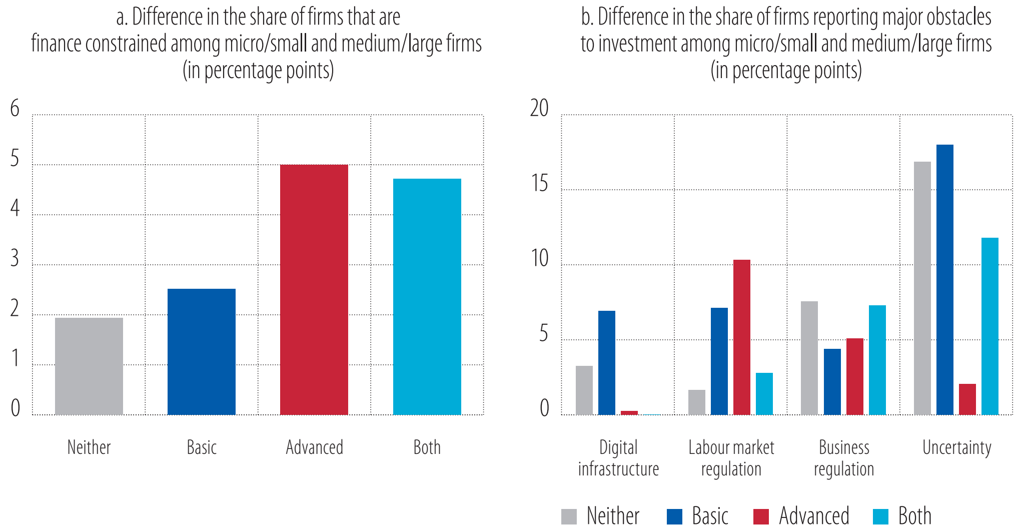


Source: EIBIS 2021 AOM — sample of EU SMEs in manufacturing and services (2021).
Note: See Figure 10 for the definition of corporate digital divide profiles.
Question: Thinking about your investment activities in digital technologies, to what extent is each of the following a major obstacle?

Difficulty attracting finance and regulatory obstacles can also create barriers to digital investment, especially for small firms. While financial conditions throughout Europe are relatively relaxed and difficulties in accessing finance are not the top obstacle to investment, small firms that implemented advanced digital technologies are more likely to say they are financially constrained (Figure 23a). Furthermore, among firms that have started investing in digitalisation, small firms perceive access to digital infrastructure to be a more severe obstacle than large firms (Figure 23b).

Figure 23

Differences between small and large firms for financial constraints and major barriers to investment



Source: *EIBIS 2021, firms in the EU27.*
Note: *See Figure 10 for the definition of corporate digital divide profiles. Micro and small: 5 to 50 employees, medium-sized and large: 50+ employees.*

Digital innovation

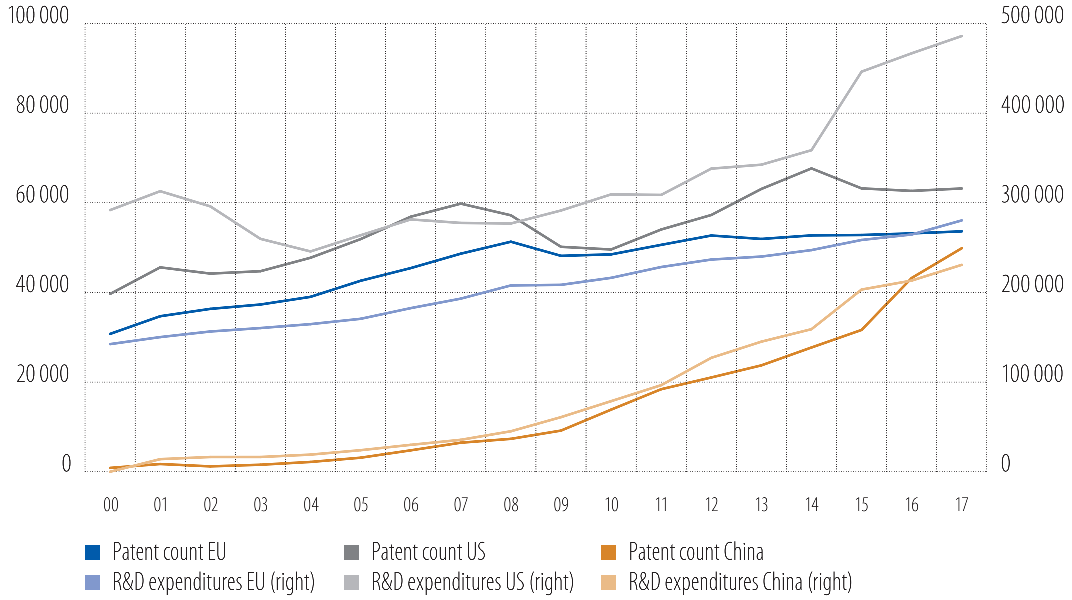
Digitalisation should also go hand in hand with digital innovation. As highlighted in the previous sections, the importance of adopting digital technologies has been analysed extensively by researchers and policymakers. However, much less is known about the different research and innovation streams that lead to the development of new digital technologies. This section presents evidence on recent developments at the cutting edge of technology and discusses possible opportunities to develop new knowledge.

Where the European Union stands on digital innovation

The European Union, the United States and China are the global leaders in innovation, as reflected in patent data and R&D expenditure. The United States and the European Union continue to lead in overall patent counts while China is rapidly catching up (Figure 24). Patent applications run parallel to R&D expenditure over time. This suggests that patents, a proxy of the output of innovation activities, are closely associated with R&D spending, a proxy for innovation input.

Figure 24

Patents and R&D expenditure, 2000-2017 (left axis: patent count; right axis: R&D expenditure in EUR million)



Source: *PATSTAT (PCT) data prepared in collaboration with the Centre for Research and Development Monitoring (ECOOM), and Eurostat data on R&D expenditure (GERD) within the European Union.*

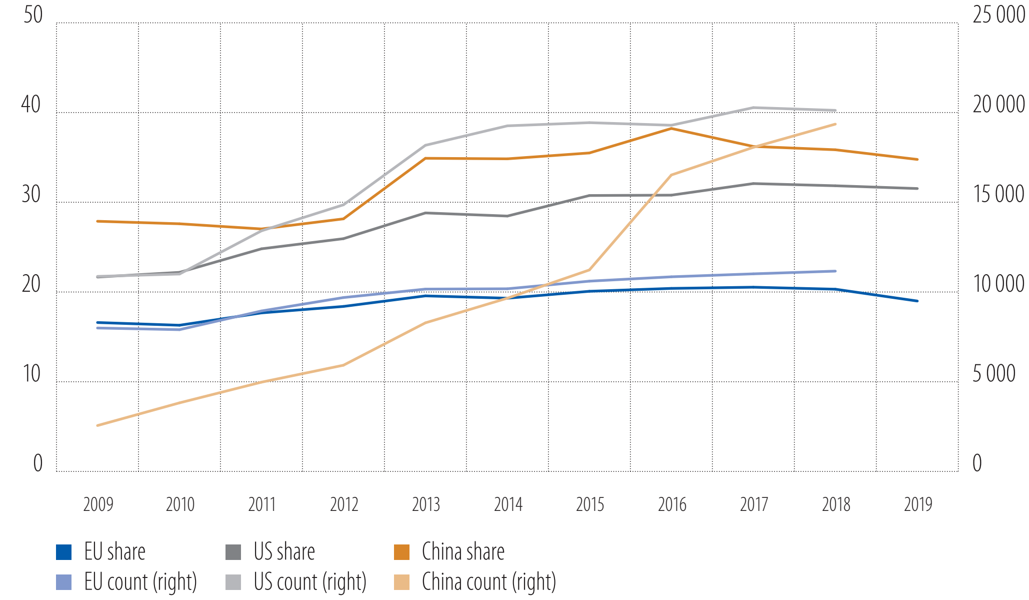
Note: *The dark lines show total patents (left axis); the light lines show R&D expenditure in EUR million of purchasing power standards (PPS) at 2005 prices (right axis).*

The European Union needs to play a more prominent role in developing new digital technologies. Figure 25 shows that the European Union is lagging behind the United States and China in patent applications in the digital and industry 4.0[7] domains, defined in Box B. While the share of digital patents in the total patent portfolio has remained relatively stable in the European Union since 2012, the US share has increased over time, widening the EU-US gap in digital innovation. Over the past 15 years, China has doubled its share of digital patents, reflecting its increased focus on developing new digital technologies. This suggests that, compared to the European Union, the United States and China have accelerated investments in digital innovation over the past decade. Within the European Union, digital innovation continues to be mainly driven by countries in Western and Northern Europe, which hold more than 90% of all EU digital patents.

US digital patents tend to be cited more often for new digital innovations than EU patents. Until recently, EU digital patents had a relatively high impact, as indicated by the forward citations they received — forward citations reflect the breadth of the patent's impact because they measure the number of times the knowledge is followed up on. However, the European Union's impact has changed in recent years. In 2010, the United States overtook the European Union in the number of digital patents receiving citations and has continued to outperform since then (Figure 26). Relative to the European Union, China continues to lag behind in the impact of its digital innovation but it is closing the gap. A similar pattern emerges when looking at each patent's average share of the total number of forward citations over a three-year timeframe, which indicates the depth of the patent's impact (Figure 26). The European Union appears to be slowly losing its influence in the development of new digital technologies, especially compared to the United States.

