2022
2023

INVESTMENT REPORT
2022/2023

Resilience and renewal in Europe

European Investment Bank

Chapter 5

Progress on digital transformation

EUROPEAN INVESTMENT BANK INVESTMENT REPORT
2022/2023

Resilience and renewal in Europe

Part II Resilience and renewal

Chapter 5
Progress on digital transformation

European Investment Bank

Investment Report 2022/2023: Resilience and renewal in Europe.

About the report

The annual EIB report on investment and investment finance is a product of the EIB Economics Department. The report provides a comprehensive overview of the developments and drivers of investment and investment finance in the European Union. It combines an analysis and understanding of key market trends and developments, with a thematic focus explored in greater depth. This year, the focus is on how Europe is progressing towards a digital and green future amid an energy crisis. The report draws extensively on the results of the annual EIB Investment Survey (EIBIS) and the EIB Municipality Survey, combining 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 to help define its positioning, strategy and policy. The director of the Economics Department, Debora Revoltella, heads a team of 40 economists.

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Chapter 5

Progress on digital transformation

The European Union is closing the digital adoption gap with the United States. More than half of EU firms responded to the pandemic by investing in digitalisation, and they are rapidly catching up with their US peers in implementing advanced digital technologies. Despite this, Europe is not well positioned in digital innovation, and is at risk of developing dependencies in several critical technologies.

Digitalisation drives firms' resilience to economic disruption and climate change, and it has helped European firms adjust at a time of repeated shocks. Digital companies displayed more resilience to the economic and trade disruptions unleashed by the COVID-19 crisis and the war in Ukraine, suggesting that they found more efficient ways of working. Digital firms generally perform better than non-digital firms, tending to be more innovative and productive. They are also more likely to engage in international trade and invest in addressing the physical and transition risks of climate change. Digital technologies will be key to meeting the ambitious goals of the European Green Deal.

Successfully managing the digital transition and taking advantage of its long-term benefits goes beyond technology adoption. The digital transformation is a societal change. Striking the right technological balance is a complex process for the European Union, which is caught between global players that are defining the cutting edge of digital innovation, national preferences and societal and regulatory patterns that set boundaries on the use of digital technologies. To make the most of the digital transformation, the European Union will need to position itself well in the global environment, creating better internal conditions for innovation in technologies that are crucial to European interests and taking full advantage of the benefits of digitalisation, while staying within the boundaries of the European economic model.

Firms' digitalisation depends on external and internal factors. These include adequate digital infrastructure and competition-friendly regulation, as well as management decisions on investment in employee training and trade with firms in innovative sectors, which accelerates the spread of digital technologies. A coordinated policy framework is crucial for addressing infrastructure gaps, improving digital skills, developing the innovation environment and regulating efficiently. Governments and municipalities also need to embrace digitalisation themselves. For many regions, this implies a coherent approach to digital governance, guided by the needs of people and firms. The right balance is especially important for businesses that are not using cutting-edge digital technologies, as recent crises — the coronavirus pandemic and the war in Ukraine — are likely to exacerbate the digital divide between more and less tech-savvy companies.

Introduction

According to the results of the EIB Investment Survey (EIBIS), more than half of companies in the European Union responded to the pandemic by investing in digitalisation. European firms are also rapidly catching up with their US peers in the implementation of advanced digital technologies. Europe continues to lag behind other global players in digital innovation, however, and it is at risk of developing dependencies in several critical technologies. The European Union needs to focus on critical factors such as digital infrastructure, regulation and digital skills, and it must further strengthen and defend its ability to innovate in strategic technologies. At a time of repeated shocks and structural transformation, digitalisation drives resilience and adaptation, and it enables firms and societies to prosper.

This chapter is split into five sections. The first assesses the current trends in technological adoption and looks at how the pandemic accelerated digitalisation, while highlighting the risk that some firms may be left behind. The second section focuses on external enablers of digitalisation and stresses the importance of adequate digital infrastructure and regulation. The third section discusses how firms' internal workings, such as investment in employee training to improve digital skills and engagement with innovative sectors, influence digitalisation, and looks at the factors affecting whether firms take advantage of digitalisation. The fourth section explores digitalisation as a driver of firms' resilience and their ability to transform to address trade shocks and structural changes being caused by the green transition. The last section presents policy implications and conclusions.

Adoption, innovation and risks of polarisation

The pandemic has accelerated digitalisation

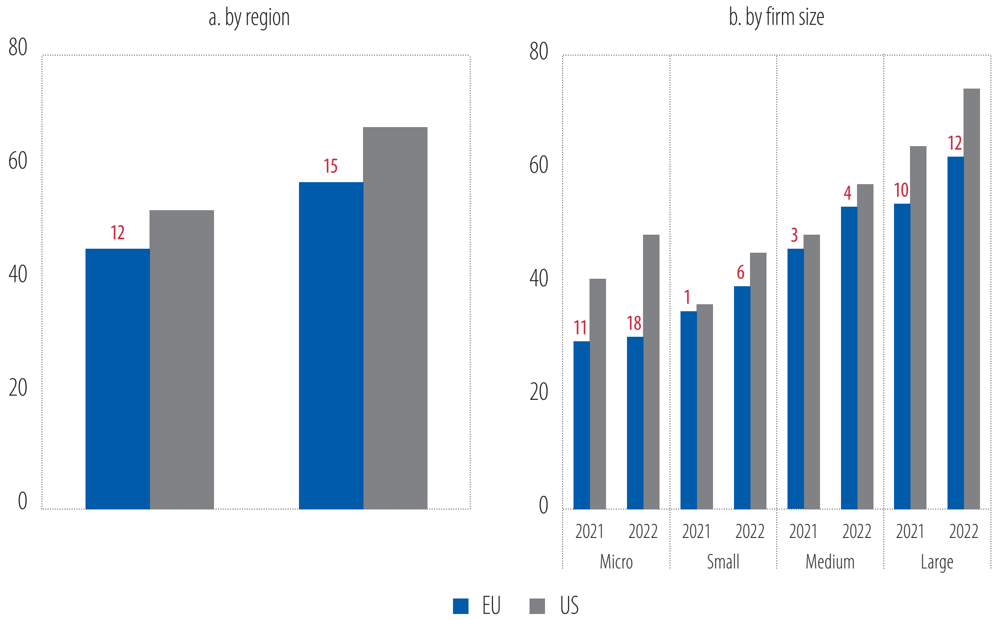
More than half of firms invested in digitalisation in response to the COVID-19 crisis. In the European Union, 53% of firms report taking action to become more digital — for example by providing services online — according to the results of the EIBIS conducted from April to July 2022. However, significant differences exist between countries and firm sizes.[1] Also, the share of firms that invested in digitalisation as a response to COVID-19 is higher in the United States than in the European Union, and this gap increased from 2021 to 2022 (Figure 1a). Micro and small firms are lagging medium-sized and large firms. In the European Union, only 30% of microenterprises stated that they took steps to improve digitalisation in 2022, compared with 63% of large firms (Figure 1b). European micro and small firms are also less likely than their US peers to report having invested in becoming more digital.

In addition to moving ahead with basic digitalisation, European firms are accelerating the adoption of new, advanced digital technologies after putting these processes on hold in the first year of the pandemic. The European Union has been closing its digital adoption gap with the United States over the past four years. But implementing advanced digital technologies requires more significant investment than simple digitalisation activities such as providing services online. Beyond the short-term response to COVID-19 and the war in Ukraine, the digital transformation of the EU economy will require the adoption of more advanced digital technologies, such as 3-D printing, advanced robotics, the internet of things, big data analytics and artificial intelligence, drones, online platforms and augmented reality. The share of EU firms implementing advanced digital technologies increased from 2021 to 2022, reaching 69%, compared with 71% in the United States (Figure 2).

1 All the associations discussed in the analysis using EIBIS data — such as the links between digitalisation and firm size, firm productivity, internet speed or digital skills — also hold in multivariate regression analysis controlling for other potential factors that may influence the analysis, such as firm age, sector and country.

Figure 1

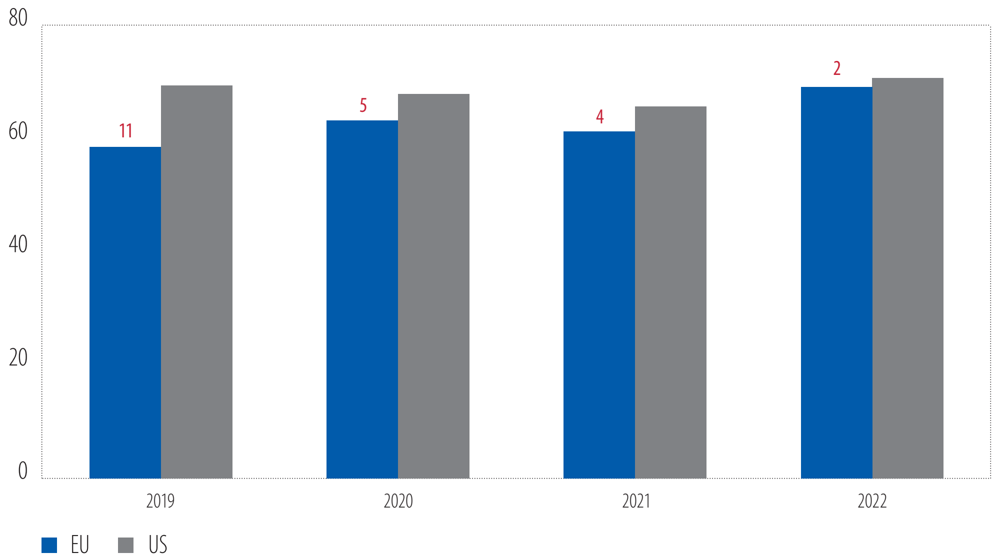
Investment in digitalisation as a response to COVID-19 (% of firms)



Source: *EIBIS 2021-2022.*
Note: *The numbers over the bars indicate differences in percentage points between the United States and the European Union.*
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 2

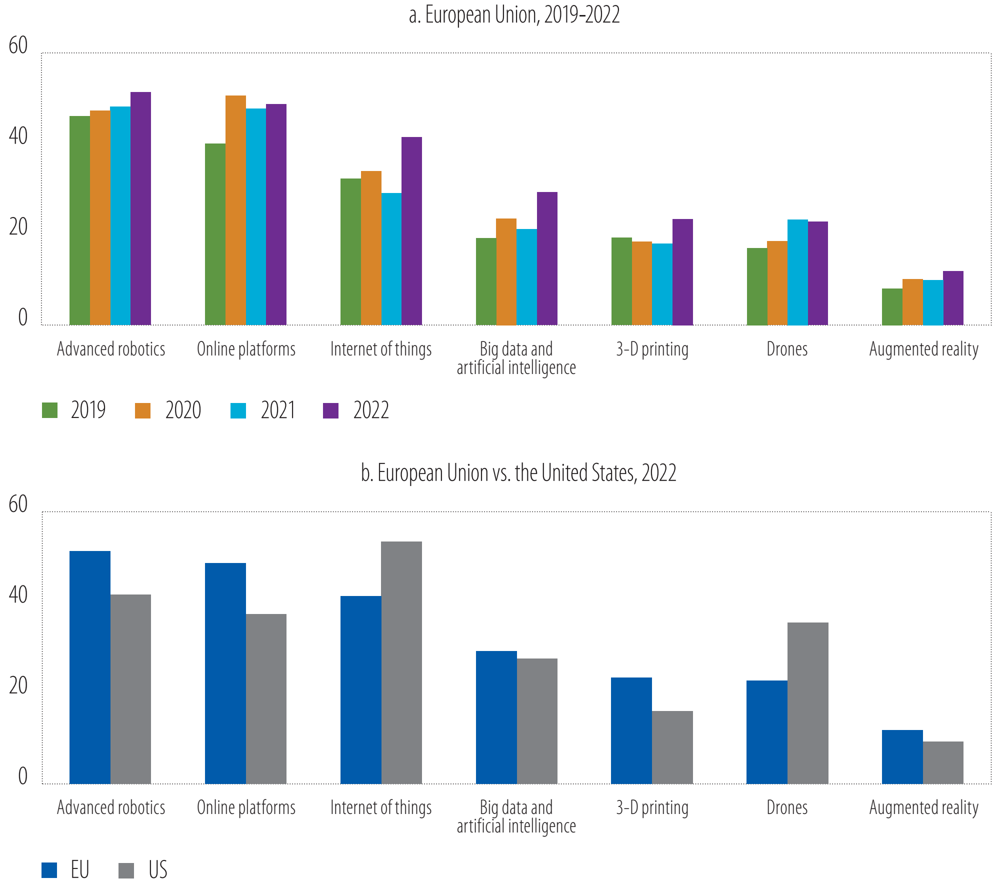
Adoption of advanced digital technologies (% of firms)



Source: *EIBIS 2019-2022.*
Note: *The numbers over the bars indicate differences in percentage points between the United States and the European Union. 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.*
Question: (2019-2021) *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 3 for the definitions of digital technologies).*
Question: (2022) *To what extent, if at all, are each of the following digital technologies used within your business? Not used in the business; used in parts of the business; entire business is organised around this technology.*

Advanced robotics and online platforms remain the most widespread digital technologies. The implementation of most advanced digital technologies has progressed over the past four years (Figure 3a). The gap in the adoption of internet of things technologies between the European Union and the United States has narrowed in the last year. The gap was 12 percentage points in 2022 (Figure 3b), compared with 18 percentage points in 2021.

Figure 3
Adoption of specific digital technologies (% of firms)

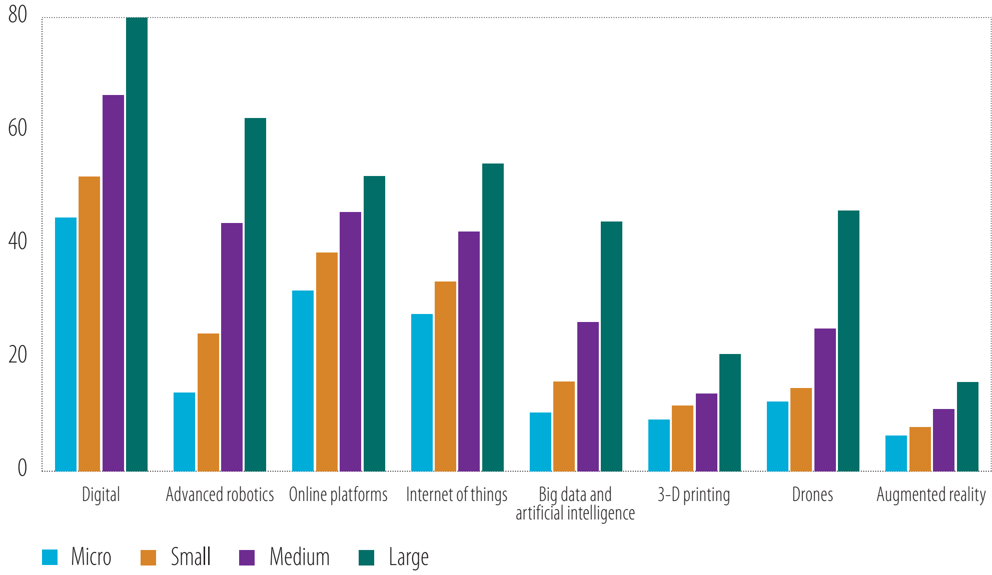


Source: *EIBIS 2019-2022.*
Note: *"3-D printing" is also known as additive manufacturing (manufacturing, construction, infrastructure). "Robotics" is automation via advanced robotics (manufacturing). "Internet of things" refers to electronic devices that communicate with each other without human assistance (all sectors). "Big data and artificial intelligence" refers to cognitive technologies, such as big data analytics and artificial intelligence (manufacturing, services, infrastructure). "Drones" are unmanned aerial vehicles (construction). "Augmented reality" refers to augmented or virtual reality, such as presenting information integrated with real-world objects using a head-mounted display (construction, services). "Online platforms" refers to a platform that connects customers with businesses or customers with other customers (services and infrastructure).*
Question: *See questions for Figure 2 for the exact wording.*

Firm size plays a key role in the adoption of advanced digital technologies. 80% of firms with more than 250 employees use advanced digital technologies, compared with around 45% of firms with fewer than ten employees (Figure 4). This disparity is likely to slow the digital transformation in Europe (Revoltella, Rückert and Weiss, 2020). The difference in adoption rates is particularly pronounced for advanced robotics, which supports the idea that certain technologies involve major integration costs, and that large firms are more likely to adopt these technologies (Acemoglu et al., 2022).