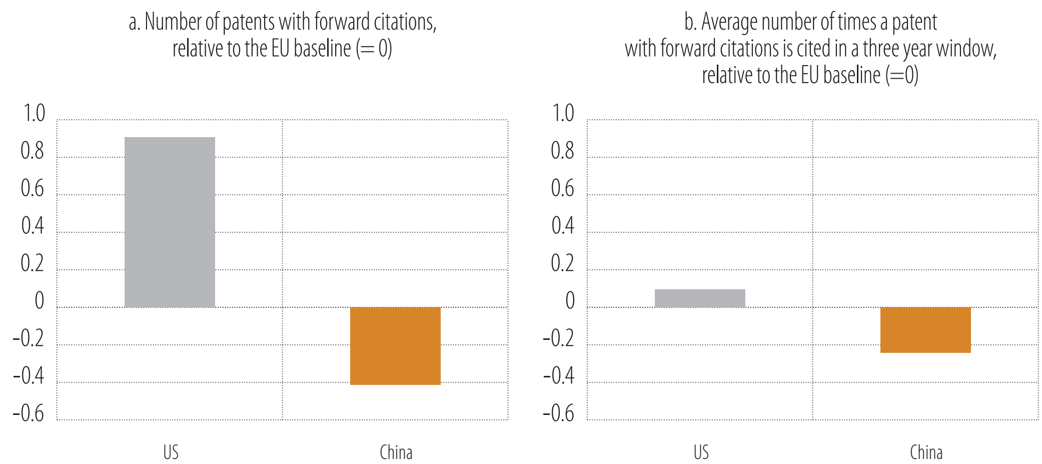
7 Industry 4.0, or the Fourth Industrial Revolution, refers to the disruption technology is causing in many major industries. In this chapter, industry 4.0 is defined in line with the classification provided by the European Patent Office (see Box B) and consists of a variety of technologies, such as big data, artificial intelligence, the internet of things and many more technologies.

Figure 25
Digital patents, 2009-2019 (left axis: patent share in %; right axis: patent count)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The light lines show the number of digital patents (right axis); the dark lines show the percentage share of digital patents in the total portfolio of domestic patents (left axis).*

Figure 26
Forward citations of digital patents



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The count measures the number of patents with forward citations (providing an indicator of the breadth of the impact or the number of times knowledge is used) relative to the EU count. Only data until 2017 are shown because forward citations of patents take time to materialise.*

Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The shares are measured as the average number of times a patent with forward citations is cited in a three-year window relative to the EU baseline. This share is computed as the ratio of its forward citations to the overall number of patents with forward citations (providing an indicator of the depth of the impact an individual patent has).*

Different domains of digital innovation

The digital transformation is affecting virtually every sector of the economy. Digital innovation is no longer the exclusive domain of software companies. An increasing number of companies are pushing the digital frontier as they try to seize new opportunities in the fast-changing digital and economic environment. Digital innovation is therefore a very broad concept. Digital technology can be the basis for and the result of digital innovations, with different types of digital innovation processes underpinning these different stages (Yoo et al., 2012). According to the European Patent Office (EPO, 2017), digital innovation can be classified into three main domains — core technologies, enabling technologies and application technologies (Figure 27). Box B discusses the classification of digital patents in more depth and gives examples of recent digital technologies.

Figure 27
Different domains of digital innovation

Core technologies

Basic building blocks upon which the digital technologies are built — inventions contributing to three of the established fields of ICT inherited from the previous industrial revolution (hardware, software, connectivity)

Enabling technologies

Technologies that are further built upon and complement the core technologies.

Application technologies

Technologies that are closest to the market and reflect the final applications of digital technologies.

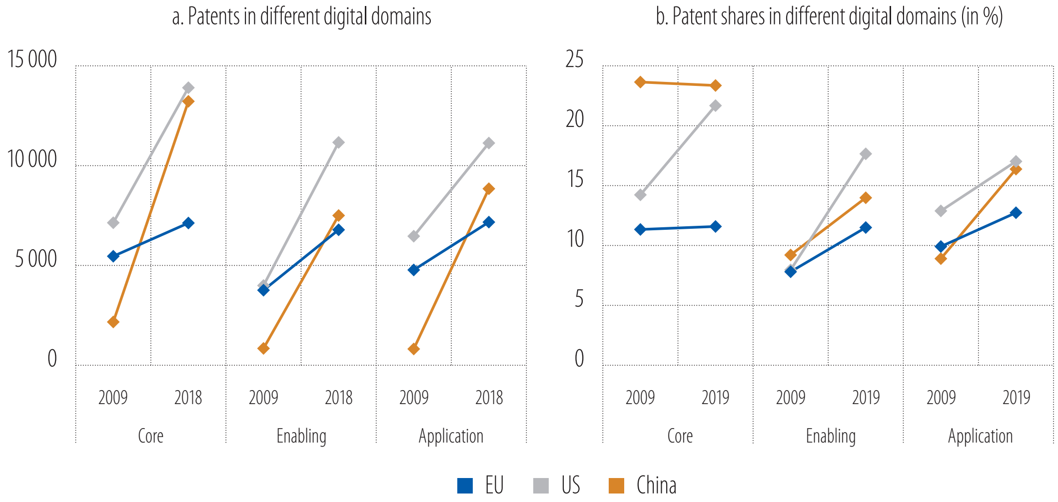
Source: *Based on EPO (2017).*
Note: *See Box B for a more detailed description of the different digital subdomains.*

The United States leads in all three domains of digital innovation. The United States is at the top of the different fields of digital innovation, while China's patenting activity has overtaken the European Union in all three domains (Figure 28a). Over the past decade, the United States has mainly increased its focus on core and enabling technologies, while China has been focusing more on enabling and application technologies (Figure 28b). While the European Union lags behind the United States in all three domains, the difference with China is less marked in enabling and application technologies. Compared to the United States and China, the European Union is less active in the innovation of core technologies that contribute to established fields of information and communications technology (ICT), such as hardware, software and connectivity.

Despite its weakness in several areas of digital innovation, the European Union is a global leader in certain subdomains. For example, it has more patents in vehicle applications, which includes autonomous driving and vehicle fleet navigation devices (Figure 29). The United States and China still lag behind the European Union in this area, but they are rapidly catching up. Europe's position in the development of new digital technologies is fragile, even in the limited number of fields where it is performing relatively well.

Figure 28

Digital innovation in different domains

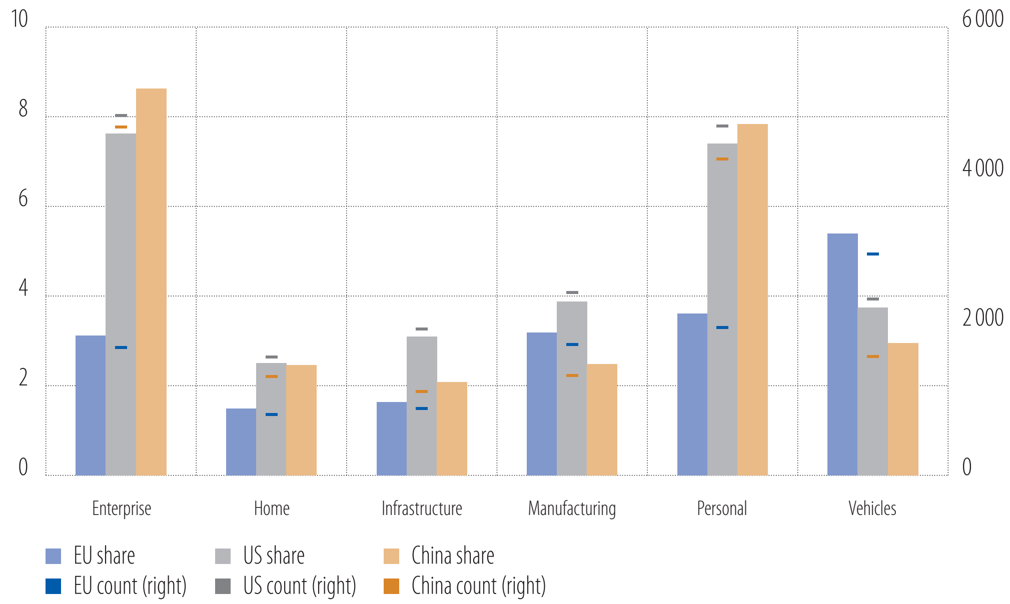


Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The figure shows the count of digital patents for the three different digital domains.*

Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The figure shows the shares of digital patents for the three different digital domains over the total portfolio domestic patents.*

Figure 29

Patents for digital application technologies in 2018 (left axis: patent share in %; right axis: patent count)

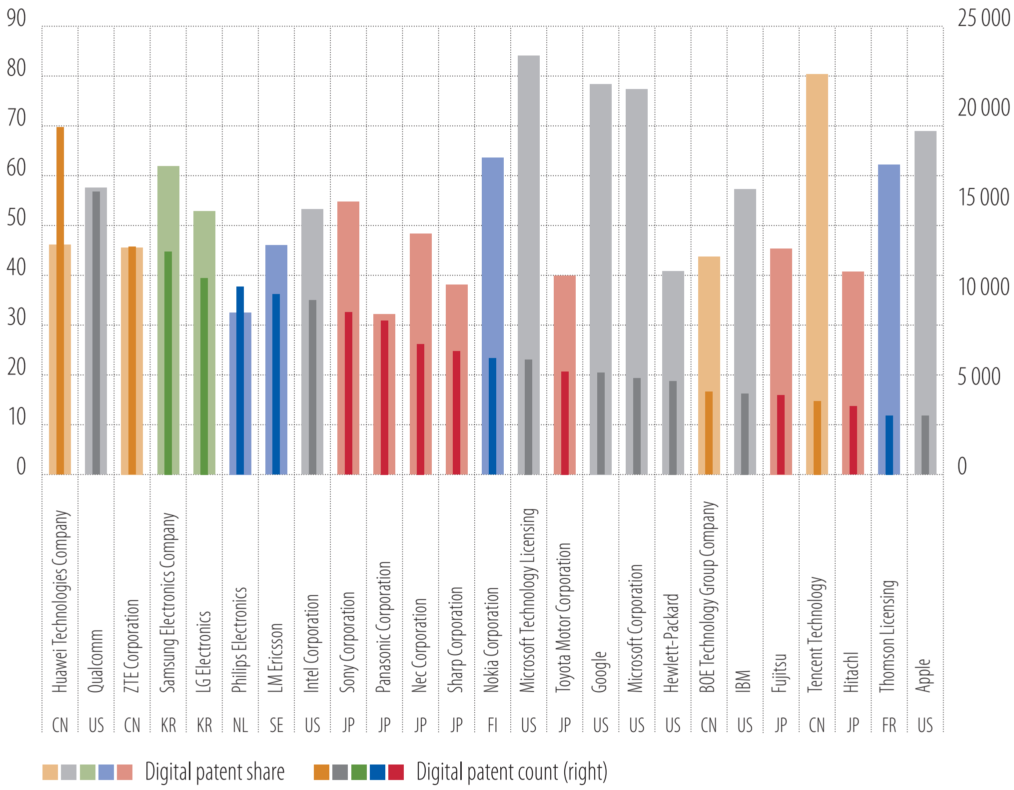


Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The lines show the count of digital patents in the digital application subdomains in 2018 (right axis); the bars show the share of patents in the respective total domestic patent portfolio for the digital application subdomains in 2018 in percent (left axis).*

Competition and concentration as key forces of digital innovation

The European Union only has four companies among the top 25 digital players, while the United States has eight. China also has four companies on this list, while the remaining strong digital innovators come from South Korea and Japan (Figure 30). The extent to which companies are leading in digital innovation can be measured by the number of patents they hold and the share of digital patents in their total patent portfolio. Some EU companies such as Philips Electronics, Ericsson, Nokia and Thomson Licensing are in the top 25 because they hold many digital patents. However, they do not have the same focus on digital technologies as other top digital players — such as Microsoft, Google and Apple in the United States or Tencent in China — for whom digital patents account for close to or more than 70% of total patents. Most other companies on the list of the top 25 digital players seem to have a more diversified patent portfolio and do not focus exclusively on digital technologies.

Figure 30
Top 25 global digital players (left axis: patent share in %; right axis: patent count)



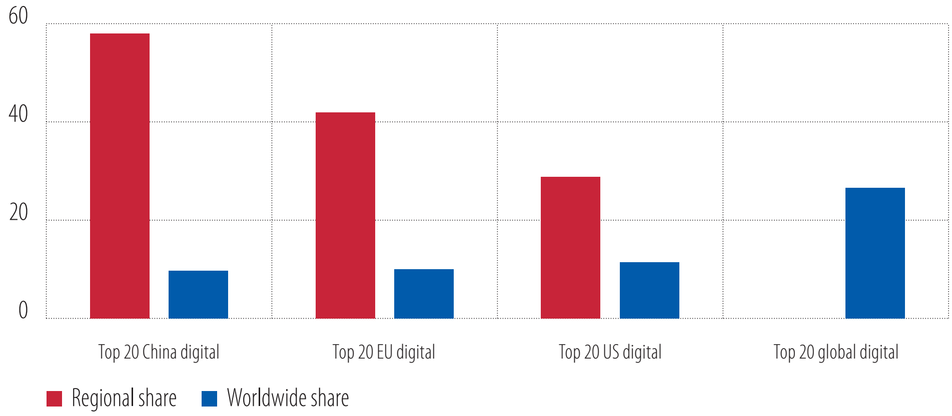
Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The bars reflect the number of digital patents as well as the share of digital patents in the patent portfolio of each company from 2000 to 2018. The figure only includes companies with a minimum of 30% digital patents in their total patent portfolio. The colours refer to different countries (blue = European Union; red = Japan; grey = United States; orange= China; green = Korea).*

The digital sector is often criticised for a lack of competition, enabling some companies to profit from winner-takes-all dynamics. A key question is whether the high concentration of key players in the digital market is also present in digital innovation. The economic literature argues that as soon as a leading technology is successful, it is rapidly implemented by leading firms (Akcigit and Ates, 2019). This rapid adoption may discourage smaller firms from innovating, thereby slowing down evolution of cutting-edge innovation. Competition is an important force that pushes down the cost of goods and improves public welfare. Some economists argue that having a few firms with significant market power is necessary to foster innovation, while others fear that market concentration leads to a general slowdown in economic progress and innovation (Philippon, 2019).

In spite of the winner-takes-all dynamics often witnessed in the US digital sector, digital innovation tends to be less concentrated in the United States and the European Union than in China. The top 20 EU digital companies hold 40% of all EU digital patents, while the top 20 US digital companies hold 30% of all US digital patents (Figure 31). In China, this share is close to 60%. This suggests that digital innovation in China is heavily concentrated among a few large digital players, particularly compared to the United States or the European Union. However, the lower concentration does not necessarily result in lower winner-takes-all dynamics in certain subdomains in these regions. For example, some of the top US digital players are particularly active in big data analytics and currently also dominate enabling technologies.

Figure 31

Digital patents held by the top 20 digital players in each market (in %)

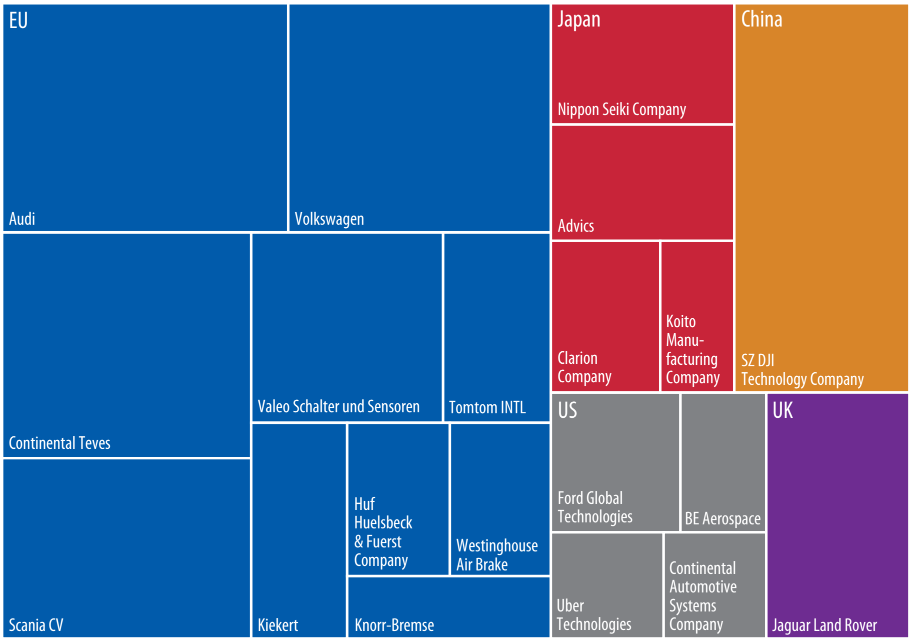


Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The red bars reflect the number of digital patents held by the top 20 domestic digital patentees as a share of the respective domestic digital patent portfolio from 2000 to 2018. The blue bars reflect the number of digital patents held by the top 20 domestic digital patentees as a share of the global digital patent portfolio. The last blue bar reflects the number of digital patents held by the top 20 global digital patentees as share of the global digital patent portfolio.*

The diversified nature of digital innovation still leaves space for EU players in several areas. For example, European firms like Audi, Volkswagen, Continental and Scania excel in specific domains, such as vehicle applications (Figure 32).[8] Whether this will be sufficient to maintain the global competitiveness of the European Union is up for debate. However, it indicates that the digital innovation landscape is sufficiently diverse enough for the European Union to still leverage its competitive advantage and digital skills.

8 The dominance of EU market players in this subdomain is the exception rather than the norm. As shown above, the European Union does not necessarily lead overall digital technology development.

Figure 32
Top 20 global players in digital vehicle applications



Source: PATSTAT (PCT) data prepared in collaboration with ECOOM.
Note: The top players in the vehicle application subdomain are represented by their patent counts. The figure only includes companies with a minimum share of 30% vehicle application patents in their total patent portfolio. The size of the tiles reflect the patent count in the vehicle application subdomain.

Box B
Measuring digital innovation with patent data

The digital patent classification used in this chapter is based on a classification of industry 4.0, published by the European Patent Office (EPO, 2017).[9] The classification identifies three broad categories of patents, each of which is further subdivided into specific technological domains. The resulting map aims to capture the buildings blocks of industry 4.0, at least for patent applications. The tables below give an overview of the different domains and their sub-technologies, as reported by the EPO.