Figure 4

Probability of adopting advanced digital technologies (in %)**, by firm size**



Source: *EIBIS 2022.*
Note: *The bars represent the probability of digital technology use by firm size class, estimated from logistic regressions. The regressions control for firm country and sector fixed effects (27 EU countries and 12 sectors).*

Europe's digital innovation delay

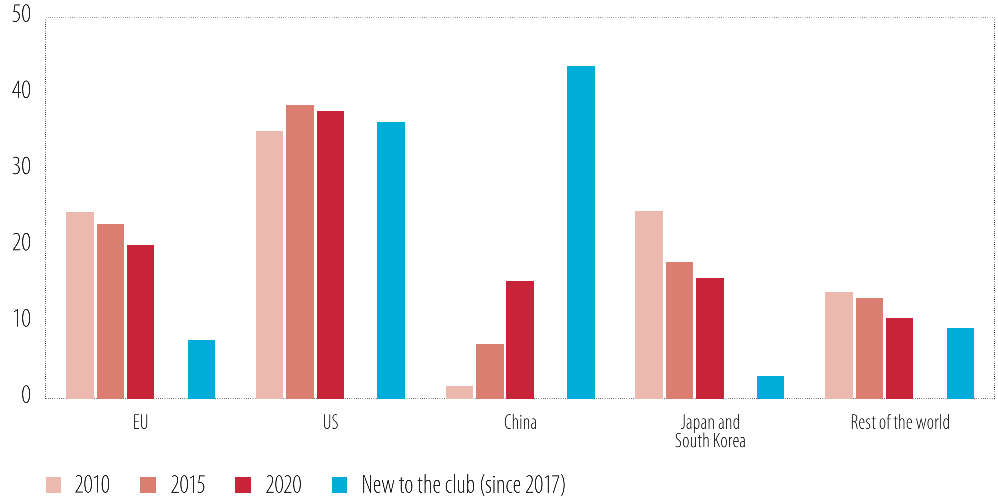
While Europe is catching up when it comes to the adoption of advanced digital technologies, it is at risk of being overtaken in digital innovation. R&D investment and patenting activities are highly concentrated among a small number of companies, sectors and countries. The world's top 2 500 R&D investors account for close to 90% of global business R&D expenditure and 60% of patent filings for all technologies (Amoroso et al., 2021). This concentration of innovation is particularly pronounced in high-tech sectors such as software and computer services, pharmaceuticals and biotechnology, and technology hardware manufacturing, but it also exists in traditional industries such as the automotive sector.[2] Compared to sales or employment, R&D investment and patenting activities are more concentrated in a small number of incumbent firms that have grown bigger over time.

The European Union remains a major global player in R&D and innovation, but the share of EU firms in the top 2 500 R&D investors has fallen over time. The share of firms from the European Union and Japan on the list of the top 2 500 R&D investors decreased from 2010 to 2020 (Figure 5). This decline can be largely attributed to the emergence of Chinese firms. While the United States remains an innovation leader, the number of Chinese companies included on the list of big R&D spenders has risen fast.

2 Eurostat classifies motor vehicle manufacturing as a medium-high-tech sector, whereas pharmaceuticals, computer, electronic and optical products, and computer programming and related activities are considered high-tech sectors.

Figure 5

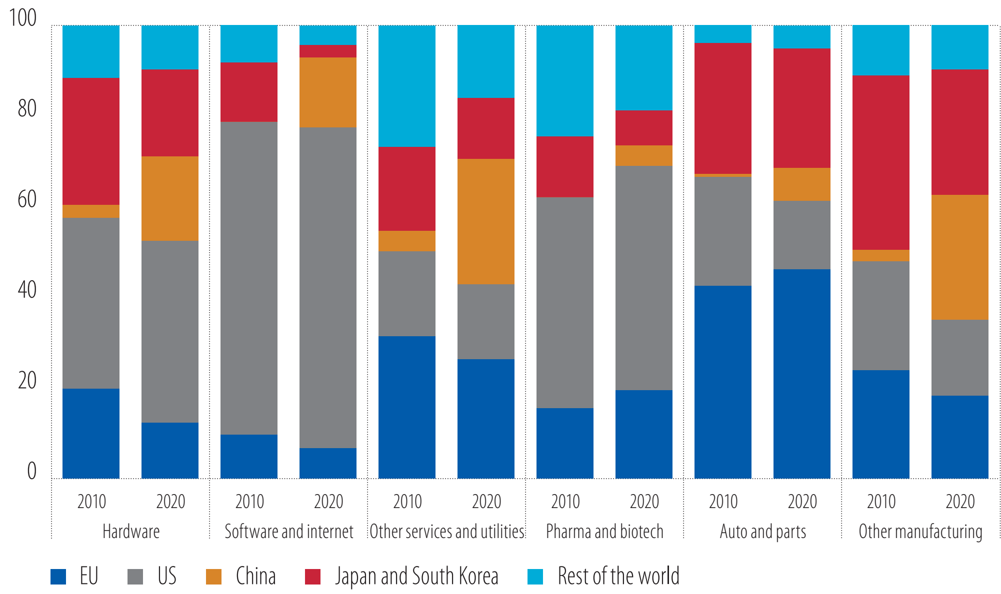
Share of top global R&D companies (in %)**, by region**



Source: *EIB staff calculations based on EU Industrial R&D Investment Scoreboard.*
Note: *"New to the club" refers to firms that entered the list of top global R&D investors after 2017.*

Figure 6

Share of R&D expenditure in 2010 and 2020 (in %)**, by sector**



Source: *EIB staff calculations based on EU Industrial R&D Investment Scoreboard.*
Note: *Share of R&D expenditure by the top R&D investors, by sector and country.* Hardware: *electronic and electrical equipment, technology hardware and equipment.* Software and internet: *software and computer services.* Other services and utilities: *fixed-line telecommunications, mobile telecommunications, food and drug retailers, general retailers, industrial transportation, travel and leisure media, banks, equity investment instruments, life insurance, non-equity investment instruments, non-life insurance, real estate investment and services, support services, alternative energy, electricity, gas, water and multiple utilities, industrial metals and mining, oil and gas producers, oil equipment, services and distribution.* Pharma and biotech: *pharmaceuticals and biotechnology, healthcare equipment and services.* Auto and parts: *aerospace and defence, automobile and parts.* Other manufacturing: *beverages, food producers, tobacco, chemicals, construction and materials, forestry and paper, general industrials, industrial engineering, household goods and home construction, leisure goods, personal goods.*

The global R&D landscape has changed rapidly over the past decade as the digital economy increased in importance and as the European Union specialised less in software and computer services than the United States and China. Among the leading companies in software and internet, EU firms only represent 7% of R&D expenditure, compared with 71% for the United States, 15% for China and 3% for Japan and South Korea (Figure 6). Similarly, the European Union accounts for 12% of R&D expenditure among leading companies producing technology hardware and electronic equipment, compared with 40% for the United States, 19% for Japan and South Korea, and 19% for China. European policymakers need to continue to stress the importance of digitalisation, or EU firms could fall into a dependency trap for a few rare and strategic technologies (see Box A). The European Union and the United States should also cooperate on technology and trade matters, following the approval of the US Inflation Reduction Act, which calls for massive investment in clean energy and climate change (von der Leyen, 2022).

Box A

EU technological leadership and vulnerabilities[3]

The coronavirus pandemic and a fast-changing geopolitical landscape has revealed EU dependencies in several strategic sectors and value chains — such as batteries, clean energy, processors and semiconductor technologies, and raw materials — confirming the need to further accelerate Europe's economic and industrial transformation (European Commission, 2022a; Ravet et al., 2022). Rising environmental, geopolitical, economic and social instability across the world increases the likelihood of extreme and disruptive events. It also draws more attention to the technological capacities of major economic players, such as the European Union, the United States and China (Crespi et al., 2021).

For Europe to remain a global economic power, it must lead on green and digital solutions. The European Union is falling far behind the United States and China in many digital technologies, such as nanotechnologies, artificial intelligence and big data (European Commission, 2022b). China has moved to the forefront of digital technology over the last decade, confirming not only its rise as an economic player on the international stage, but also the importance of its research and innovation efforts for future digital technologies.

Europe needs to maintain its strategic autonomy, or the ability to act autonomously and strategically on the geopolitical scene, without jeopardising its open economic model. The European Union has nothing to gain from heeding domestic interest groups and protecting its market under the pretext of technology sovereignty. Open and fair trade has already helped its societies to prosper. Not being able to access technologies critical for implementing the European Union's main policy priorities, however, could have severe repercussions for its ability to compete freely on the global market.

The European Union has already presented major initiatives supporting its strategic autonomy. It has responded to European hardship caused by the energy market crisis and Russia's invasion of Ukraine with REPowerEU, an initiative to replace fossil fuels with more sustainable sources. The European Green Deal is also a key example of EU efforts to create autonomy without sacrificing the drive towards sustainability. Preserving the strategic autonomy of the European Union also means looking strategically at which technologies to focus on. For example, the European Chips Act will mobilise EUR 43 billion in public and private investments to strengthen the semiconductor industry, with the goal of increasing Europe's share of global chip production from 10% currently to at least 20% by 2030.

If the European Union is to compete internationally in strategic technological fields, it needs to assess the technological capabilities that influence innovation. This will highlight gaps in strategic technologies and indicate how EU policies can best address those gaps. More complex technologies are more likely to remain in the countries or regions that already use them, which creates a competitive advantage for these areas (Balland et al., 2019).

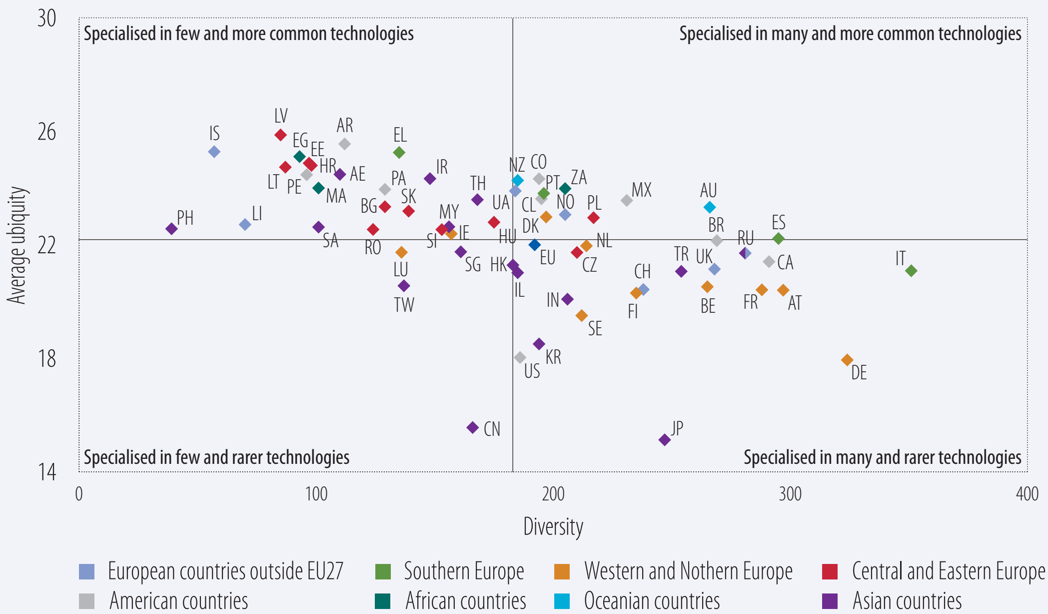
3 This box was prepared by Valentina Di Girolamo and Alessio Mitra (European Commission, Directorate-General for Research and Innovation).

Using patent data retrieved from the Organisation for Economic Co-operation and Development (OECD) database, the research (European Commission – DG Research and Innovation, 2022) factors in the heterogeneity in technology complexity and assess EU technological capabilities compared to other international economies. The research does this by looking at the relationship between a country's technology diversity (the number of different technology specialisations) and a technology's average ubiquity (the average number of countries specialised in the same technologies as the country in question).

China is less diversified than the European Union, the United States, Japan and South Korea (Figure A.1). Nevertheless, it specialises in technologies that are also quite rare (low ubiquity), placing it in the bottom-left quadrant and making it an emerging innovation leader. The United States and South Korea are slightly more diversified than the average, while their ubiquity remains low, signalling an overall ability to specialise in rarer technologies. Japan is also in the bottom-right quadrant. It is highly diversified yet specialises in relatively rare technologies.

Figure A.1

Technology diversity and average ubiquity in 2016-2020, by country



Source: *Authors' calculations based on an OECD database with a sample of 645 technologies at the 4-digit level according to the International Patent Classification system, using patent fractional counting.*

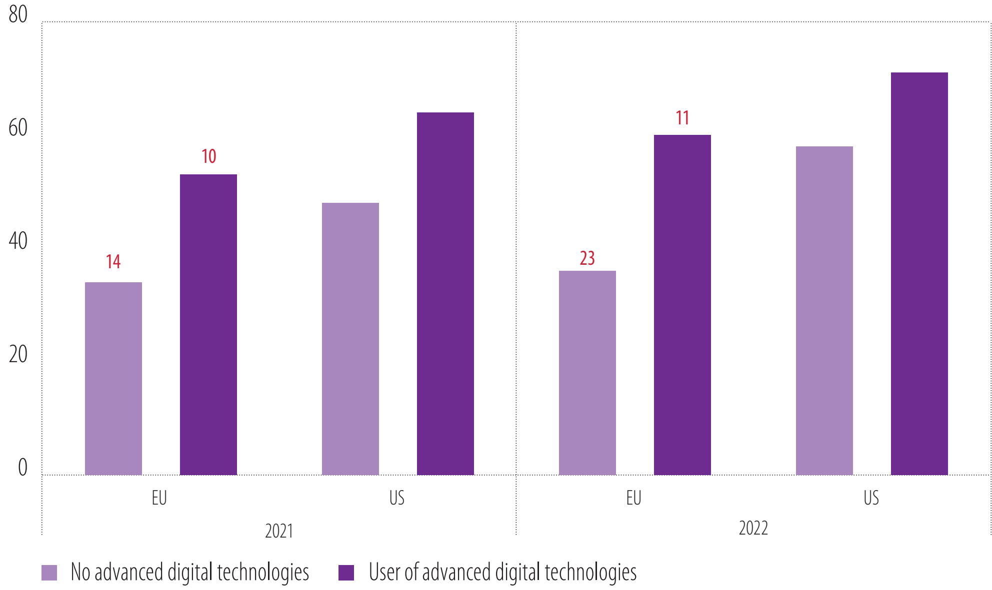
Note: *Technological diversity provides information on how many different technology specialisations are in the basket of each country. Average ubiquity instead captures the average rareness of the technologies a country is specialised in, providing information on how many other countries are specialised in the same technology fields. The vertical line and the horizontal line denote the mean diversity and the mean average ubiquity, respectively. Data for the European Union are calculated as the mean of EU Member States.*

Overall, the analysis shows that the European Union is more diversified than other main international innovation leaders — notably the United States and China. It tends to specialise, however, in technologies that are relatively common (higher than average ubiquity). This suggests that the European Union should increase its innovative efforts in more sophisticated technologies, supported by innovation policies in line with EU policy priorities. This would also strengthen the European Union's strategic autonomy, as it would make it less dependent on other countries in these more sophisticated technological fields.