The three main sectors identified in the classification are "core technologies," "enabling technologies" and "application domains." Core technologies are considered to be the basic building blocks upon which the technologies of the fourth industrial revolution are built. This class consists of inventions that contribute to three of the established fields of information and communications technology (ICT) inherited from the previous industrial revolution.

Table B.1

Core technologies	Including
Hardware	Sensors; advanced memories; processors
Software	Intelligent cloud storage and computing structures; adaptive databases; mobile operating systems; virtualisation
Connectivity	Network protocols for massively connected devices; adaptive wireless data systems

9 This box was prepared by Julie Callaert (ECOOM, KU Leuven).

The second domain captures enabling technologies. These technologies are further built upon and complement the core technologies. The EPO subdivides this second domain into seven technology fields.

Table B.2

Enabling	Including
Analytics	Diagnostic systems for massive data
User interfaces	Virtual reality; information display in eyewear
3-D support systems	3-D printers and scanners for parts manufacture; automated 3-D design and simulation
Artificial intelligence	Machine learning; neural networks
Position determination	Enhanced GPS; device-to-device relative and absolute positioning
Power supply	Situation-aware charging systems; shared power transmission objectives
Security	Adaptive security systems; intelligent safety systems

The third "application" domain captures technologies that are closest to the market and reflect the final applications of digital technologies. This domain is subdivided into six different sectors of applications to indicate in which part of the economy the various technologies can potentially add value.

Table B.3

Application domain	Including
Personal	Personal health monitoring devices; smart wearables; entertainment devices
Home	Smart homes; alarm systems; intelligent lighting and heating; consumer robotics
Vehicles	Autonomous driving; vehicle fleet navigation devices
Enterprise	Intelligent retail and healthcare systems; autonomous office systems; smart offices; agriculture
Manufacture	Smart factories; intelligent robotics; energy saving
Infrastructure	Intelligent energy distribution networks; intelligent transport networks; intelligent lighting and heating systems

Depending on the focus of the analysis, different levels of aggregation are used in this chapter. Digital patents refer to all patents belonging to one of the three main domains of industry 4.0. In other cases, the indicators are broken down into the three main classes, namely core technologies, enabling technologies and application domains. Throughout the chapter, the subdomains of these three building blocks of digital patents are only used in some specific settings.

The crossroads between digital technologies and innovation

Digital innovation could play a major role in a multitude of existing economic sectors. Some of Europe's traditional economic sectors could potentially find themselves in a new era of innovation thanks to major changes triggered by digital technologies (Haskel and Westlake, 2017; Cockburn, Henderson and Stern, 2018; Branstetter, Drev and Kwon, 2019; Ghobakhloo, 2020).

Digital technologies could enable certain industries to meet strict climate targets and could transform the automotive sector. If emerging digital technologies are properly employed, they could play an essential role in tackling environmental challenges (GeSI 2019; Intergovernmental Panel on Climate Change (IPCC), 2021). Digital technologies could be instrumental for the European Green Deal and in reaching carbon neutrality. The automotive sector, one of the European Union's main traditional sectors, is being transformed by the need to develop engines that are not reliant on fossil fuels. The automotive sector is also witnessing an increased use of digital technologies and new trends such as autonomous driving and car sharing (MIT Energy Initiative, 2019).

Digitalisation could also play a major role in other sectors such as healthcare — especially in light of the coronavirus pandemic. The recent health crisis has put enormous pressure on the healthcare system. Not only were hospitals faced with a large influx of new patients, they also had to cope with the indirect victims of the crisis, namely patients with existing conditions that were left untreated. In addition, the pandemic brought about an unprecedented search for COVID-19 treatments and prevention, such as vaccines (International Monetary Fund (IMF), 2021). Innovation in healthcare could benefit massively from digital technologies (Kraus et al., 2021).

The European Union's position on innovation targeting healthcare, the automotive industry and climate change

The European Union continues to be one of the main players in new technologies developed to tackle climate change. The European Union has many climate change-related patents and is far ahead of the United States and China (Figure 33a). However, Europe's climate change innovation is stagnating and has even been declining in recent years (see Chapter 6).

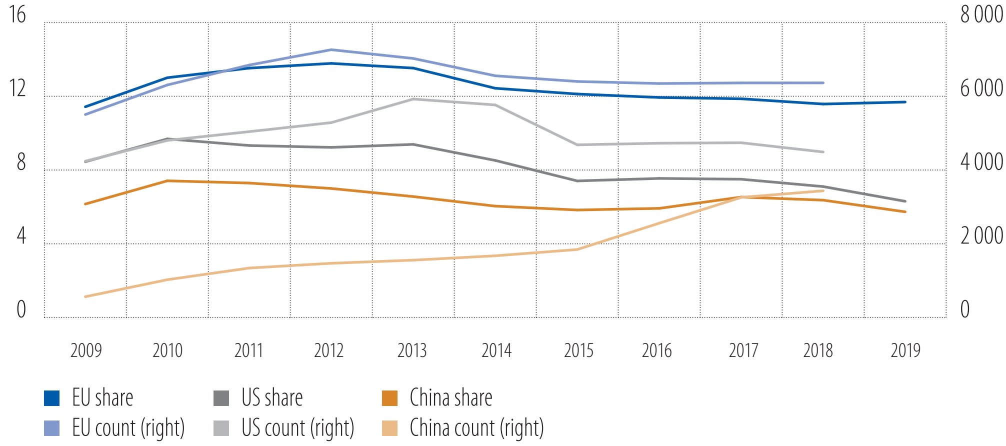
The European Union is a leading innovator in the automotive sector. The European Union continues to show a steady upward trend for automotive patents (Figure 33b).[10] China is lagging behind the European Union with less than half the amount of patents and lower specialisation (as measured by the patent share) in automotive technologies.

The European Union's relative position is weaker in healthcare technologies. But Europe remains ahead of China, in absolute (patent count) and relative (patent share) terms. Until 2019, before the outbreak of the COVID-19 pandemic, the increase in patent applications in healthcare was mainly driven by US patentees. In the European Union and China, healthcare patenting activity has remained relatively stable since 2012 (Figure 34a).

10 The patent classification in different technologies — such as digital, transportation, climate change and healthcare — is based on the classification established by Katholieke Universiteit Leuven, among others. The exhaustive classification of key technologies and priorities was developed as part of the P&L project INCENTIM-KU Leuven, with the support of Bocconi University, Technopolis and numerous experts from the European Commission. A modular approach was developed, resulting in IPC based search keys for a majority of themes.

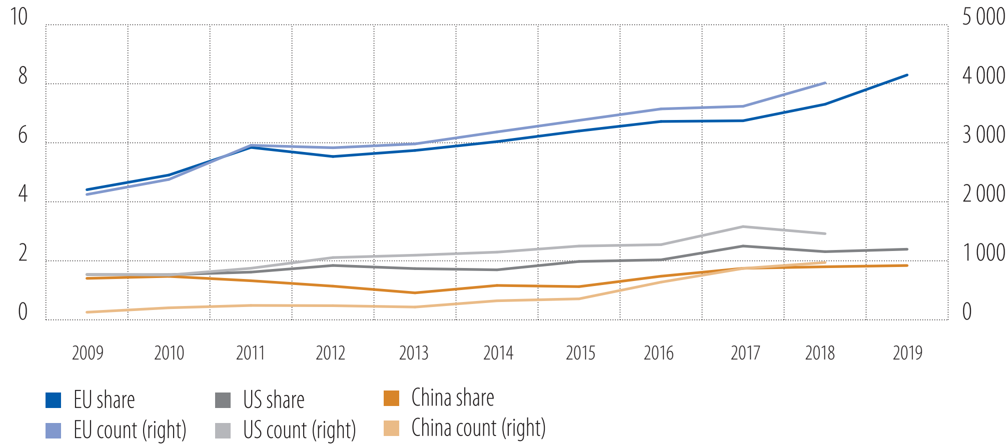
Figure 33
Patents in climate change and automotive

a. Patents in climate change (left axis: patent share in %; right axis: patent count)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The light lines show the number of climate change patents (right axis); the dark lines show the share of climate change patents in the total portfolio of domestic patents (left axis).*

b. Patents in automotive (left axis: patent share in %; right axis: patent count)

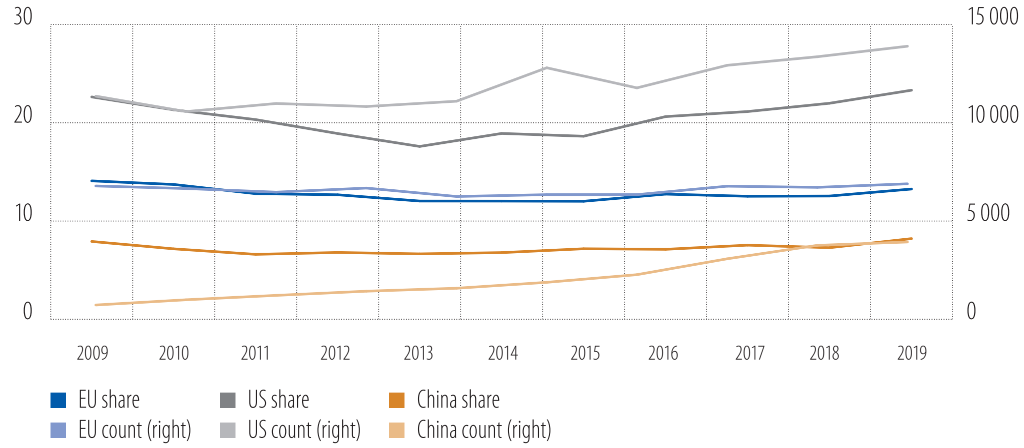


Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The light lines show the number of automotive patents (right axis); the dark lines show the share of automotive patents in the total portfolio of domestic patents (left axis).*

Nevertheless, preliminary patent data for 2020 suggest that firms have responded to the COVID-19 crisis by increasing their healthcare innovation. The statistic is preliminary because it is only based on a partial count of patent applications in 2020. However, there is a strong contrast with the 2019-2020 trends in digital, climate change and transportation patenting activity (Figure 34b). The data indicate strong activity in patent applications and a focus on healthcare technologies at the beginning of 2020. New updates of patent data will confirm whether this strong increase continued for the rest of 2020.

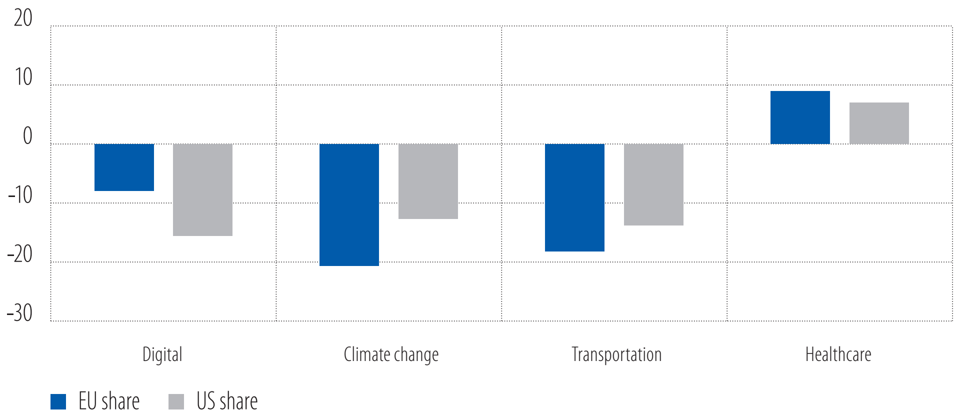
Figure 34
Patents in healthcare and patent growth in different technologies

a. Patents in healthcare (left axis: patent share in %; right axis: patent count)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The light lines show the count of healthcare patents (right axis); the dark lines show the share of healthcare patents in the total portfolio of domestic patents (left axis).*

b. Growth in shares of patents in different technologies from 2019 to 2020 (in %)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The bars show the growth rate of the share of patents in the listed technologies in the total portfolio of domestic patents from 2019 to 2020. PATSTAT data do not yet include all patents filed in 2020 and the figure is only indicative of a potential future trend. China is excluded from this chart due to a very low number of patents in 2020.*

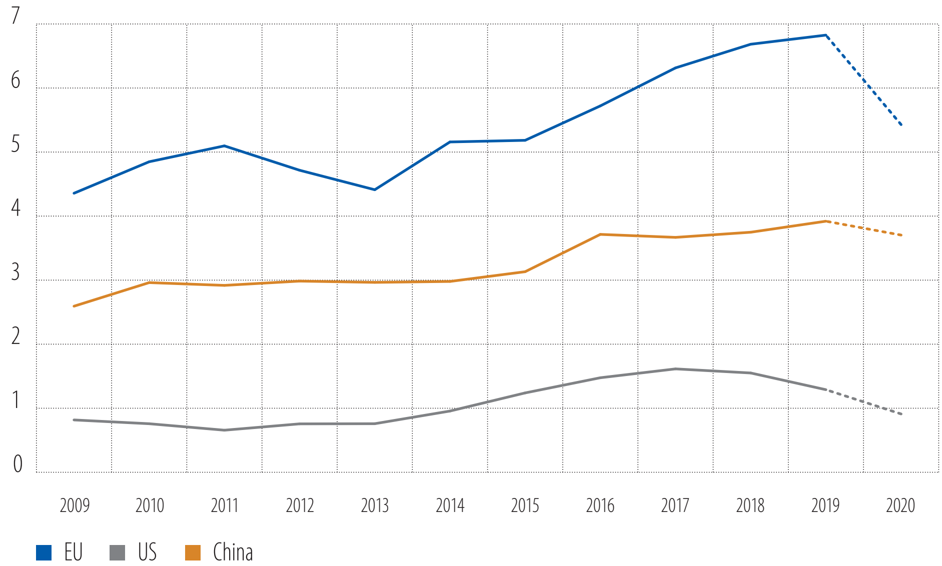
Digital technologies enable healthcare innovation

The COVID-19 crisis could spark a digital revolution in healthcare. The analysis of healthcare data has been integral to the pandemic response. The sharing of healthcare research and data helped spur the development of vaccines (like Pfizer BioNTech), for example. Digital technologies have also been used for remote doctor consultations, which oftentimes replaced in-person visits during the pandemic. In addition, artificial intelligence could lead to major changes in healthcare by enhancing medical devices, sometimes in combination with robotic technology.

Patenting activity combining digital and healthcare applications did not pick up immediately during the crisis, however, unlike overall healthcare innovation. The development of patenting activities in digital and healthcare technologies, or even the citing of digital technologies in healthcare patents, appears to have slowed down in the patent data available for 2020 — numbers for 2020 are preliminary and only based on a partial count of patent applications (Figure 35). The falloff in healthcare patents using digital technologies, however, contrasts sharply with overall healthcare patenting activities and the trend of strong specialisation in healthcare technologies at the beginning of 2020 (Figure 34b). This suggests that the surge in healthcare patents at the beginning of 2020 did not focus on digital technologies. Until 2019, patenting activity in healthcare technologies that co-develop or cite digital technologies rose, especially in the United States.

Figure 35

Healthcare patents citing digital technologies (in %)**, 2009-2019**



Source: PATSTAT (PCT) data prepared in collaboration with ECOOM.
Note: The lines show the share of healthcare patents with digital citations in the total portfolio of domestic patents.

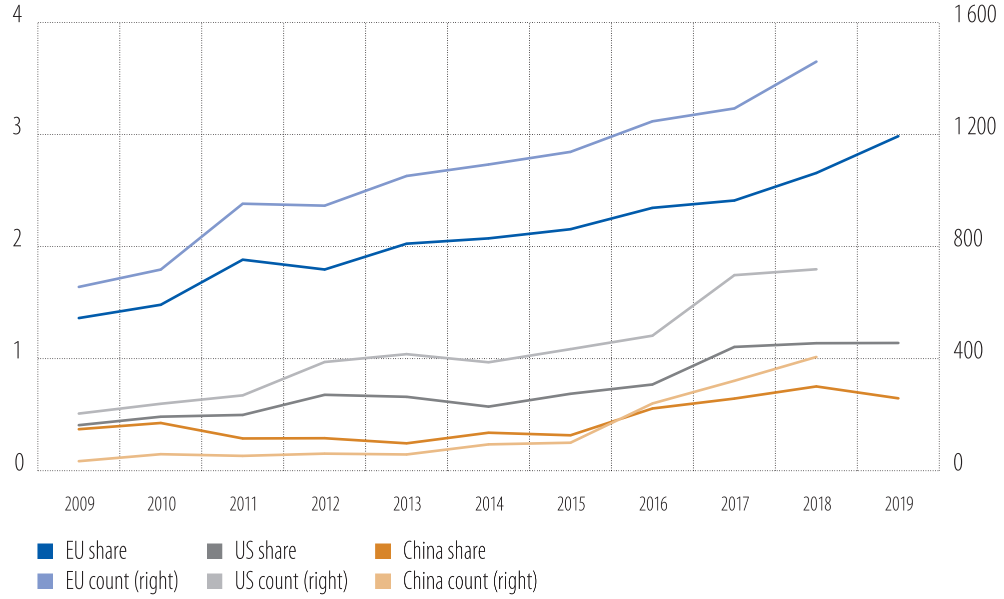
Digital innovation in the automotive sector

The digitalisation of the automotive sector is an integral part of the European Green Deal. Demand for personal mobility services that offer convenience and flexibility is expected to increase. However, environmental challenges are expected to push the evolution of mobility and related services, leading to a more sustainable transportation model. Overall, the technologies and infrastructure currently used are not adapted to 21st century needs. Even before the announcement of the European Green Deal, the European Commission highlighted increased digitalisation in transport as a key priority.

The European Union has had a significant head-start in technologies at the crossroads of automotive and digital services. Although the European Union is lagging behind in most sectors of digital innovation and digital adoption, the automotive sector is following a different pattern (Figure 36). The European Union is more active in innovation in digital automotive technologies than the United States and China. In addition, the European Union has been able to further strengthen its leading position in these technologies over the past decade.