Digital divides between European firms

Companies that were already digital before the pandemic are more likely to have invested further in digitalisation in response to COVID-19. The crisis may have further deepened the digital divide, as leading firms have accelerated digitalisation, while laggard firms fell further behind (Rückert et al., 2021). Only 36% of non-digital firms in Europe have used the crisis as an opportunity to begin investing in their digital transformation, while 60% of firms that had already adopted advanced digital technologies invested in becoming more digital in 2022 (Figure 7). Importantly, the share of European firms that started investing in digitalisation is significantly lower than in the United States, where 58% of non-digital firms invested in becoming more digital in 2022.

Figure 7
Investment in digitalisation as a response to COVID-19 (% of firms)**, by prior adoption of advanced digital technologies**



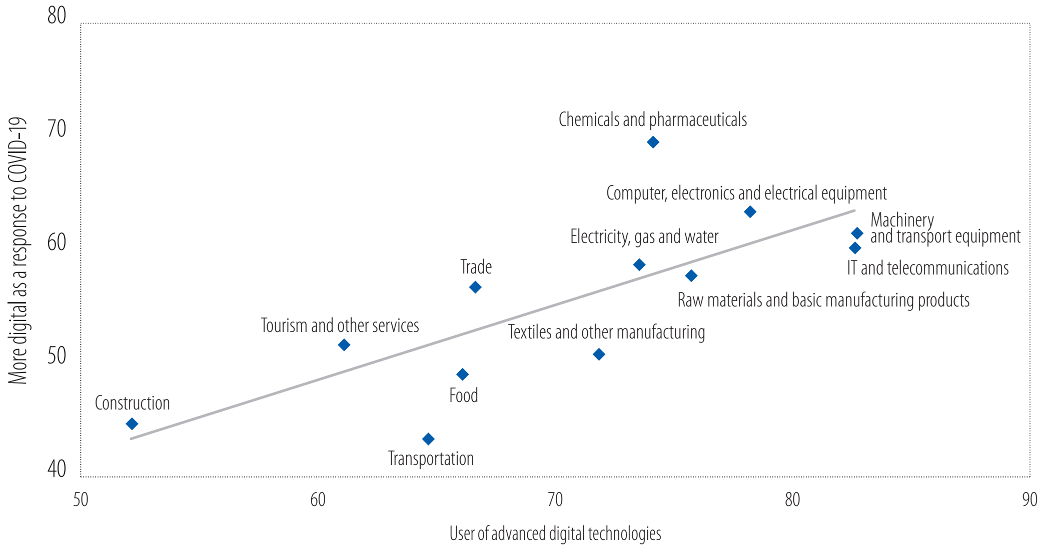
Source: *EIBIS 2021-2022.*
Note: *The numbers over the bars indicate differences in percentage points between the United States and the European Union.*
Question: *As a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital (e.g. moving to online service provision)? See note to Figure 2 for the definition of the adoption of advanced digital technologies.*

Digitalisation varies widely among economic sectors. For example, 83% of firms in the machinery and transport equipment sector use advanced digital technologies, far more than in the construction sector (52%). One explanation for differing levels of digitalisation is that industries produce different products, and that only certain tasks can be performed using advanced digital technologies. There is also a strong correlation in all industries between the use of advanced technologies and digital uptake during the pandemic (Figure 8).

Firms have been grouped into four different digitalisation profiles to better determine whether gaps are emerging. The four categories — neither, basic, advanced and both — are based on companies' implementation of advanced digital technologies, and the steps they took to become more digital as a response to the COVID-19 crisis (Figure 9). "Neither" refers to firms that have not implemeted any advanced digital technolgies, while "basic" means firms that have not yet implemented any advanced digital technology in their business but have taken action to become more digital as a response to COVID-19. "Advanced" refers to firm that have invested in advanced digital technologies but have not taken action to become more digital as a response to COVID-19, while "both" means firms that have implemented advanced digital technologies and have also invested further in digitalisation as a response to COVID-19.

Figure 8

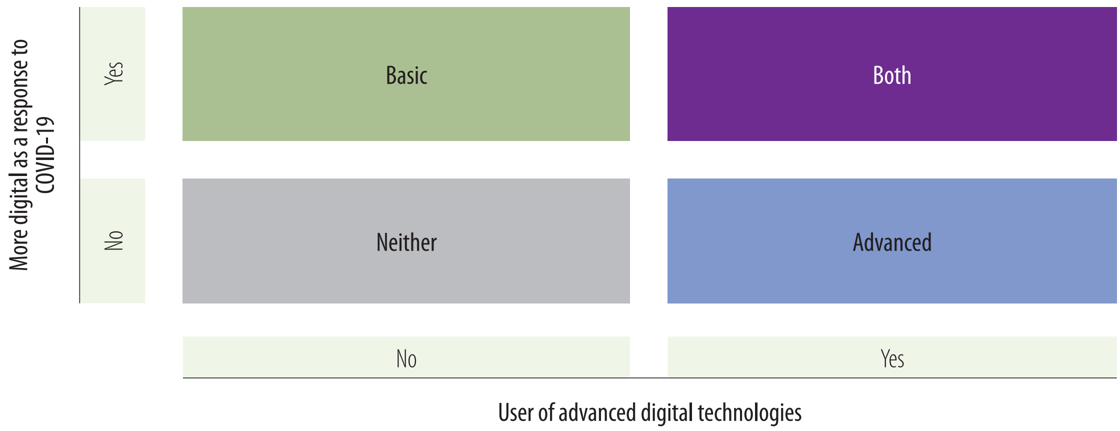
Investment in digitalisation as a response to COVID-19 and advanced digital technologies (% of firms)**, by sector**



Source: EIBIS 2022.
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 2 for the definition of the adoption of advanced digital technologies.

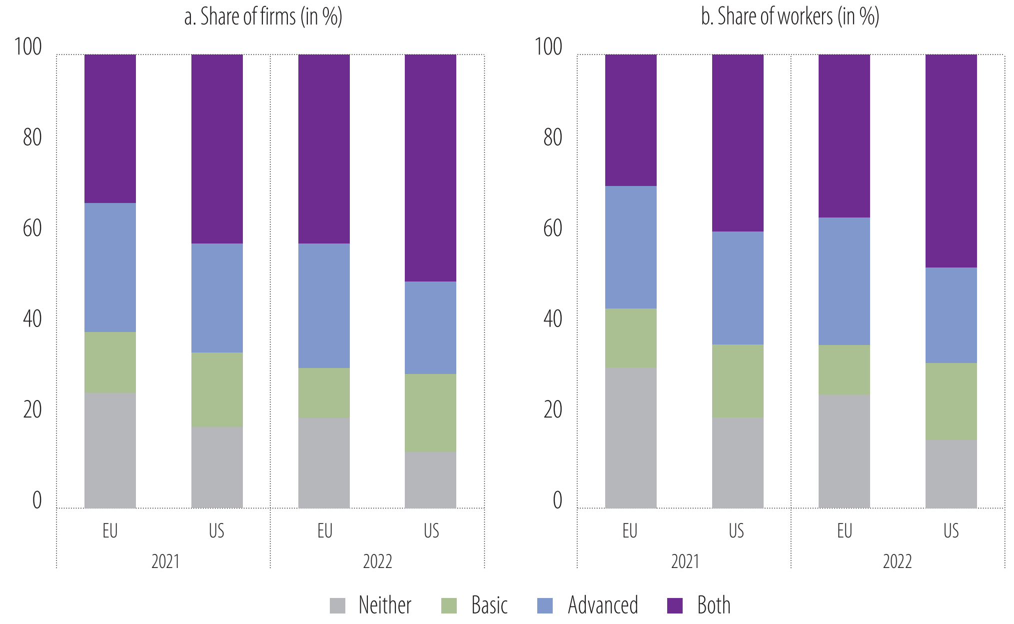
Figure 9

Corporate digital divide profiles



The share of EU firms that did not invest in digitalisation decreased in the second year of the pandemic. One-fifth of EU firms did not invest in digital transformation in 2022, down from 26% in 2021 (Figure 10). The share of workers at firms that fell in the "neither" category decreased to 25% in 2022 from 31% in 2021, but this share remains significantly higher than in the United States (15%). It is encouraging to see that, over time, fewer firms and workers fall into this category. However, firms in the "neither" category may need stronger or more specific policy support to prevent them from falling behind.

Figure 10
Corporate digital divide profiles



Source: *EIBIS 2021-2022.*
Note: *See Figure 9 for the definition of digital profiles.*

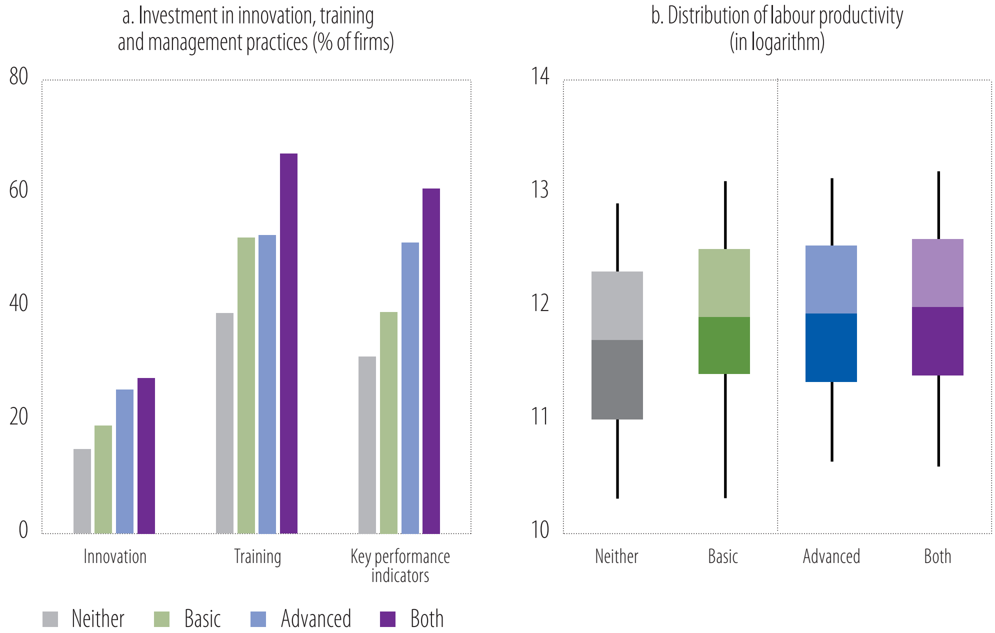
Source: *EIB staff calculations based on EIBIS 2022, Eurostat and the US Census.*

A non-negligible share of firms used the crisis to start the digitalisation process. These companies have not yet implemented any advanced digital technology in their business, but they have taken action to become more digital as a response to COVID-19 — for example, by providing services online — and their digitalisation is categorised as "basic." In the European Union, 13% of firms fall into this category, and the share has remained stable over time.

At the other end of the spectrum, 69% of EU firms have already adopted advanced digital technologies. Among firms that have implemented advanced digital technologies, some did not invest in increasing their digitalisation activities during the pandemic. These companies are categorised as "advanced." Finally, firms that use digital technologies and that have also invested in further digitalisation as a response to the pandemic are categorised as "both" because they have fully embraced the digital transformation. 42% of European businesses fell into the "both" category in 2022 (a 9 percentage-point increase compared with 2021), while one-half of US firms fits in the "both" category.

The digital divide between firms may continue to grow over time. Most companies that cite developing or introducing new products, processes or services as their main investment priority over the next three years are already more digitally advanced (Figure 11a, Innovation). On the other hand, non-digital firms are more likely to say replacing capacity is their investment priority. In addition, about 20% of non-digital firms report not having any investment plans, compared with 6% of the most digitally advanced firms. Digital companies are more likely to report investing in employee training and using strategic business monitoring systems that compare current performance to a series of strategic key performance indicators (KPIs), which indicates advanced management practices. Digitalisation is also associated with higher labour productivity (Gál et al., 2019; Cathles, Nayyar, and Rückert, 2020). Digital firms that fall into the "both" category tend to have the highest levels of labour productivity (Figure 11b). These differences in investment priorities risk exacerbating the digital divide.

Figure 11
Firm performance, by digital profile



Source: *EIBIS 2022.*
Note: *See Figure 9 for the definition of digital profiles.*
Question: *Looking ahead to the next three years, is the development or introduction of new products, processes or services your main investment priority?*
In the 2021 financial year, did your business invest in the training of employees?
Does your company use a formal strategic business monitoring system that compares the firm's current performance against a series of strategic key performance indicators (KPI)?

Source: *EIBIS 2022.*
Note: *See Figure 9 for the definition of digital profiles. Labour productivity is defined as sales per employee. Figure 11 shows the 10th, 25th, 50th, 75th and 90th percentiles of the distribution of labour productivity, by digital profile.*

External factors enabling digitalisation: Digital infrastructure and product market regulation

The external environment in which firms operate contributes significantly to their digitalisation efforts. Digital infrastructure, regulation and market concentration can all limit or enhance digital adoption. In these areas, a coherent set of public policies can make a major difference. The analysis presented in this section shows how firms' operating environment can enable digitalisation and maximise returns from digitalisation investments.