Figure 36

Patents at the crossroads of digital and automotive, 2009-2019 (left axis: patent share in %; right axis: patent count)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The light lines show the count of patents that can be categorised as digital and part of the automotive sector (right axis); the dark lines show the share of patents that can be categorised as digital and part of the automotive sector in the total portfolio of domestic patents (left axis).*

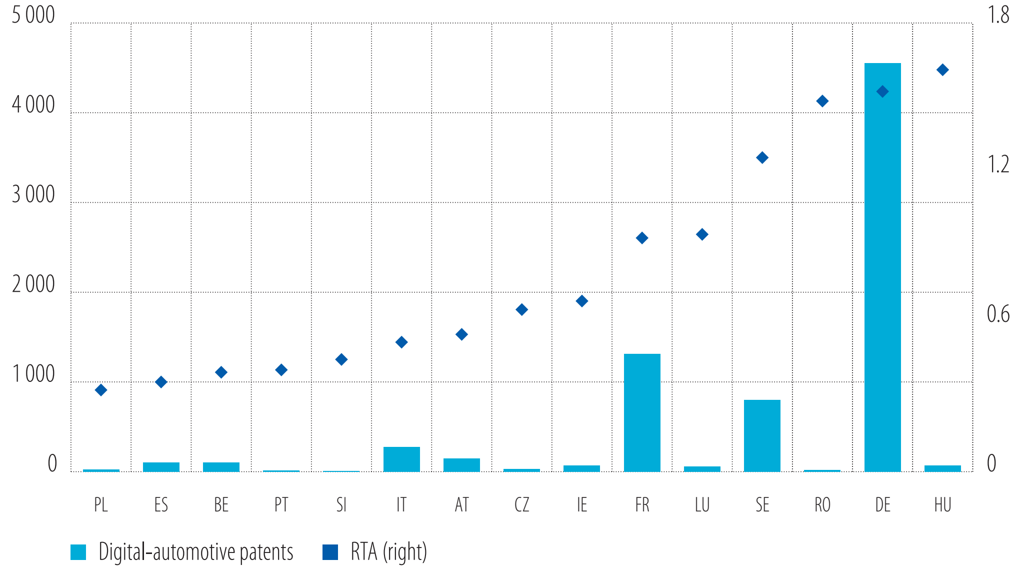
Within the European Union, Central and Eastern Europe have been very active in digital automotive patenting. Although the region produces relatively few patents overall, its specialisation in automotive patenting (measured as revealed technological advantage, or RTA) has increased in the past decade. The automotive sector is core to the economies of Central and Eastern Europe. The automotive patent activity highlights that countries in this region are also engaged in cutting-edge research, development and innovation, going well beyond basic car assembly or parts manufacturing. Nevertheless, the large automotive players in Western and Northern Europe are clearly the technological leaders (for patenting activity). Within Western and Northern Europe, the main driving force behind digital automotive patenting is, not surprisingly, Germany. Sweden and France are strong runners-up (Figure 37).[11] See Box C for a discussion of the radical transformation of the automotive sector expected from the electric revolution, and the consequences the revolution is expected to have in the European Union and in particular Central and Eastern Europe.

Automotive patents that use digital technologies mainly focus on vehicles, hardware and analytics (see Box C for a description of the different automotive domains). While the automotive sector needs to undergo a massive transformation, it is somewhat surprising that digital domains such as power supply, artificial intelligence and position determination combine fewer automotive and digital technologies (Figure 38). The lower prevalence of automotive technologies co-developing digital infrastructure could be addressed by policies that create incentives for innovation and the development of new applications.

11 The companies leading automotive patenting are very much in line with Figure 32, which shows EU companies leading in innovation in digital vehicle applications.

Figure 37

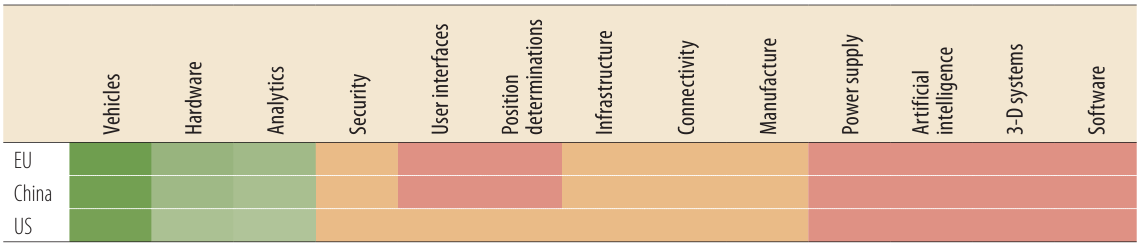
Digital automotive patents in selected EU members (left axis: patent count; right axis: RTA)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The figure shows the number of digital and automotive patents (bars, left axis) and the RTA (diamonds, right axis). The revealed technological advantage (RTA) index is the share of digital and automotive patents in the country portfolio relative to the share of digital and automotive patents in the European Union. The graph excludes EU countries with a total number of patents below 500. The index was calculated for 2012-2017.*

Figure 38

Digital domains used in automotive patents

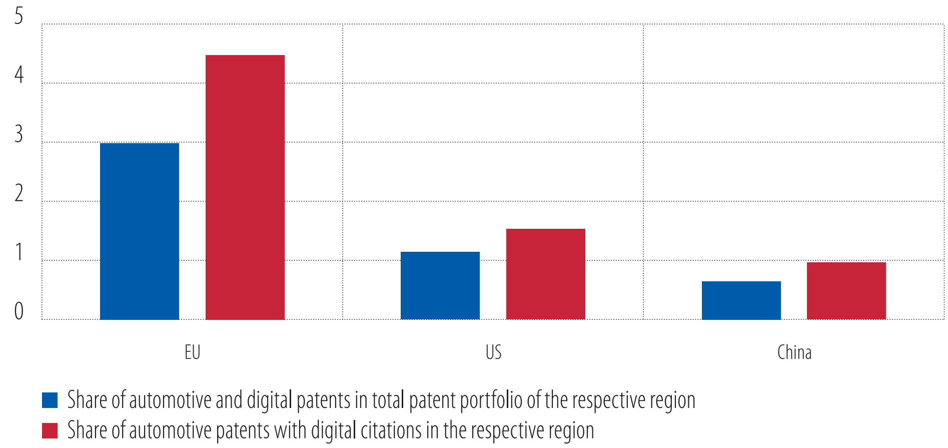


Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The green areas indicate digital domains that are often co-developed with automotive applications. The red areas indicate digital domains that are less intensely co-developed with automotive applications. The yellow-orange area is the continuum in between. Digital domains that are rarely co-developed with automotive patents, such as home or personal applications, are not shown.*

The European Union is not only co-developing automotive and digital technologies in combination, it is also actively citing digital patents when developing automotive technologies. Instead of co-developing technologies, it may be easier to integrate existing digital technologies into automotive innovations.[12] Close to 5% of all patents in the European Union were automotive patents citing digital technologies in 2019 (Figure 39). The trend has grown steadily in the European Union in recent years, while it seems to be stabilising in the United States and China. This suggests that Europe could be one of the driving forces behind the mobility revolution. At the same time, incentives for innovation will need to be aligned if the automotive transformation is to be successful. European policymakers could make a difference by laying a strong foundation that would enable the revitalisation of the automotive industry and innovation to bring it into the future.

12 Figure 39 explores digital subdomains in the automotive patents. The figure would be similar for digital domains cited in transportation patents.

Figure 39
Digital automotive patents and automotive patents that cite digital technologies in 2019 (in %)



Source: PATSTAT (PCT) data prepared in collaboration with ECOOM.

Box C

The electric revolution in the automotive sector

The future of the automotive sector — at least in Europe — is fully electric.[13] After 120 years of producing and improving petrol and diesel engines, most major automakers (original equipment manufacturers, or OEMs) are phasing out new investments in internal combustion engines and announcing new targets for electric vehicle production. The targets are typically more ambitious in Europe than in other regions where electrification is also advancing at a fast pace (such as China and the United States).

The market is reacting quickly. While new sales of pure electric, plug-in hybrids and hybrids accounted for a mere 1% of the vehicles in circulation in the European Union in 2019, new sales of those vehicles[14] were responsible for 18% of total auto sales in 2020 and 35% in the first part of 2021, thanks in part to public incentives.

The electric revolution is expected to gain further momentum following a series of legislative changes. Under the umbrella of the European Green Deal, the European Commission is proposing the Fit for 55 package (presented in July 2021), which targets a 55% reduction in carbon emissions by 2030 and 100% from 2035. The European Commission will soon introduce new, stricter Euro7 emissions standards. Moreover, some countries are announcing specific dates for the phasing out of sales of new internal combustion engine cars over the next decade.

13 This box was prepared by Matteo Ferrazzi and is based on Delanote at al. (2022).
14 Electrification can take different forms, as the family of electric and hybrid vehicles is composed of various categories: pure electric models (BEV — battery electric vehicles), plug-in hybrids (PHEV — plug-in hybrid electric vehicles, which use both petrol and a battery pack that can be plugged in to charge it up) and hybrid models (HEV — hybrid electric vehicles).

The combined effect of the carbon-emission regulations, public policies at the local level and automakers' plans suggest that a de facto ban on internal combustion engines will materialise in Europe before 2035. The increased cost of internal combustion engine powertrains (including for plug-in hybrids and hybrids) will make them less competitive and push them out of market, at least for light vehicles. In less than 15 years, pure electric models, which represented only 0.2% of the cars in circulation in Europe in 2019, may dominate the entire range of new car sales.