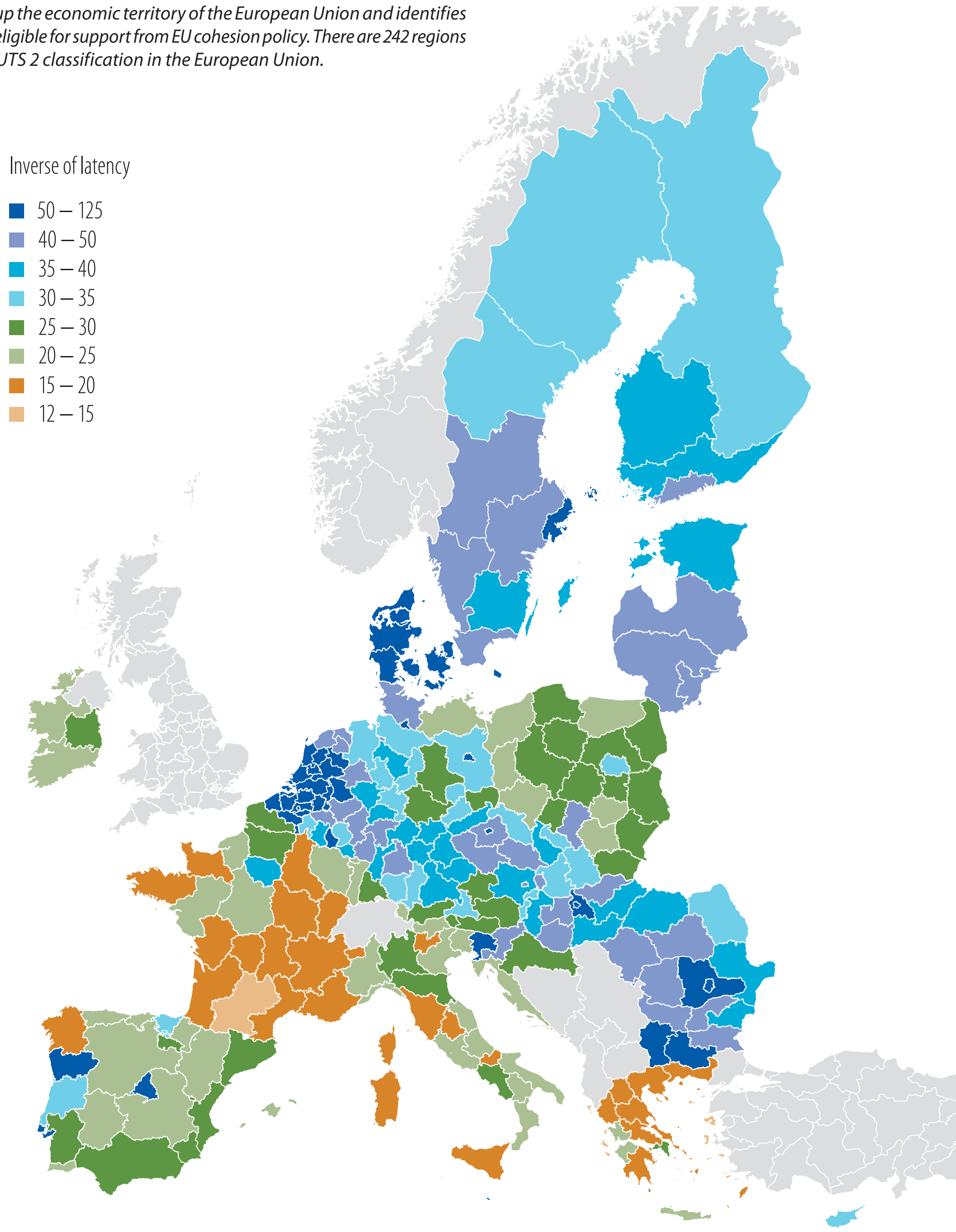
Digital infrastructure as an enabler of firm digitalisation

Digital infrastructure played a critical role during the COVID-19 crisis. 14% of EU firms surveyed in the latest EIBIS consider access to digital infrastructure to be a major obstacle to investment. A key consideration is internet access and speed. Using data on internet speeds, Figure 12 shows that significant differences exist in the quality of digital infrastructure between EU regions and countries.

Figure 12

Internet speed estimates at the NUTS 2* level in the European Union, in 2019

** The Nomenclature of Territorial Units for Statistics (NUTS) classification divides up the economic territory of the European Union and identifies regions eligible for support from EU cohesion policy. There are 242 regions in the NUTS 2 classification in the European Union.*

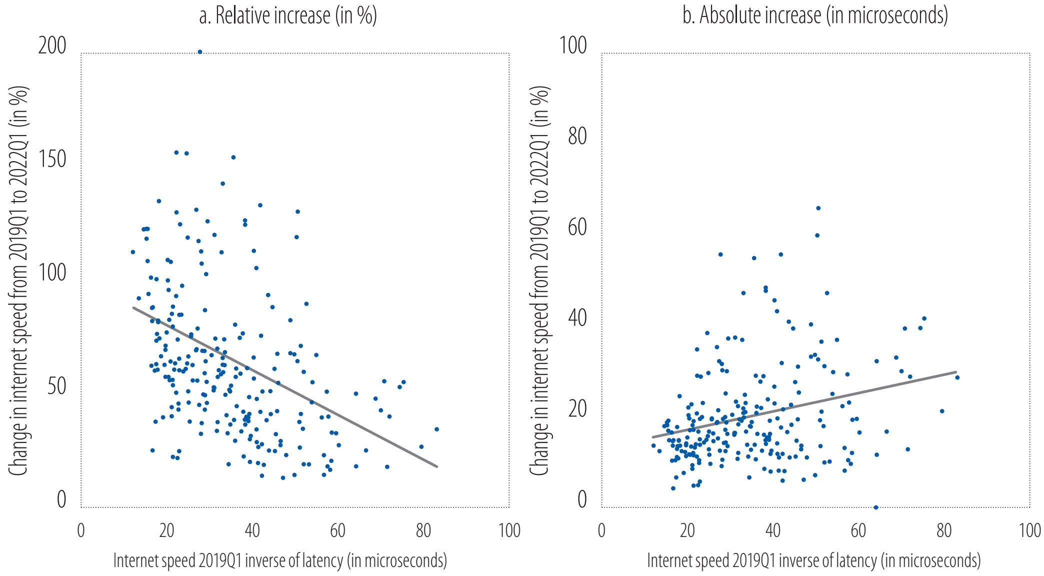


Source: *Authors' calculations based on Ookla.*

Note: *The figure shows data from the first quarter of 2019 and is based on more than 11 million internet speed tests during this period. Internet speed is proxied by the measure of average latency during internet speed tests performed using the website Speedtest.net. Latency is the time it takes for data to be transferred between its original source and its destination, measured in microseconds. The measure is transformed as the inverse of latency (one over latency) to show a positive increase when internet speed is higher. The original data is provided at the level of mercator tiles (approximately 610.8 metres by 610.8 metres at the equator), which is aggregated to NUTS 2 level averages, using the number of tests as weights.*

Persistent and major differences in access to digital infrastructure continue to exist between EU regions. While internet speed has increased throughout the European Union, regions that previously had poor internet access have experienced the greatest relative improvement recently (Figure 13a). Internet speed more than doubled from 2019 to 2021 in some EU regions — primarily in France, Poland and Romania. However, the improvement in digital access has not been sufficient to close regional gaps. Instead, regions that already had better digital infrastructure have increased internet speed more quickly in absolute terms (in microseconds) (Figure 13b). This suggests that digital infrastructure gaps between regions have been widening over time.

Figure 13
Change in internet speed in European regions, 2019-2021



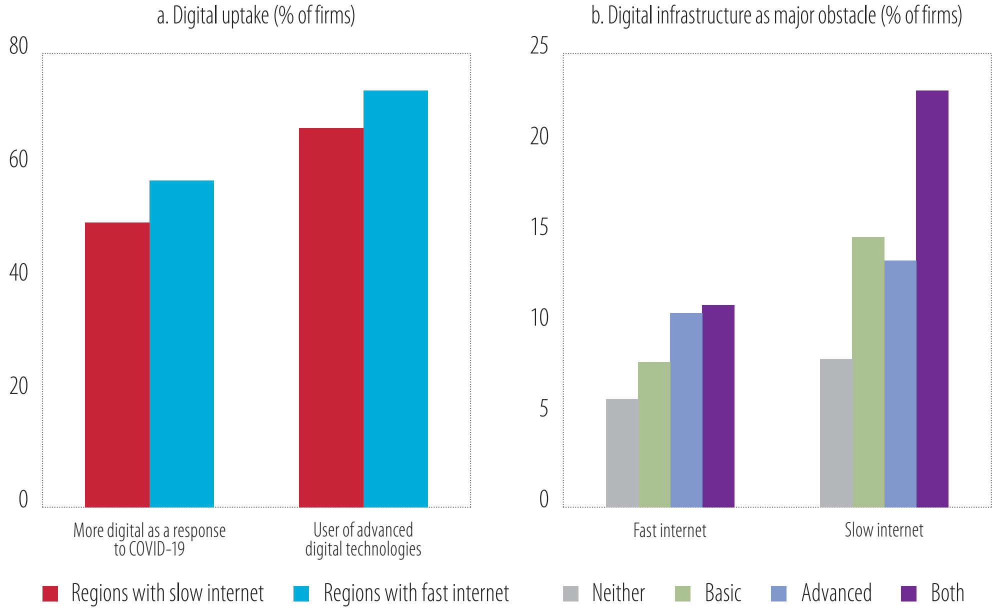
Source: *EIB staff calculations based on Ookla.*
Note: *The figure shows data from the first quarter of 2019 to the first quarter of 2022. Each point represents a NUTS 2 region in the European Union. The left panel shows the increase in internet speed (the inverse of average latency) in relative terms, while the right panel shows the increase in the latency measure in absolute terms. See note to Figure 12 for the definition of internet speed in a region.*

Regions with faster internet speeds tend to have a higher share of digital firms. Regions with fast internet (where internet speed is above median internet speed across NUTS regions) have a higher share of companies that use advanced digital technologies and a higher share of firms that invested in becoming more digital as a response to COVID-19 (Figure 14a). Digitally advanced firms that operate in regions with slow internet also cite the lack of adequate digital infrastructure as an investment barrier (Figure 14b).

The returns from digitalisation are greater for firms located in regions with better infrastructure and faster internet speeds. Better digital infrastructure has provided additional productivity gains for firms that invested in becoming more digital as a response to COVID-19. In regression analysis, the effect can be seen as the positive interaction between investment in digitalisation and fast internet (Table 1).[4] At the same time, while firms that use advanced digital technologies tend to be more productive, firms that already use advanced digital technologies in regions with fast internet see no benefit. In the regression, the interaction term is close to zero. This highlights how critical digital infrastructure was in supporting firms' rapid digital transformation during the pandemic. More generally, it also illustrates how complementary public and private digital investments can improve firm performance and economic resilience.

4 Table 1 reports estimates from ordinary least square regressions (OLS), but the results are similar when using Huber robust regressions.

Figure 14
Digital adoption and regional internet speed



Source: *EIB staff calculations based on EIBIS 2022 and Ookla 2021.*
Note: *See note to Figure 12 for the definition of internet speed in a region. See note to Figure 2 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)? Thinking about your investment activities, to what extent is access to digital infrastructure a major obstacle?*

Source: *EIB staff calculations based on EIBIS 2022 and Ookla 2021.*
Note: *See note to Figure 12 for the definition of internet speed in a region. See Figure 9 for the definition of digital profiles.*
Question: *Thinking about your investment activities in the last financial year, to what extent is access to digital infrastructure an obstacle? Is it a major obstacle, a minor obstacle or not an obstacle at all?*

Table 1
Digital adoption, digital infrastructure and firm productivity

Dependent variable	Total factor productivity	Labour productivity	Total factor productivity	Labour productivity
More digital during COVID-19	0.073*** (0.019)	0.095*** (0.024)		
Advanced digital technologies			0.106*** (0.019)	0.133*** (0.024)
Regions with fast internet	0.071*** (0.020)	-0.034 (0.023)	0.106*** (0.022)	-0.022 (0.028)
More digital x fast internet	**0.086*** (0.028)**	**0.086** (0.035)**		
Advanced digital technologies x fast internet			0.000 (0.028)	0.030 (0.035)
Sample size R-squared	9 678 0.370	11 300 0.259	9 672 0.369	11 298 0.259

Source: *EIB staff calculations based on EIBIS 2022 and Ookla 2021.*
Note: *Firms in the EU27. Total factor productivity and labour productivity are expressed in natural logarithms. The ordinary least squares (OLS) regressions control for firm size, firm age, country and sector (three groups of EU countries and four macroeconomic sectors). Region with slow internet: NUTS 2 region with average latency higher than the median latency across all regions (based on Ookla data). See note to Figure 12 for the definition of internet speed in a region. Bootstrap standard errors with 500 replications are in parentheses for total factor productivity, and robust standard errors are in parentheses for labour productivity. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

Investment in digital infrastructure by European municipalities

The coronavirus pandemic forced municipalities to find new ways of working. The EIB Municipality Survey 2022 asked municipalities in the European Union about the development and deployment of different digital capabilities. These include (i) ensuring the integrity and protection of IT systems (cyber security), (ii) providing digital or online government services, (iii) systematically assessing the adequacy of digital infrastructure, (iv) deploying and using remote sensors (such as real-time traffic or weather monitoring) and (v) employing staff to work exclusively on digitalisation plans.

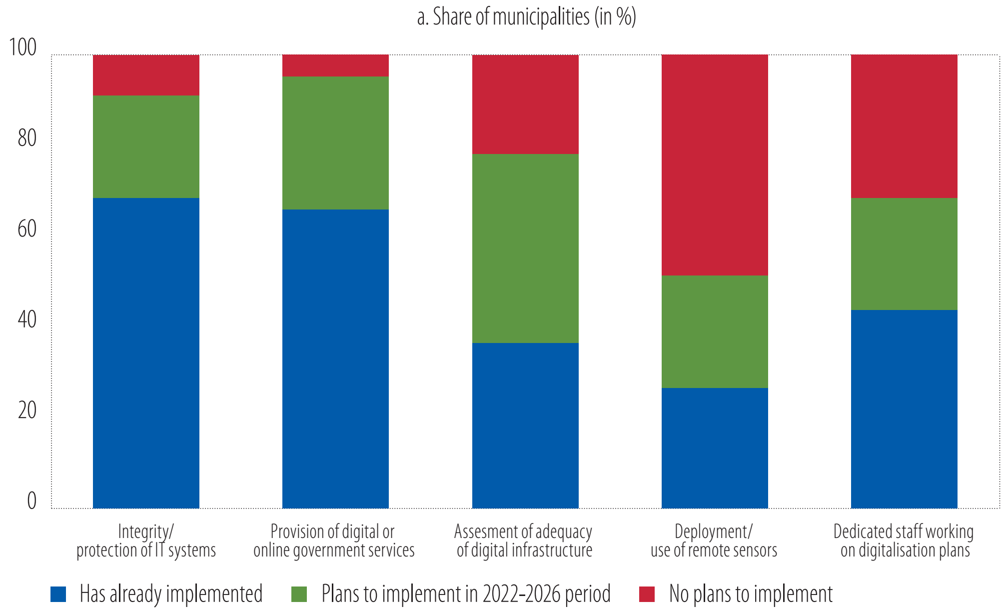
Most municipalities in the European Union have already implemented measures to support the integrity and protection of IT systems. Most municipalities also provide digital or online government services (Figure 15a). However, deploying remote sensors and employing staff to work exclusively on digitalisation plans appear to be less of a priority in the short to medium-term (2022 to 2026).

Municipalities in Central and Eastern Europe tend to be less digitally advanced. The municipality survey response can be used to create an indicator of digital capability, acting as a proxy for the degree to which municipalities are addressing the challenges of digitalisation. Municipalities are considered to have advanced digital capability and sophistication if they have implemented at least three of the five digital capabilities in Figure 15a. About one-third of municipalities in Central and Eastern Europe tend to be digitally advanced, compared with one-half of municipalities in Southern Europe and 45% of municipalities in Northern and Western Europe.

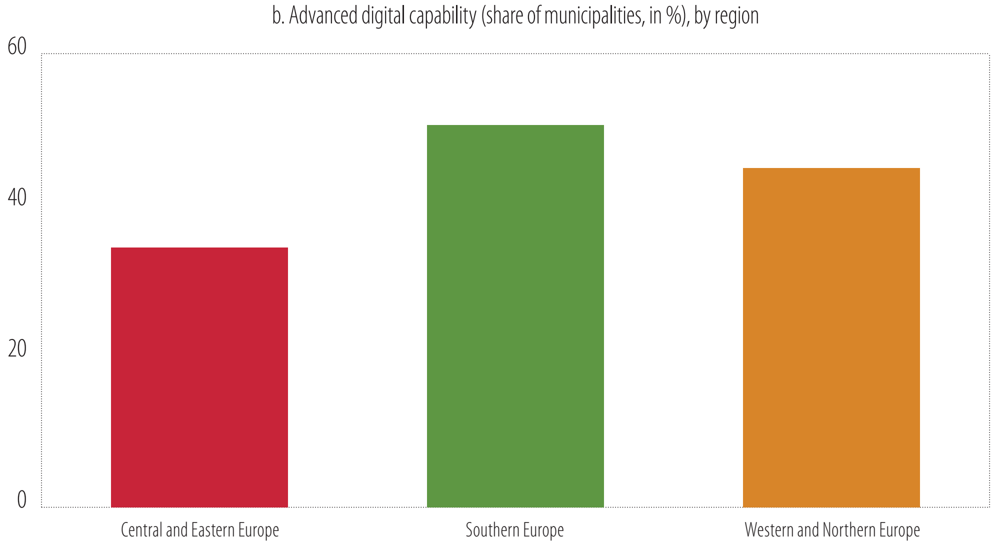
Municipalities with greater digital capabilities and sophistication are less likely to report a lack of investment in digital infrastructure. This relationship is particularly strong in Southern Europe, where digitally advanced municipalities are more likely to judge their investment in digital infrastructure to have been broadly adequate over the last three years (from 2019 to 2021) than digital laggard municipalities (Figure 16). Investment in digital infrastructure appears to be closely linked to the digitalisation of key digital public services, such as the integrity and protection of IT systems (including cyber security) and the provision of digital or online government services.

Figure 15

Municipal administrative digital capability and sophistication



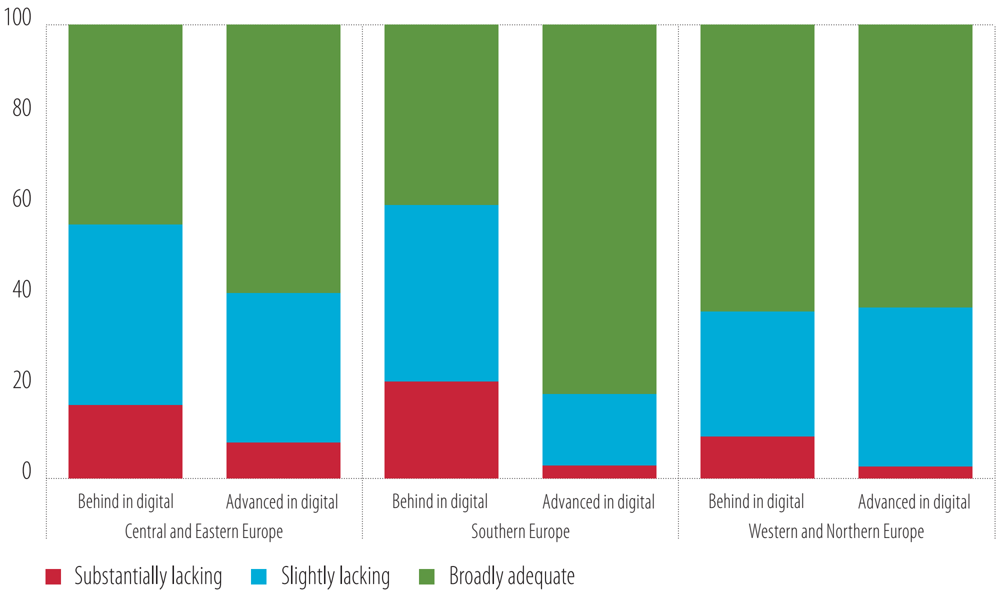
Source: *EIB Municipality Survey 2022.*
Question: *Thinking about digital technologies: For each of the following please tell me whether your municipality has already implemented, has plans to implement in the 2022-2026 period or has no plans to implement in the 2022-2026 period?*



Source: *EIB Municipality Survey 2022.*
Note: *A municipality is considered advanced in digital capability if it has implemented at least three of the five digital capabilities in Figure 15a.*

Figure 16

Assessment of digital infrastructure quality (share of municipalities, in %)**, by digital capability**

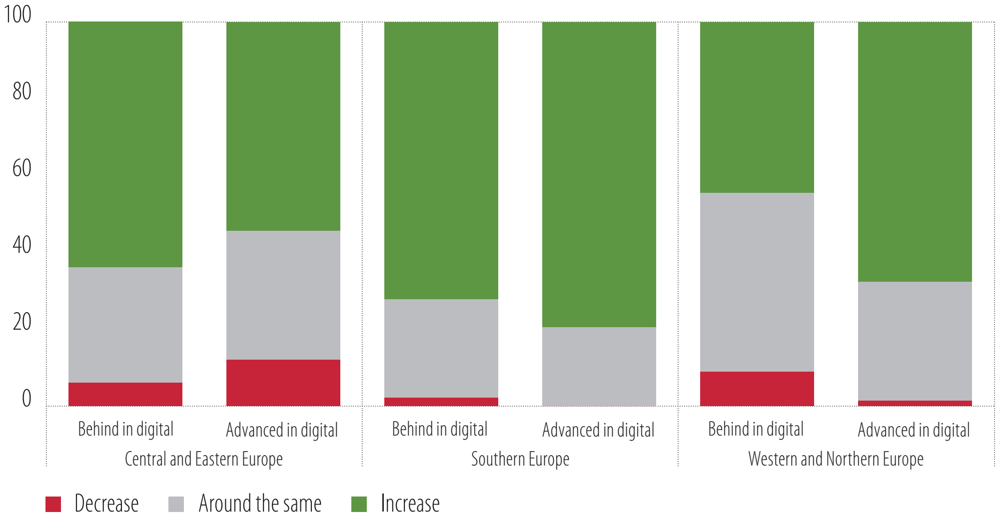


Source: *EIB Municipality Survey 2022.*
Note: *See note to Figure 15b for the definition of municipalities advanced in digital capability.*
Question: *In the last three years, that is to say between 2019 and 2021, would you say that within your municipality the level of investment in digital infrastructure projects was broadly adequate, slightly lacking or substantially lacking?*

Municipalities with better digital capabilities and sophistication are also more likely to state that they are planning to increase investment in digital infrastructure. A large share of municipalities in Western and Northern Europe that are lagging on digitalisation said they do not plan to increase investment in infrastructure from 2022 to 2026 (Figure 17), potentially exacerbating the infrastructure gap with more digitally advanced municipalities. Policy support will be key to reducing regional disparities in digital infrastructure.

Figure 17

Outlook of digital infrastructure spending (share of municipalities, in %), **by digital capability**

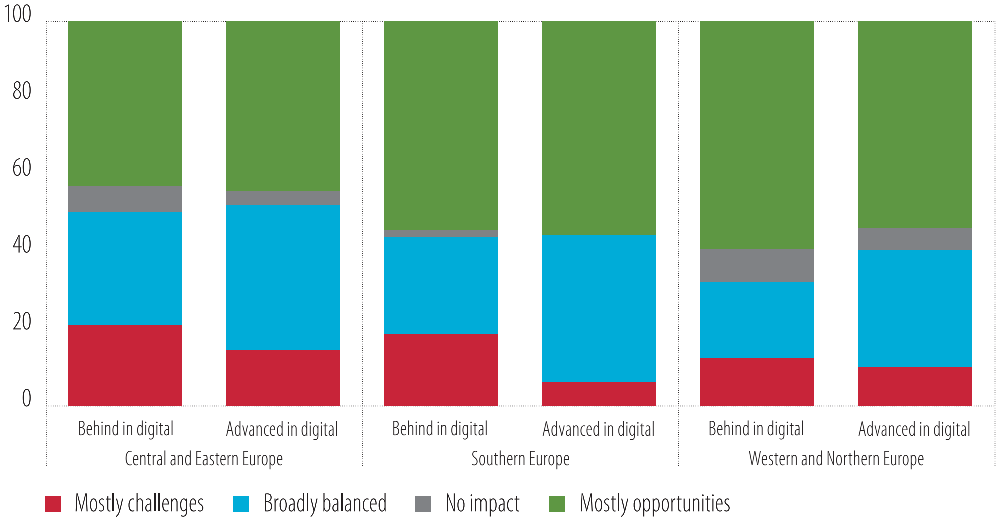


Source: *EIB Municipality Survey 2022.*
Note: *See note to Figure 15b for the definition of municipalities advanced in digital capability.*
Question: *For digital infrastructure, if you compare the average annual infrastructure investment you are planning for the 2022-2026 period vs. the average annual infrastructure investment recorded in 2019-2021, does your municipality expect to increase, decrease or have around the same level of spending on infrastructure investment?*

Municipalities with lower digital capabilities and sophistication tend to be less optimistic about the digital transition. In contrast, digitally advanced municipalities see more digitalisation-related opportunities than challenges (Figure 18). Overall, the evidence hints at a growing digital divide between municipalities.

Figure 18

Opportunities and challenges stemming from digitalisation (share of municipalities, in %), **by digital capability**

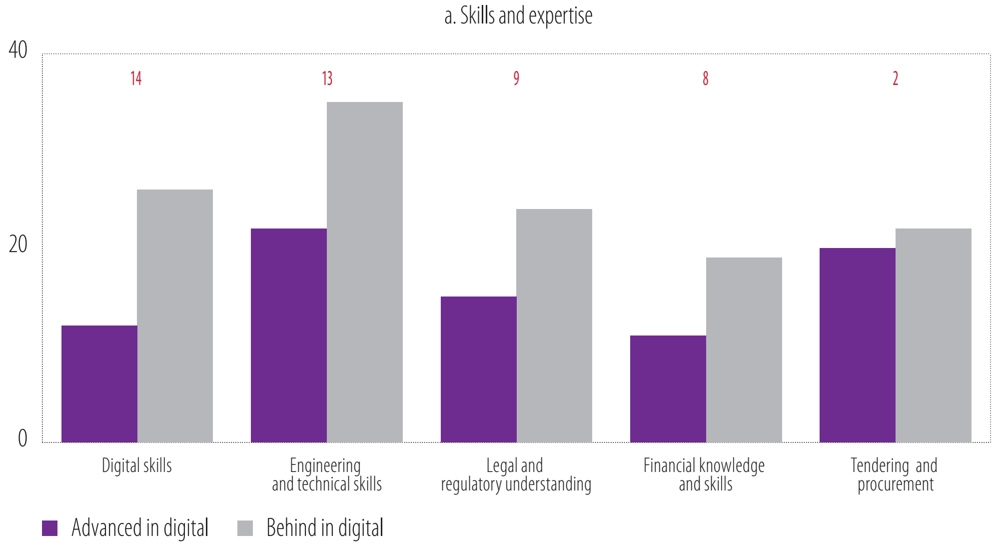


Source: *EIB Municipality Survey 2022.*
Note: *See note to Figure 15b for the definition of municipalities advanced in digital capability.*
Question: *Thinking about digitalisation, do you expect this global trend to present opportunities or challenges to your municipality?*

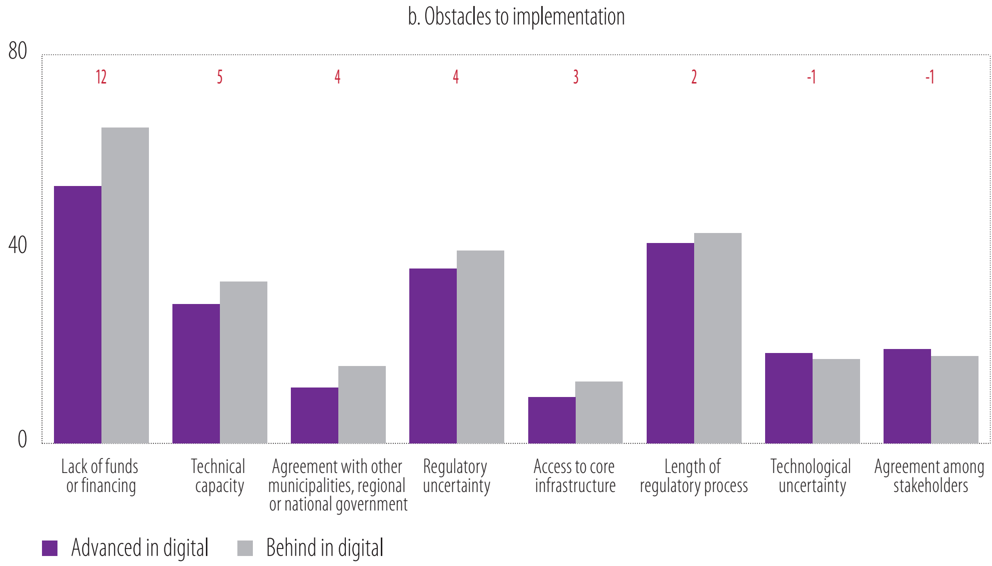
Access to digital and a lack of technical skills are major obstacles to EU municipalities' digital transformation. These obstacles are more prevalent among municipalities that are lagging digitally (Figure 19a). Other obstacles confronting laggard municipalities are a limited availability of funding and a lack of technical capability (Figure 19b). Improving digital capabilities and sophistication is not only about financing digital infrastructure but also about the skills that are required and regulatory uncertainty.