The electric revolution has taken off against a backdrop of numerous other changes affecting the sector, which had already been moving quickly in recent years. Looking at longer-term trends, car production moved to emerging markets. The so-called Triad (EU15, the United States and Japan) produced 70% of cars in 2000, but it now accounts for less than 33% of global production. More recent trends, such as shared mobility (especially related to mobility-as-a-service and car sharing), and connectivity also reflect the sector's evolution (Cassia and Ferrazzi, 2018). In addition, the coronavirus pandemic caused a collapse in production (down 25% in 2020, with only a partial recovery in 2021), and supply bottlenecks (including a shortage of computer chips). The possible effects of changes in mobility due to increased teleworking arrangements are still not fully clear (Klein, Høj and Machlica, 2021). While automotive players are working on providing incremental automation capabilities, autonomous vehicles — one of the most ground-breaking innovations to ever come out of the automotive industry — may gradually arrive on the market before the end of the current decade. In the meantime, new cars are concentrating digital technologies on improving comfort, entertainment and safety.

Batteries and charging infrastructure are key for the electrification of Europe's automotive sector. Batteries, the prices of which are falling fast, are becoming the most important component in electric vehicles. They currently account for one-third of the weight and 30% of the value of a vehicle, figures similar to those of internal combustion engines in the past. Battery production is dominated by China (75% of global capacity) and the European Union is lagging behind (currently less than 10%, thanks solely to factories in Poland and Hungary). Around 20 new production sites for electric batteries are needed in Europe over the next ten years to serve the growing needs of automotive players, and various projects are ongoing. Some automakers are establishing joint ventures with battery producers or implementing vertical integration strategies.

Around 213 000 publicly accessible rechargers had been deployed in the European Union by the end of 2020, of which around 10% were fast chargers. However, the distribution of charging points remains very uneven across Europe, with significant gaps in the network. At least 1 million publicly accessible charging stations must be put in place by 2025 (according to the European Green Deal) to support an expected 13 million electric vehicles, and 3.5 million stations by 2030 (Fit for 55 package) to support an expected 30 million vehicles.

Various factors will shape the electrification of the "machine that changed the world" (Womac, Jones and Roos, 1990) in Europe over the next few years. Firstly, technological advances, regulations and price convergence will soon make electric vehicles more affordable than internal combustion engine vehicles. The localisation of battery cell production and the deployment of recharging infrastructure will also affect electrification, as will supply chains and the geographical distribution of activities. In this context, Germany appears to be the best positioned to become the new electrification hub of Europe, for electric car production and battery production. Countries strongly integrated into German supply chains — the Czech Republic, Slovakia, Poland and Hungary in particular — are expected to be among those that will benefit the most from the transformation of the European Union's automotive industry (Transport & Environment, 2021).

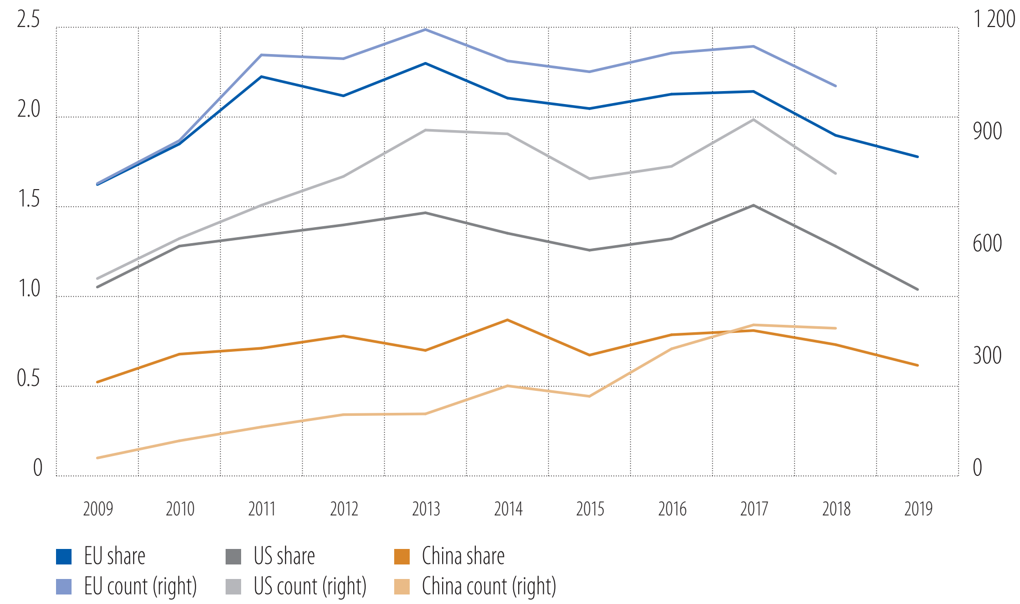
The twin transition: green and digital

Digital technologies are expected to be critical to the green transition and to meeting the sustainability goals defined in the European Green Deal. Many of the digital technologies being developed in transportation could help combat the devastating impacts of climate change. The development and rollout of a wide range of technologies with environmental benefits are crucial for green growth (Aghion et al., 2019). If digital technologies are properly employed, they could play an essential role in tackling environmental challenges, for example by improving food production with precision agriculture or by reducing energy consumption. Digital technologies can also be instrumental in monitoring climate change and facilitating the much-needed shift towards a circular economy. They can foster more sustainable supply chains. The cloud, in combination with mobile data and social media, can take products or even entire industries fully online. Moreover, 3-D printing creates opportunities for manufacturing goods locally, leading to quicker turnaround of product designs and development (Lacy and Rutqvist, 2015). Recent reports convincingly document that the ICT sector and its recent digital advances are contributing to growing energy consumption, but that the net benefits of the sector outweigh the costs (GeSI 2019; IPCC, 2021).

The European Union is currently a global leader in innovation that combines digital and green applications. While Europe may not be a global leader when it comes to digital innovation (Figure 25), it clearly is at the forefront of green technologies (see Figure 33a and the discussion in Chapter 6) and a leader in combining digital and green innovations (Figure 40). This trend has been clear for a while (EIB, 2021b). Nevertheless, in recent years, patenting that combines green and digital technologies seems to have stabilised. That slowdown should be a wake-up call for policymakers, as the transition will rely on green and digital innovations.

Figure 40

Green and digital patents, 2009-2019 (left axis: patent share in %; right axis: patent count)

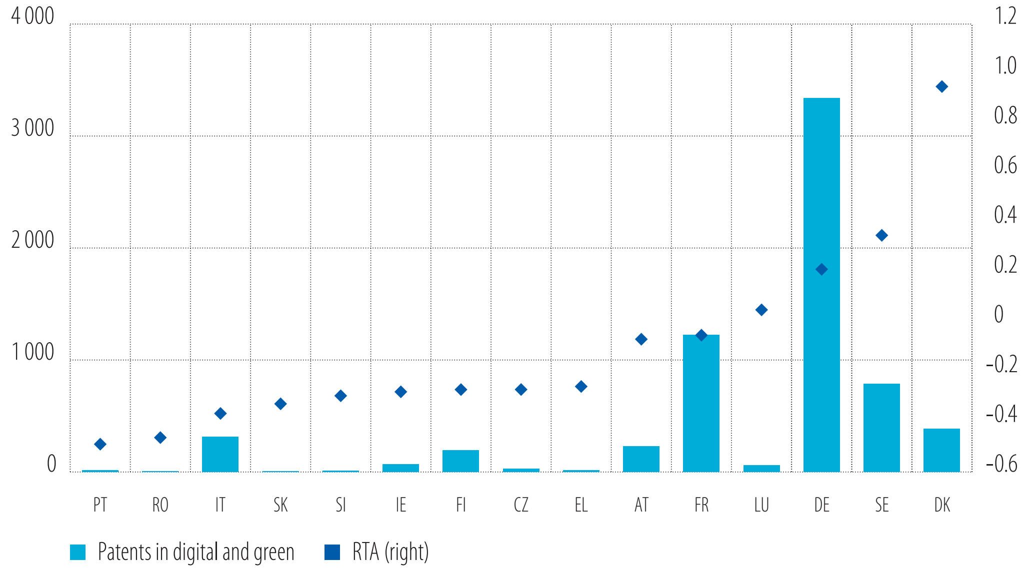


Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The light lines show the count of digital and green patents (right axis); the dark lines show the share of digital and green patents in the total portfolio of domestic patents (left axis).*

Sweden, Denmark, Germany and France are leading green and digital innovation. Within the European Union, countries in Western and Northern Europe clearly lead the way — with an above-average score in the revealed technological advantage (RTA) index in the digital and green domain and/or an above-average number of patents in both green and digital innovations (Figure 41). Overall, patenting of green and digital innovations is mainly driven by a handful of countries that tend to be specialised in these technologies.

Figure 41

Green and digital patenting in selected EU members (left axis: patent count; right axis: RTA)



Source: *PATSTAT (PCT) data prepared in collaboration with ECOOM.*
Note: *The figure shows the number of digital and green patents (bars, left axis) and the RTA (diamonds, right axis). The revealed technological advantage (RTA) index is the share of digital and green patents in the country portfolio relative to the share of digital and green patents in the European Union. The graph excludes EU countries with a very low number of patents. The index was calculated for 2013-2018.*

The European Union is not only a leading force combining digital and green development in patents, but also in adopting existing digital knowledge in its green patents. In addition to patents combining digital and green technologies (Figure 40), the European Union has the highest share of green patents in which digital technologies are cited. The United States and China have, on average, 50% fewer digital citations in their green patents than the European Union. This citation pattern provides a clear view on the extent to which digital technologies are adopted (and not necessarily co-developed) in green innovation. The citations indicate that digital technologies are successfully circulating and becoming more integrated into green technologies, especially in the European Union.