Figure 19

Major barriers to digitalisation (share of municipalities, in %)**, by digital capability**



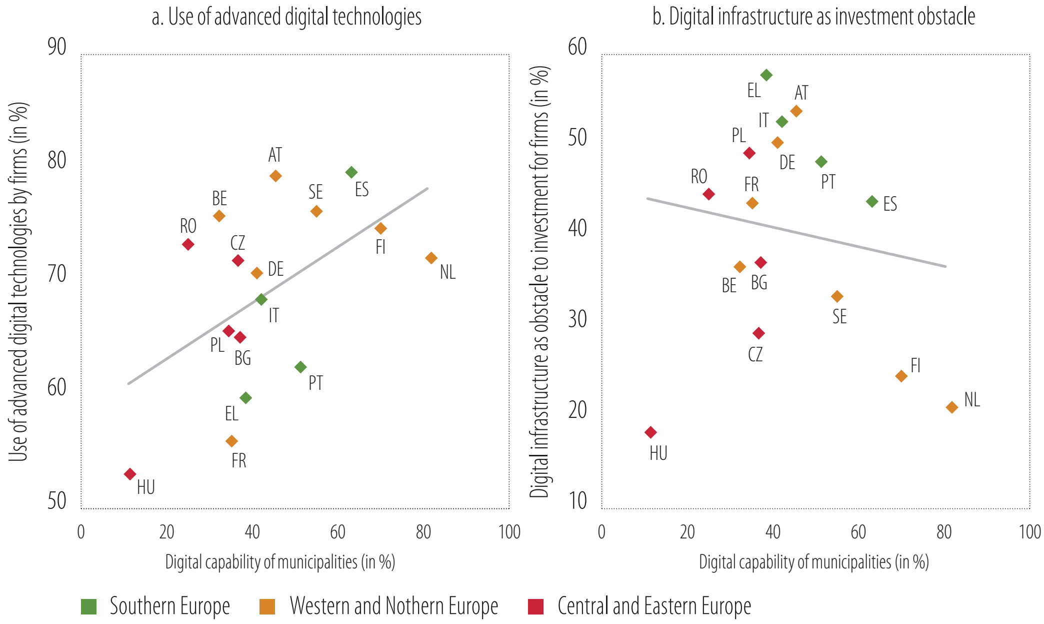
Source: *EIB Municipality Survey 2022.*
Note: *See note to Figure 15b for the definition of municipalities advanced in digital capability. The numbers over the bars indicate the percentage point difference in firms behind and advanced in digital technologies.*
Question: *For each of the following areas, to what extent is access to experts a major problem to the delivery of your municipality's investment programme?*



Source: *EIB Municipality Survey 2022.*
Note: *See note to Figure 15b for the definition of municipalities advanced in digital capability. The numbers over the bars indicate the percentage point difference in firms behind vs. advanced in digital technologies.*
Question: *To what extent is each of the following an obstacle to the implementation of your infrastructure investment activities? Is it a major obstacle, a minor obstacle or not an obstacle at all?*

The digital capabilities of municipalities are positively correlated with firm uptake of digital technologies. Firms have higher rates of digital adoption in countries where a high share of municipalities are digitally sophisticated (Figure 20a). In addition, there is a slight negative correlation between municipal adoption of digital technologies, and the share of firms reporting the lack of digital infrastructure as an investment obstacle (Figure 20b).

Figure 20
Digital activities of firms and digital capability of municipalities



Source: *EIB Municipality Survey 2022 and EIBIS 2022.*
Note: *See note to Figure 15b for the definition of municipalities' digital capability and Figure 2 for the definition of firms' use of advanced digital technologies. Only municipalities with at least 30 observations are considered.*

Source: *EIB Municipality Survey 2022 and EIBIS 2022.*
Note: *See note to Figure 15b for the definition of municipalities' digital capability.*
Question: *Thinking about your investment activities, to what extent is access to digital infrastructure an obstacle? Only municipalities with at least 30 observations are considered.*

Digital security concerns are a major barrier to the adoption of digital technologies. More digital operations, teleworking and virtual client interaction increase risks and the vulnerability of digital systems. Digital security threats have increased markedly since the coronavirus pandemic. To address the issue, digital security must move up from a mere technical issue to the top tier of business decision-making. This involves raising awareness and empowering all stakeholders to understand and manage digital security risks, and to continuously assess those risks.

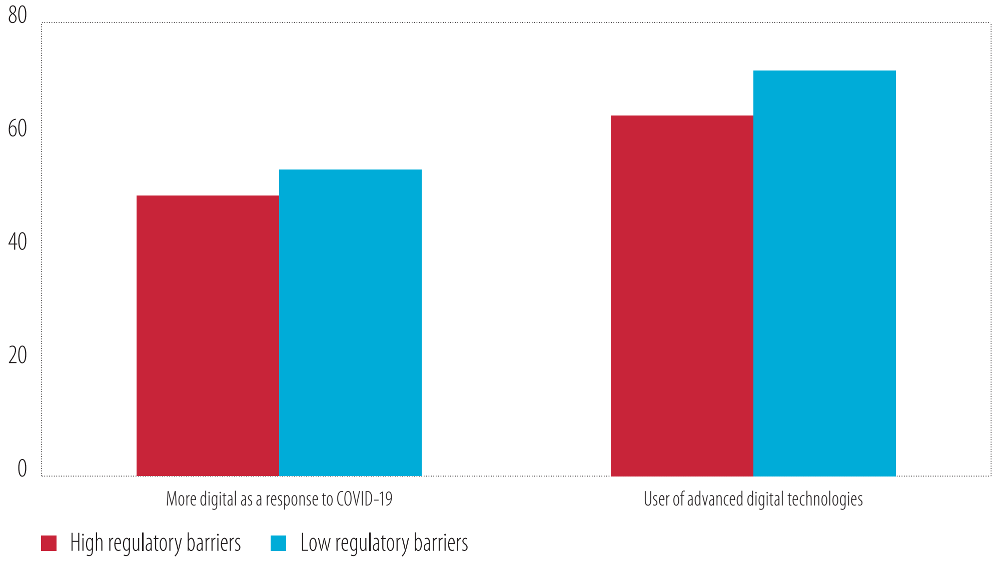
Product market regulation and market power

Regulation has a direct impact on competition and innovation. Policymakers are increasingly turning their attention to the effect competition regulation has on innovation and digital adoption. Several studies highlight the positive impact a regulatory environment that encourages competition has on innovation (Akcigit, Ates and Impullitti, 2018; Perla, Tonetti and Waugh, 2021). However, while competition may push firms to innovate more, it may also dissuade them from innovating because of decreasing innovation returns (Aghion et al., 2005; Griffith and van Reenen, 2021). In addition, trade regulation influences import competition and innovation, but the effects differ from country to country and from firm to firm (Shu and Steinwender, 2019). Policymakers are therefore presented with a trade-off between rewarding inventors with monopoly power and fostering competition to push technology forward.

Lower regulatory barriers for firms entering a market and increased competition tend to enhance digitalisation. Firms operating in an environment with lower regulatory barriers (using the OECD Product Market Regulation indicators at the country level as a proxy) tend to invest more in digitalisation (Figure 21). Firms using advanced digital technologies are also more prevalent in regions with low regulatory barriers. National regulatory frameworks can play an important role in the ability of firms to react to crises.

Figure 21

Digital adoption and regulatory environment (% of firms)



Source: *EIB staff calculations based on EIBIS 2022 and OECD Product Market Regulation indicators 2018.*
Note: *The data for the product market regulation indicators are at the country level and are not available for some countries.*
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 2 for the definition of the adoption of advanced digital technologies.*

Digitalisation is at the heart of policy discussions on rising market concentration and competition policies. Digital technologies often come with scale and synergies, giving an advantage to large firms. The high mark-ups and profits enjoyed by these firms often foster market concentration (Haskel and Westlake, 2017). These factors help create a few superstar firms that dominate a very large share of their market (Philippon, 2019; Autor et al., 2020). In the past two decades, the productivity gap between firms on the global cutting edge and laggards has risen (Andrews, Criscuolo and Gal, 2016). Cutting-edge firms are typically larger, are more innovative and have higher rates of digital technology adoption. Market concentration and mark-ups tend be more pronounced in sectors in which digital technologies, especially digital services, are developed or widely adopted (Calligaris, Criscuolo and Marcolin, 2018; Diez, Leigh and Tambunlertchai, 2018). The rapid increase in the adoption of digital technologies and the acceleration during the pandemic have added new layers to the debate on the polarisation created by technology and winner-takes-all dynamics in which a few firms dominate a market (Rückert et al., 2021).

Firms operating in more concentrated markets tend to be more digital. Competition (or the lack thereof) can be measured by the share of overall sales occupied by the top five or ten firms in a country and industry.[5] The estimates in Table 2 show that firms operating in markets in which the top five (or top ten) firms play a more dominant role are more likely to fall into the "both" category — firms that invested in becoming more digital as a response to COVID-19 and use advanced digital technologies. In other words, market concentration is strongly associated with digital adoption.

5 Using Orbis data, Bajgar et al. (2019) measure market concentration using the top four, top eight and top 20 firms in an industry.

Table 2

Market concentration and digital adoption

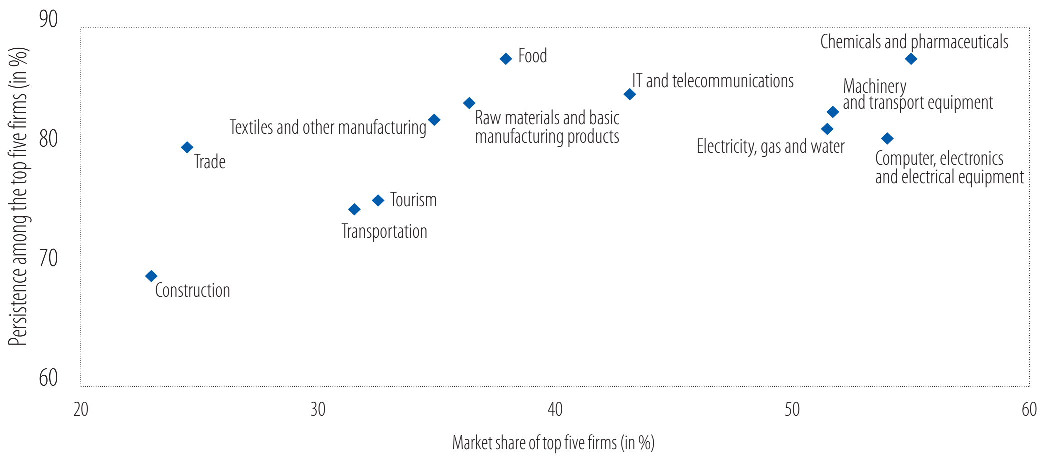
Dependent variable: "Both": more digital during COVID-19 and user of advanced digital technologies		
Market share of top five firms	0.0454** -0.0205	
Market share of top ten firms		0.0504** -0.0208
Sample size	11 566	11 566
R-squared	0.115	0.115

Source: Authors' calculations based on EIBIS 2022 and Orbis.
*Note: All regressions control for firm size, age, country and sector (27 EU countries and 12 sectors). Robust standard errors are in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

In more concentrated markets, firms are more likely to remain among the top market leaders. Sectors where the top five (or top ten) firms play a dominant role in terms of market share tend to see a lower turnover of these firms (Figure 22). This winner-takes-all market dynamic is particularly strong in the chemicals and pharmaceuticals sector and utilities (electricity, gas and water companies), but also in the digital sectors, such as computer and electronics, machinery and transport equipment, and IT and telecommunications. These sectors experience stronger digital adoption (Figure 8).

Figure 22

Market concentration and persistence of firms remaining in the top five, by sector



Source: EIB staff calculations based on Orbis.
Note: Persistence refers to the annual probability of remaining among the top five firms for market share.

Policymakers should focus on the conditions and incentives needed to help smaller firms transform digitally. The results linking the importance of market concentration to digital adoption do not indicate the direction of causality. However, the positive correlation between market concentration and digital adoption is in line with previous studies (for example, Acemoglu et al., 2022). The research also argues that the high costs of adopting advanced digital technologies can be a major issue for small firms, creating advantages for large firms in the adoption and use of these technologies. This dynamic, in turn, further drives rising market concentration. The findings suggest that policymakers should focus on the conditions and incentives needed for the digital transformation of smaller businesses. These companies might otherwise fall victim to bigger firms with excessive market power, and their disappearance might be associated with lower market contestability and openness to innovation. Such issues are particularly relevant for Europe's strategic autonomy in certain industries, keeping in mind that it needs to increase the resources available for research, innovation and critical technologies.

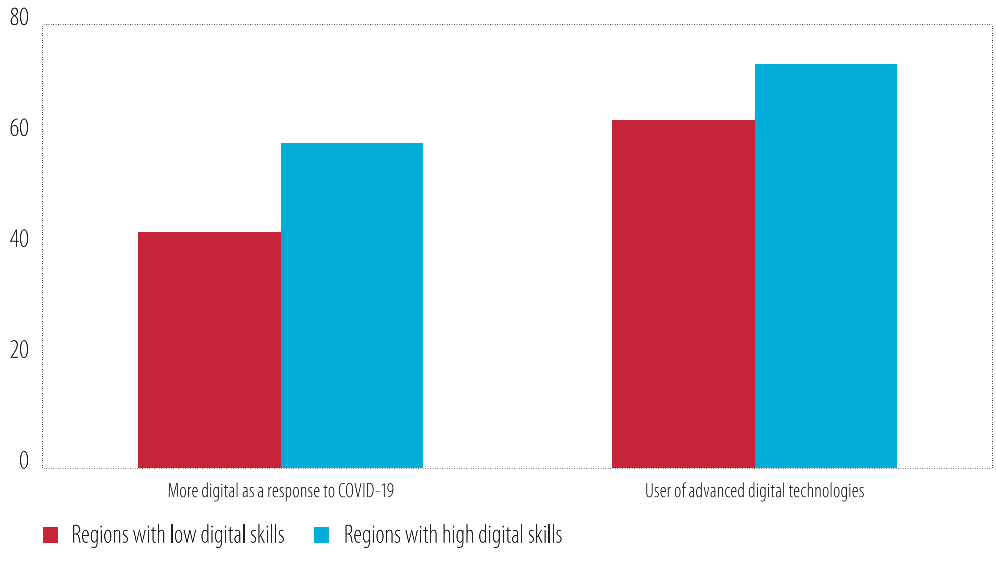
Internal factors enabling digitalisation: Skills, management decisions and the diffusion of digital innovation

This section focuses on internal factors and management decisions that help firms take advantage of the upside of digitalisation. These factors include investment in employee training to improve digital skills, modern management practices and trade with firms in innovative sectors, which enhances the diffusion of cutting-edge digital technologies.

Digital skills and worker exposure to digitalisation

The availability of workers with digital skills supports the digital transformation. Firms operating in regions where the population has above-average digital skills tend to have implemented advanced digital technologies more often (Figure 23). They are also more likely to have invested in becoming more digital as a response to COVID-19. This may be the result of firms' tendency to hire skilled labour already available on the market rather than bearing the costs of in-house training (Brunello et al., 2023). 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).

Figure 23
Digital adoption and digital skills (% of firms)

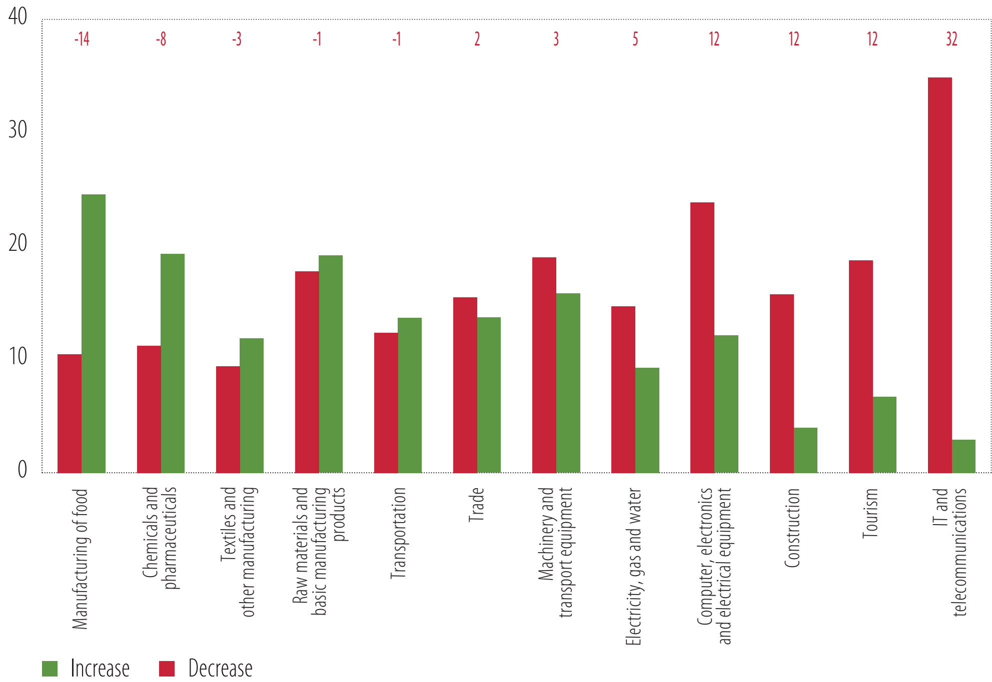


Source: *EIB staff calculations based on EIBIS 2022, Regional Innovation Scoreboard (RIS), 2021 and European Innovation Scoreboard (EIS), 2021.*
Note: *The level of digital skills in each NUTS region is based on the indicator "individuals who have above basic overall digital skills" in the Regional Innovation Scoreboard (RIS) and European Innovation Scoreboard (EIS). Regional data for digital skills from the RIS are available at the NUTS level 2 for most countries and at the NUTS level 1 for Austria, Belgium, Germany, Greece, Spain, Finland, France and Portugal. Data for Cyprus, Estonia, Malta, Lithuania and Luxembourg are only available at the country level and from the EIS.*
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 2 for the definition of the adoption of advanced digital technologies.*

The adoption of advanced digital technologies may facilitate the automation of tasks previously performed by employees. Advanced robots can be used in manufacturing to automate tasks such as welding and assembly. Artificial intelligence can also be used to create algorithms capable of achieving human-level proficiency at predictive tasks, such as driving autonomous vehicles. At the same time, firms using these technologies introduce new processes and create new tasks for workers (Goergieff and Hyee, 2021). Affected workers will need to learn new skills or improve their existing skills to adapt to the reorganisation of tasks and the emergence of new tasks following the introduction of advanced digital technologies, and to navigate transitions to new jobs (Brunello et al., 2023).

Workers' exposure to automation differs from sector to sector. To understand the importance of automation, the EIBIS asks firms using advanced digital technologies how they expect digital technologies to affect employment. Workers in the food manufacturing and chemicals and pharmaceuticals sectors are most exposed to automation (Figure 24). On balance, firms in these sectors expect a stronger decrease in employment than in the construction and tourism sectors. Employees in the IT and telecommunications sector appear the least affected, with 35% of firms reporting an expected increase in employment, compared with only 3% that expect a decrease.

Figure 24
Worker exposure to automation (% of firms)**, by sector**



Source: *EIBIS 2022.*
Note: *Weighted for employment. The numbers over the bars indicate the net balance (the share of firms that expect an increase in the number of employees minus the share of firms that expect a decrease) in percentage points.*
Question: *Over the next three years, what impact do you expect your business' use of this technology to have on the number of people your company employs? Increase employees, decrease employees, no change?*

Management decisions and investment in employee training play a crucial role in whether firms see advantages from adopting technologies. Well managed firms may be better able to identify their digital needs and to allocate digital resources more efficiently. Firms with advanced managerial practices are not only more likely to implement advanced digital technologies, but they also tend to have higher productivity (see Box B). Providing employees with training to improve their digital skills also influences whether firms benefit fully from advanced digital technologies (see Box C). This suggests that firms' digitalisation strategies should also look at the need for transforming managerial practices and skills.

Box B

Digital adoption, labour share and labour productivity

Following Acemoglu et al. (2022), this analysis uses firm-level data on digital adoption, the labour share of revenue (wage bill divided by revenue), the average wage per employee (wage bill per employee) and labour productivity (revenue per employee).[6] The estimates in Table B.1 show that the higher labour productivity of digital adopters is driven by the lower share of revenues taken by labour and by higher wages. Advanced digital technologies enable firms to produce in a more capital-intensive way by relying more on specialised equipment and software and less on labour. Furthermore, these technologies may reduce the employment of less-skilled workers and increase the hiring of skilled workers, and this focus on skilled workers can also increase labour productivity.

Table B.1

Labour productivity, labour share, average wage per employee and adoption of digital technologies

Dependent variable: Advanced digital technologies		
Labour productivity	0.165*** (0.012)	
Labour share		-0.319*** (0.052)
Average wage		0.192*** (0.016)
Use of KPIs	0.698*** (0.022)	0.693*** (0.023)
Sample size	46 796	44 100

Source: *EIB staff calculations based on EIBIS 2019-2022.*
Note: *Labour productivity, labour and average wage per employee are in natural logarithms. All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors). Logit regressions were used. Use of key performance indicators (KPIs): The firm uses a formal strategic business monitoring system that compares the firm's current performance against a series of strategic indicators. Robust standard errors are in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

Although the correlations in Table B.1 do not provide guidance on the direction of causality, digital adopters paying higher wages is in line with the theory that higher wages generate incentives for automation. Likewise, users of advanced technologies having lower labour shares and higher labour productivity is consistent with the evidence that these technologies can lead to automation. Across all technologies, larger firms tend to be more digital (see Figure 4). Looking at individual technologies, firms that use advanced robotics, the internet of things and big data analytics tend to pay higher wages and have lower labour shares (Table B.2). Furthermore, firms with advanced managerial practices are not only more likely to implement advanced digital technologies, but they also tend to have higher productivity.

Labour productivity is associated with the use of advanced digital technologies. Advanced robotics, big data, the internet of things, drones, online platforms and augmented reality are positively associated with labour productivity, whereas 3-D printing is negatively associated (Table B.3). In addition, labour productivity increases with firm size and age.

6 Labour productivity can also be defined as the average wage per employee divided by the labour share of revenue.

Table B.2

Labour share, average wage per employee and adoption of advanced digital technologies

Dependent variable	Internet of things	Artificial intelligence	3-D printing	Advanced robotics	Online platforms	Augmented reality
Labour share	-0.195*** (0.055)	-0.378*** (0.087)	0.205** (0.094)	-0.368*** (0.123)	-0.177** (0.074)	-0.176 (0.153)
Average wage	0.097*** (0.016)	0.264*** (0.028)	-0.026 (0.029)	0.146*** (0.034)	0.203*** (0.023)	0.210*** (0.045)
Use of KPIs	0.554*** (0.024)	0.866*** (0.036)	0.506*** (0.041)	0.508*** (0.044)	0.692*** (0.033)	0.784*** (0.060)
Sample size	43 282	34 162	32 625	13 201	20 971	20 172

Source: *EIB staff calculations based on EIBIS 2019-2022.*
Note: *Labour share and average wage per employee are in natural logarithms. All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors). Logit regressions are used. Use of key performance indicators (KPIs): The firm uses a formal strategic business monitoring system that compares the firm's current performance against a series of strategic indicators. Robust standard errors are in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

Table B.3

Adoption of advanced digital technologies and labour productivity

Dependent variable: Labour productivity Sector	All sectors	Manufacturing	Construction	Services	Infrastructure
Advanced digital technologies	0.150*** (0.010)				
3-D printing		-0.096*** (0.020)	-0.076** (0.037)		-0.086** (0.043)
Advanced robotics		0.080*** (0.017)			
Internet of things		0.032* (0.017)	0.000 (0.023)	0.065*** (0.023)	0.068*** (0.022)
Big data and artificial intelligence		0.134*** (0.022)		0.101*** (0.031)	0.177*** (0.028)
Drones			0.295*** (0.026)		
Augmented reality			0.139*** (0.037)	-0.046 (0.039)	
Online platforms				0.106*** (0.022)	0.117*** (0.022)
Sample size	44 983	13 194	9 373	10 891	10 085

Source: *EIB staff calculations based on EIBIS 2019-2022.*
Note: *All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors). OLS regressions. Standard errors are in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

Box C

Smart technologies, workforce training and investment strategy: Evidence from European firms[7]

EU countries have implemented various policies fostering the adoption of smart or digital technologies in recent years. However, official statistics and the relevant literature have struggled to gauge the causal impact of technology adoption on productivity, labelling it the productivity paradox. While it is becoming clearer that the adoption of smart technologies by firms should be accompanied by a parallel investment in workforce retraining to take full advantage of technology's potential, not enough evidence exists on this complementarity yet. Whether firms are currently on track to strike the right balance between machine input and human labour is therefore a salient policy question.

Novel ways of measuring smart technology adoption using EIBIS data and distinguishing between technology types shed light on this phenomenon. These methods analyse adoption patterns and performance when technology adoption comes with large-scale investment in workforce training. The analysis shows that productivity improves when firms adopt technologies and invest heavily in training. Conversely, firms that only partially adopt smart technologies and do not invest in workforce retraining do not seem to realise increases in productivity.

Smart technologies and adoption patterns

The economic literature considers different technologies and mainly identifies firms as technological adopters by counting the number of smart technologies adopted (McElheran et al., 2021). This analysis, however, created adoption indicators based on the type of technology used. The indicators make it possible to distinguish between big data[8] and hardware[9] technologies, considering the firm's sector of activity.

Figure C.1 reports adoption rates for the two types of technologies according to two different firm-level characteristics: firm size and innovation profiles, as defined by Veugelers et al. (2019). Overall, there is a strong positive correlation between hardware and big data technology adoption rates, suggesting that the two investments complement one another. When it comes to firm size, larger companies are more likely to adopt both types of technology. When considering firm-level innovation profiles, adoption rates are higher for more innovative firms, with leading innovators recording the highest shares.

7 This box was prepared by Giacomo Casali and Andrea Coali (Bocconi University).

8 The big data indicator considers the adoption of big data analytics and/or the internet of things. A firm is labelled as an adopter if it uses at least one of the two technologies. For firms in construction, which are only questioned about their use of the internet of things (but not big data analytics), a firm is labelled as an adopter if it uses the internet of things.

9 The hardware indicator depends on the firm sector. For firms in manufacturing, it is whether the firm has either 3-D printing capabilities and/or advanced robotics; in construction, whether it has drones and/or 3-D printing capabilities; and in infrastructure, whether it has 3-D printing capabilities. For firms in the service sector, this indicator is not used.

Figure C.1
Big data and hardware adoption rates (% of firms)

Source: Authors' calculations based on EIBIS 2019-2021.
Note: Statistics for hardware and software technologies have been weighted by value added on the EU sample of firms.

Smart adoption and training

To better explore the relationship between technology adoption, investment in workforce training and firm productivity, a workforce training index was created based on information about investment in employee training. A firm is deemed to have high investment in training if its per-employee investment levels are in the upper quartile of the distribution. Productivity is estimated using either a firm-specific Cobb-Douglas production function, where output is estimated using value added (revenues minus material costs), or by using labour productivity. The production function is estimated using the Wooldridge (2009) approach, while labour productivity divides value added by the number of employees. The analysis uses EIBIS data from 2019 to 2021.

Table C.1 considers both the direct relationship between technology adoption (hardware or big data) and investment in training, and the interaction between the two variables. There is a positive relationship between productivity outcomes and big data or technology adoption. Similarly, high investment in human capital (training) is associated with higher productivity. On the other hand, and quite counterintuitively, the coefficient on the interaction term shows there is no productivity premium for firms with both high investment levels and technology adoption when looking at hardware technologies. The literature highlights that these two aspects complement each other strongly. However, given the relatively recent introduction of such technologies, this analysis does not find a complementary relationship because training activities are not yet designed to take full advantage of the digital capabilities of the firm more broadly. Skilled labour can be directly hired when new technologies are implemented, but the positive productivity gained from combining digital investments with training may not yet have been fully realised (Brunello et al., 2023).

Table C.2 further explores these patterns, considering firms that have adopted big data and hardware technologies vs. those that have adopted only one technology. A triple interaction between the big data indicator, the hardware indicator and the training indicator is also considered. The results show a positive productivity premium when firms combine the technologies with high levels of human capital investment. Larger productivity gains from the adoption of smart technologies may only be seen in the few firms that invest heavily in smart technologies and workforce upskilling.

Table C.1

Digital technologies and productivity

Dependent variable: Total factor productivity				
Big data	0.058*** (0.011)	0.057*** (0.012)		
Training	0.207*** (0.016)	0.206*** (0.020)	0.183*** (0.017)	0.207*** (0.019)
Big data X High training		0.002 (0.023)		
Hardware			0.089*** (0.014)	0.112*** (0.016)
Hardware X High training				-0.082** (0.024)
Sample size	27 466	27 466	20 838	20 838
R-squared	0.509	0.509	0.554	0.554
Dependent variable: Labour productivity				
Big data	0.061*** (0.011)	0.061*** (0.012)		
Training	0.232*** (0.016)	0.232*** (0.021)	0.207*** (0.017)	0.225*** (0.019)
Big data X High training		0 (0.022)		
Hardware			0.090*** (0.015)	0.108*** (0.016)
Hardware X High training				-0.064* (0.025)
Sample size	28 428	28 428	21 534	21 534
R-squared	0.425	0.425	0.463	0.464

Source: *Authors' calculations based on EIBIS 2019-2021.*
Note: *Pooled-OLS regression, including controls for wave, sector and country, firm age and firm size (log of number of employees) and total investments per employee in intangibles. Standard errors clustered by country and sector are in parentheses. Includes the EU sample only. Statistical significance: *** p-value<0.001 ** p-value<0.01 *p-value<0.05, ^p-value<0.1.*

Overall, these results show that there is still a long way to go for European firms to take full advantage of the opportunities and benefits of smart technologies, with only a handful of firms currently achieving this. Policy interventions could target not only the adoption of smart technologies, but also the promotion of the accompanying training needed to unlock their full potential. Incentive schemes could be designed to increase firms' investment in workforce upskilling when they also invest in technological upscaling. This could be especially important when dealing with hardware technologies in sectors where these are often seen as substitutes for human labour, with the aim of fully applying the synergies between human and machine contributions.