Conclusion and policy recommendations

The pandemic has accelerated the digital transformation, but European policymakers should be concerned that the COVID-19 crisis may exacerbate the digital divide. Although 34% of firms that do not already use advanced digital technologies have taken steps to become more digital as a response to the pandemic, a significant share of firms, 26%, still have not started to invest in the digital transformation. These firms are lagging behind, as they have not adopted advanced digital technologies or used the crisis as an opportunity to become more digital. The share of non-digital firms is particularly large among small firms. Major barriers to investment in digital technologies include finding employees with the right skills to identify and implement digital technologies, the cost of the investments and access to digital infrastructure.

Dealing with laggard, non-digital firms and pushing EU digital innovators to catch up with their US peers should be high on the policy agenda. Digitalisation needs to be dealt with urgently, as Europe lacks global digital champions that produce cutting-edge innovation. Europe has only a handful of firms among the top digital innovators, and it is strong only in one digital domain (vehicle applications). As a result, Europe has a long way to go to catch up with the competition. Nevertheless, the diversified nature of digital innovation — being an area that covers many different domains and sectors — still leaves space for EU firms. Box D discusses EU programmes to support digitalisation and research and innovation activities in the digital field.

Advanced digital technologies must enter general use for the productivity and innovation benefits to be shared widely across the European Union. Furthermore, digital technologies could be critical enablers in meeting the European Union's strict targets for tackling climate change and for the automotive sector. The digital transformation could also play a major role in other sectors, with one important example being healthcare – especially in light of the coronavirus pandemic. While the United States leads innovation in healthcare, the European Union is on top for the development of new technologies in the automotive sector and for combatting climate change.

The European Union seems to have had a strong head-start in technologies that combine automotive and digital innovations. In addition, the European Union has further strengthened its position in the development of digital technologies as critical enablers of the green transition. Given the key importance of transportation and the fact that the world has reached a critical juncture for climate change, it is crucial for Europe to keep its advantage in these domains, which are to a large extent interrelated. Nevertheless, European policymakers will have to do everything it takes to ensure that this dominant position is not rapidly lost. The strong position of the United States and China in the development of new technologies in most digital fields could make it difficult for Europe to remain on top in the areas in which it currently excels. The European Green Deal and the European Union's Digital Strategy are the cornerstone of the recovery plan for Europe. Combined with the national recovery and resilience plans, the initiatives present a unique opportunity to transform the EU economy and make it greener, more digital and more innovative.

Box D

Digitalisation and EU research and innovation policy

Digitalisation has accelerated the pace at which research and innovation activities emerge and has transformed them in several ways.[15] Firstly, it has renewed the DNA of innovation, and the convergence of the digital and physical worlds has enabled a deep-tech wave of science-based, digitally enabled innovations (European Commission, 2020). A few remarkable examples are new battery technologies, precision agriculture, 3-D bioprinting and autonomous vehicles. Secondly, digitalisation has intensified the spread and application of knowledge by boosting open innovation — facilitating the relationship

15 This box was prepared by Ana Correia, Océane Peiffer-Smadja and Julien Ravet (DG Research and Innovation).

between supply and demand for technology, services and skills — and by opening up access to larger talent pools. Thirdly, digitalisation has increased the speed at which technology proliferates. This is especially true for consumer-driven innovations, which spread faster than ever due to the transition from physical to digital goods and powerful network effects in the digital age. For example, while it took 75 years for 100 million people to have a landline telephone, it only took two years and eight months for Skype to reach 100 million users worldwide.

Digitalisation can be also regarded as a game-changer for scientific research, considering its potential for increasing the productivity of science, enabling novel forms of collaboration and discovery, and enhancing research reproducibility (Organisation for Economic Co-operation and Development (OECD), 2019). All areas of research are becoming data-intensive, increasingly relying upon and generating big data. The most evident consequence is that digitalisation poses a challenge in terms of intellectual property production, protection and sharing, and calls for new methods of intangible asset management. It also affects the set of skills that researchers need to master; they must have a good command of digital tools such as gathering, digitising or curating information, but also using computational modelling and simulation methods (OECD, 2020), to name just a few.

To exploit the full potential of science digitalisation, policies must be adapted to reinforce researchers' digital skills and promote open science while preserving intellectual property and ensuring the necessary investment in high-quality data infrastructure. The promotion of the FAIR (findability, accessibility, interoperability and re-usability) principles and the **European Open Science Cloud** will foster the creation of interlinked digital research resources (research data, methods, software and publications). The European Open Science Cloud will enable the vision set out in the communication on "a European strategy for data of a single European data space — a genuine single market for data". As noted in the 2020 communication for **a New European Research Area**, the European Commission will, "together with the Member States […] work towards a world-class research infrastructures ecosystem focusing on the broader range of the EU's policy priorities and improve its governance […] and establish a new governance structure for Technology Infrastructures."

Research and innovation is critical to delivering on the European Commission's twin priorities of the green and digital transition. The Commission's analysis of digital investment gaps[16] in the European Union relative to its main competitors reveals that EUR 20 billion more per year in public and private investments are needed to foster the development of artificial intelligence, EUR 6 billion per year to support digital green technologies, and EUR 5 billion per year for digital innovations, data and next generation internet. As outlined by European Commission President Ursula von der Leyen in the 2020 State of the European Union Address, both the European Green Deal and the EU Digital Strategy constitute the cornerstone of the recovery plan for Europe, a EUR 1.8 trillion stimulus package. National recovery plans also had to dedicate at least 20% of their funds to supporting the European Union's digital transformation.

New investments are key to boosting productivity and supporting the European Union's twin transitions, as well as to reinvigorating the continent´s positioning in digital technologies. The European Union trails behind the United States and China in the number of firms active in artificial intelligence and their patenting activity (De Prato et al., 2019). The United States and China also lead for blockchain startups, with the European Union accounting for only 15% of these startups (Anderberg et al., 2019). Moreover, funding for blockchain startups also appears more readily available in the United States than in the European Union. When it comes to quantum computing, the largest number of applicants are headquartered in the United States, followed by Japan, Canada, and then Europe (Travagnin, 2019). Currently, the market for cloud infrastructure is US-centric, with the top three cloud providers accounting for around 60% of the market. The analysis in the EU Industrial Strategy also

16 DG CNECT estimates, 2 May 2020. The investment gap estimated as a difference between what EU competitors (the United Sates and China) and the European Union invest (including both private and public investment). Table 2 of Commission SWD/2020/98 final.

confirms that the European Union's competitive position appears to be weaker in strategic fields such as artificial intelligence, high performance computing, big data, cloud, industrial biotech and micro-electronics (including semi-conductors).

At the EU level, Horizon Europe has also a key role to play, in full synergy with other programmes in enabling the deployment, uptake and rollout of its digital research and innovation activities. Horizon Europe will contribute to these efforts with a substantial increase of spending in digital research and innovation activities compared to the Research and Innovation Framework Programme Horizon 2020 (from which EUR 13 billion was invested in digital research and innovation activities from 2014 to 2020). This should ensure that Europe remains at the forefront of global research and innovation in the digital field.

Horizon Europe features European missions focusing on ambitious but time-bound and achievable goals, such as adapting to climate change or unlocking the potential of smart, climate-neutral cities. Missions can therefore serve as enablers and accelerators for the European Union's digital objectives, by creating experimental spaces for new solutions and serving as focal points for technological applications. For instance, the cancer mission contributes to creating and funding research programmes for developing artificial intelligence screening and diagnostic tools. At the same time, artificial intelligence is also developed and harnessed to research new drugs through intelligent protein and RNA folding research. **European Partnerships** are another key implementation feature of Horizon Europe, which also contributes to achieving the European Union's political priorities. In the digital field, for instance, Horizon Europe has the following candidate partnerships: European Partnership for High Performance Computing, European Partnership for Key Digital Technologies (KDT), European Partnership for Smart Networks and Services and the European Partnership on Artificial Intelligence, Data and Robotics.

Across the European Union, governments have also strengthened both investments and policies to support digitalisation and research and innovation activities in the digital field at a national level. In 2019, the European Union's five biggest public funders of ICT research and development were Germany (EUR 1.8 billion or 26% of public funding in the European Union for ICT), followed by Italy (EUR 802 million or 11%), France (EUR 689 million or 10%), the United Kingdom (EUR 652 million or 9%) and Spain (EUR 523 million or 7%). Together, those five countries accounted for 63% of total public funding for ICT research and development. However, when looking at the rates of ICT public funding as a proportion of total public R&D investments, Cyprus led the way in the European Union with the highest rate (29%), followed by Ireland (15%), Latvia and Sweden (both close to 13%), Finland (12%) and Hungary (11%).

In 2021, national governments have chosen to allocate more than the required 20% of funding to digitalisation in their recovery and resilience plans. In total, across the European Union, more than 27% (about EUR 135 billion) of the Recovery and Resilience Facility is dedicated to digital, and 43% (EUR 210 billion) to green priorities (Darva et al., 2021). Moreover, it appears that artificial intelligence is the largest emerging trend in science, technology and innovation for a number of policies put in place at national level, gathering schemes that support the development, use, adoption or rollout of artificial intelligence systems (OECD, 2020).

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