Table C.2
Digital technologies and firm productivity — three-way interaction

	Total factor productivity	Labour productivity
Big data (one tech)	0.026 -0.023	0.045^ -0.023
Big data (two tech)	0.073** -0.024	0.085*** -0.024
Hardware	0.121*** -0.02	0.131*** -0.019
High training investment	0.189*** -0.023	0.210*** -0.022
Big data (one tech) X Hardware X High training	-0.005 -0.06	0.01 -0.057
Big data (two tech) X Hardware X High training	0.123* -0.063	0.121* -0.06
Sample size R-squared	20 640 0.556	21 329 0.466

Source: *Authors' calculations based on EIBIS 2019-2021.*
Note: *Pooled-OLS regression, including controls for wave, sector and country, firm age and firm size (log of number of employees) and total investments per employee in intangible assets. Standard errors clustered by country and sector are in parentheses. Includes the EU sample only. Statistical significance: *** p-value<0.001 ** p-value<0.01 *p-value<0.05, ^p-value<0.1.*

Innovative environments and the diffusion of digital innovation

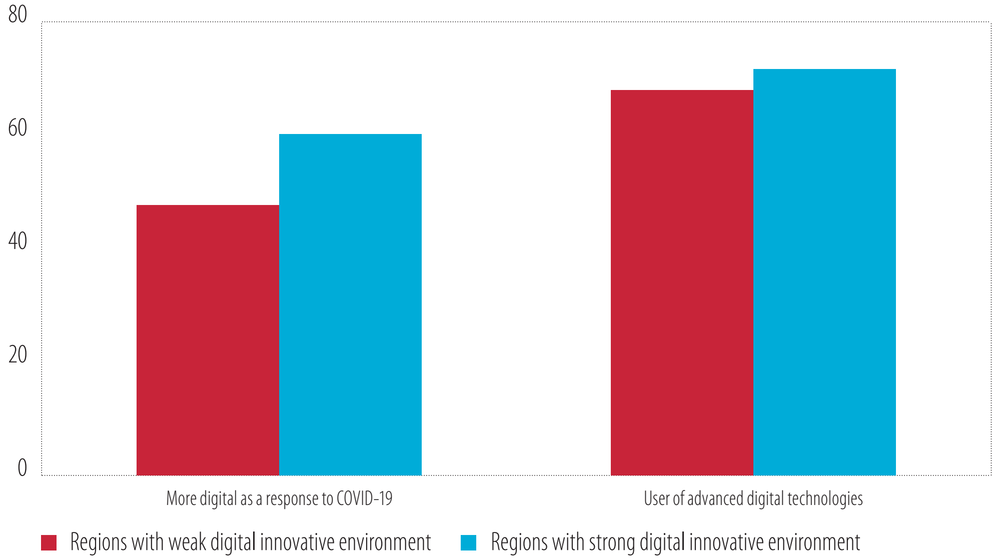
Operating in a more innovative environment helps firms to digitalise. Firms operating in highly digitally innovative environments were more likely to invest in digitalisation as a response to COVID-19 (Figure 25). This is in line with the evidence reported in the previous section, showing that digital responsiveness depends on multiple factors. At the same time, highly digitally innovative regions and weaker regions show no significant difference in the use of advanced technologies. This suggests that, while the innovative environment may have played a role in fostering transformative capabilities during the pandemic, the adoption of advanced digital technologies does not necessarily depend on geography, and other factors are at play.

EU firms operating in industries that are digitally innovative tend to adopt more digital technologies (Figure 26). The number of digital patents produced by an industrial sector and the digital patent intensity (the number of digital patents divided by all patents held in that sector) are strongly associated with digital adoption, even after controlling for firm characteristics such as firm size, age, country, sector and year (Table 3). In other words, firms operating in sectors where digital innovation is particularly active are more likely to use digital technologies.[10]

10 In this section, digital innovation in a sector is based on patenting activities in digital technologies by the top 2 000 global R&D investors. The digital innovators can be located outside the European Union, for example in the United States, China, Japan or South Korea. Digital adoption is based on EIBIS, see Figure 2.

Figure 25

Digital adoption and innovative environments (% of firms)



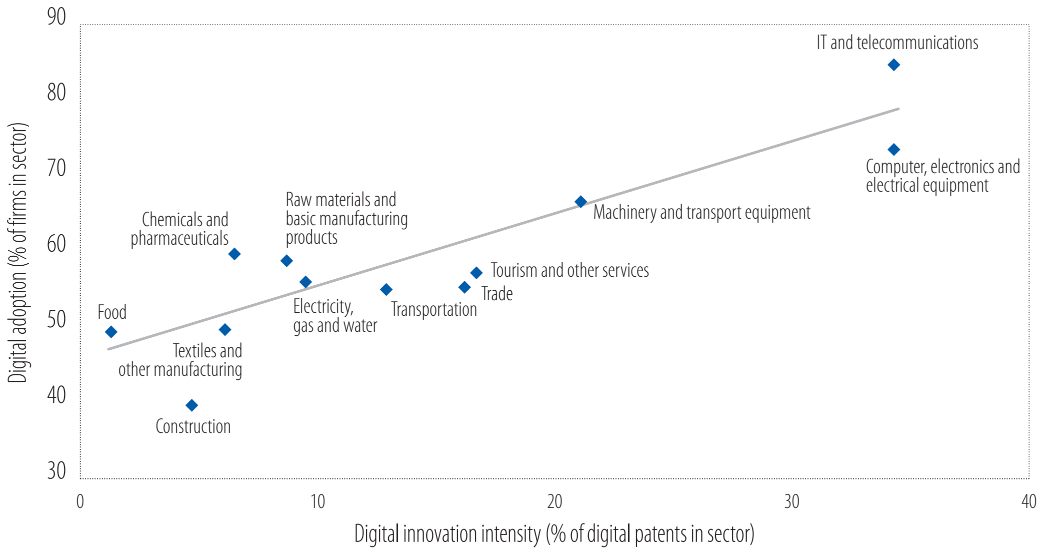
Source: *EIB staff calculations based on EIBIS 2022 and PATSTAT (PCT) data prepared in collaboration with the Centre for Research and Development Monitoring (ECOOM).*

Note: *The digital innovative environment in a region is considered strong if the digital patent intensity (the share of digital patents out of all patents held in the region) is above the 75th percentile of the distribution of digital patent intensity across NUTS 2 regions.*

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 2 for the definition of the adoption of advanced digital technologies.*

Figure 26

Adoption of advanced digital technologies and digital innovation intensity, by sector



Source: *EIB staff calculations based on EIBIS 2019-2021 for digital adoption and the JRC-OECD COR&DIP database v.3 for digital innovation.*

Note: *Digital innovation is measured by the share of digital patents of a sector (the number of digital patents divided by all patents held in that sector).*

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.*

Table 3

Digital innovation intensity and digital adoption

Dependent variable: Advanced digital technologies		
Digital patents (share)	0.343*** (0.030)	
Digital patents (sum)		0.013*** (0.001)
Sample size	36 312	36 312
R-squared	0.118	0.119

Source: EIB staff calculations based on EIBIS 2019-2021 for digital adoption and the JRC-OECD COR&DIP database v.3 for digital innovation.
*Note: All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors). OLS regressions. Digital innovation is measured with the share of digital patents of a sector (the number of digital patents divided by all patents held in that sector) or the number of digital patents held by firms operating in a sector. Robust standard errors are in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

However, the diffusion of digital innovation is also likely to be driven by the sectors with which firms trade. The analysis below uses input-output tables to look at the data from a more macroeconomic standpoint. These tables depict industrial relationships within an economy, showing how output from one industrial sector may become an input to another.[11] The tables illustrate how interdependent the sectors are, in the purchasing of outputs and supplying of inputs. Firms can also act as purchasers and suppliers within the same sector.

Digital innovation in upstream and downstream sectors (suppliers and clients of firms) drives digital adoption. Figure 27 shows that digital innovation in upstream and downstream sectors is strongly associated with digital adoption. The first bar illustrates the role of sectors outside the firm's industry, while the second bar shows the role of the firm's sector as a source of inputs (for upstream sectors) or as a provider of intermediate inputs (for downstream sectors).

The adoption of digital technologies is also strongly associated with firm performance. Companies have started to take advantage the positive effects of digitalisation. Businesses that adopt digital technologies tend to be more productive, grow faster (for employment), and are more likely to invest in employee training and to use strategic monitoring systems (with key performance indicators) (Table 4). These results are in line with previous evidence on the positive relationship between digital adoption and firm performance (European Investment Bank, 2022).

Table 4

Digital adoption and firm performance

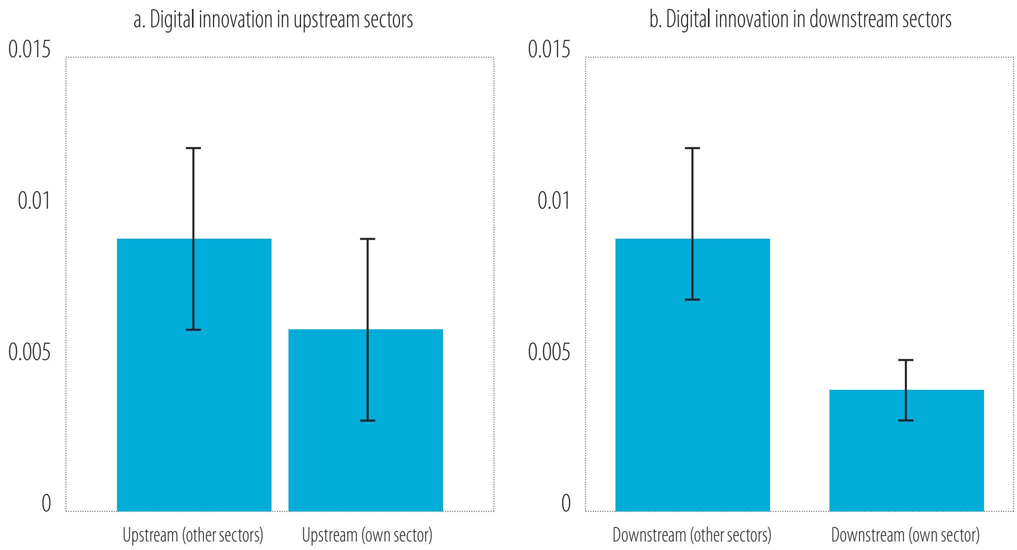
Dependent variable:	Labour productivity	Positive employment growth	Training	Management
Advanced digital technologies	0.158*** (0.012)	0.046*** (0.005)	0.113*** (0.005)	0.150*** (0.005)
Sample size	38 589	38 147	35 358	38 896
R-squared	0.274	0.096	0.126	0.198

Source: EIBIS 2019-2021.
*Note: Labour productivity is expressed in natural logarithm. Positive employment growth, investment in employee training and the use of advanced management practice (formal strategic business monitoring system with key performance indicators) are binary variables. All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors). OLS regressions. Robust standard errors are in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

11 The input-output framework centres on tables tracking supply and use, which shows how domestic production and imports of goods and services in an economy are used by industries for intermediate consumption and final use.

Figure 27

Firms' digital adoption as a response to digital innovation (regression estimates)



Source: *EIB staff calculations based on EIBIS 2019-2021 for digital adoption, JRC-OECD COR&DIP database v.3 for digital innovation, and Eurostat input-output tables (updated in March 2022) for upstream and downstream sectors.*
Note *Digital innovation is measured with the share of digital patents of a sector (the number of digital patents divided by all patents held in that sector) held by firms in upstream and downstream sectors. The lines represent the coefficients from OLS regressions with 95% confidence interval. All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors).*

Digital adoption has a causal effect on firm performance. To identify the causal relationship between the adoption of digital technologies and firm performance, digital innovation is used as an instrumental variable for digital adoption in a first stage regression. The estimates reported in Table 5 have the same implications, in terms of the sign, as those in Table 4, but the magnitude of the causal estimates reported in Table 5 is significantly higher. This underscores the positive benefits of firms adopting digital technologies if they trade with upstream sectors that are more active in digital innovation. These findings have implications for trade regulations and policy aiming to further strengthen and defend the European Union's ability to innovate and to develop and use strategic technologies.

Table 5

Digital adoption and firm performance, instrumental variable regressions

Dependent variable:	Labour productivity	Positive employment growth	Training	Management
Advanced digital technologies	0.793	0.352***	0.630***	0.463***
	(0.923)	(0.136)	(0.230)	(0.110)
Sample size	37 646	37 162	34 453	37 888
First stage F-test statistic	9.49	9.90	9.39	9.37

Source: *EIB staff calculations based on EIBIS 2019-2021 for digital adoption, JRC-OECD COR&DIP database v.3 for digital innovation, and Eurostat input-output tables (updated in March 2022) for upstream and downstream sectors.*
Note: *Labour productivity is expressed in natural logarithm. Positive employment growth, investment in employee training and the use of advanced management practice (formal strategic business monitoring system with key performance indicators) are binary variables. All regressions control for firm size, age, year, country and sector (27 EU countries and 12 sectors). Instrumental variable two-stage least squared regressions. Digital innovation in upstream sectors is used as the instrumental variable for digital adoption. Digital innovation in the first stage regression is measured with the share of digital patents (the number of digital patents divided by all patents of a sector) held by firms in upstream sectors. Standard errors are clustered by sector in parentheses. Statistical significance: *** p-value<0.01, ** p-value<0.05, * p-value<0.1.*

How digitalisation drives firms' resilience to trade disruptions and climate change

Digitalisation can be a driver of firm resilience and is critical to adapting quickly to changing environments. This section highlights the importance of digitalisation in managing trade disruptions and the economic transformation required by climate change.

International trade, digitalisation and firms' ability to react to shocks

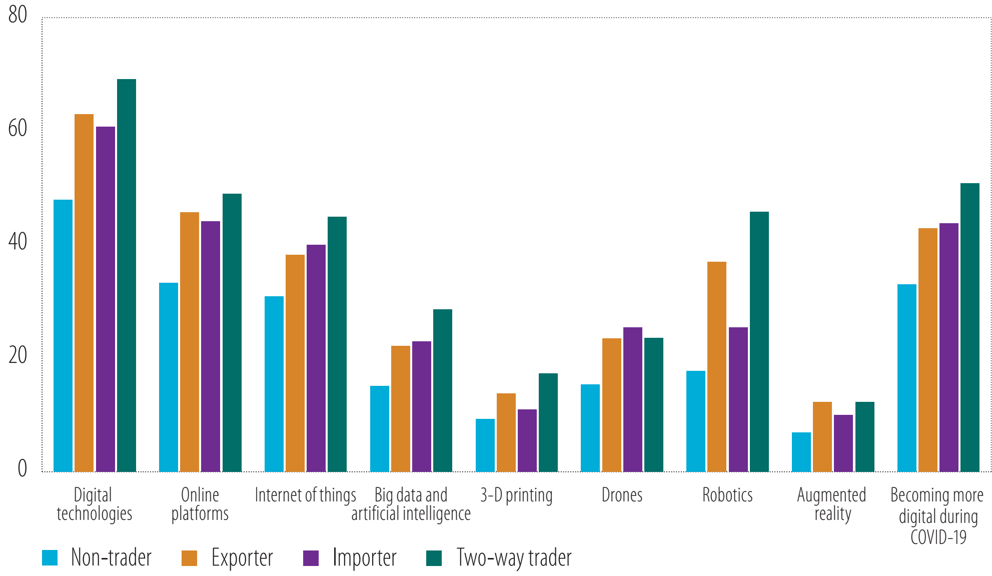
The rise of internet and digital technologies have improved trade-related information flows and reduced communication costs. They have made it easier for firms to find foreign buyers and integrate foreign customers and suppliers into their production processes, enhancing participation in global value chains and reaping the benefits of economies of scale (Abel-Koch, 2013; World Trade Organization (WTO), 2019). Trade in digital services from the European Union has also been growing rapidly over the past decade.

Firms that engage in international trade are more likely to use advanced digital technologies or build their business around such technologies. Exporters and importers are more than 10 percentage points more likely to adopt advanced digital technologies than non-trading firms (Figure 28). The difference for firms that export and import (two-way traders) is even higher — more than 20 percentage points. This is in line with evidence showing that exporters and importers are more likely to invest in the development of new products and modern technologies to maintain their market share (Melitz and Redding, 2021).

Firms that traded internally were more likely to respond to the COVID-19 crisis by increasing their digitalisation efforts. One-third of non-trading firms invested in increasing digitalisation during the pandemic, compared with 40% of exporters and importers and more than half of two-way traders.

Figure 28

Probability of digitalisation (in %), **by trade profile**

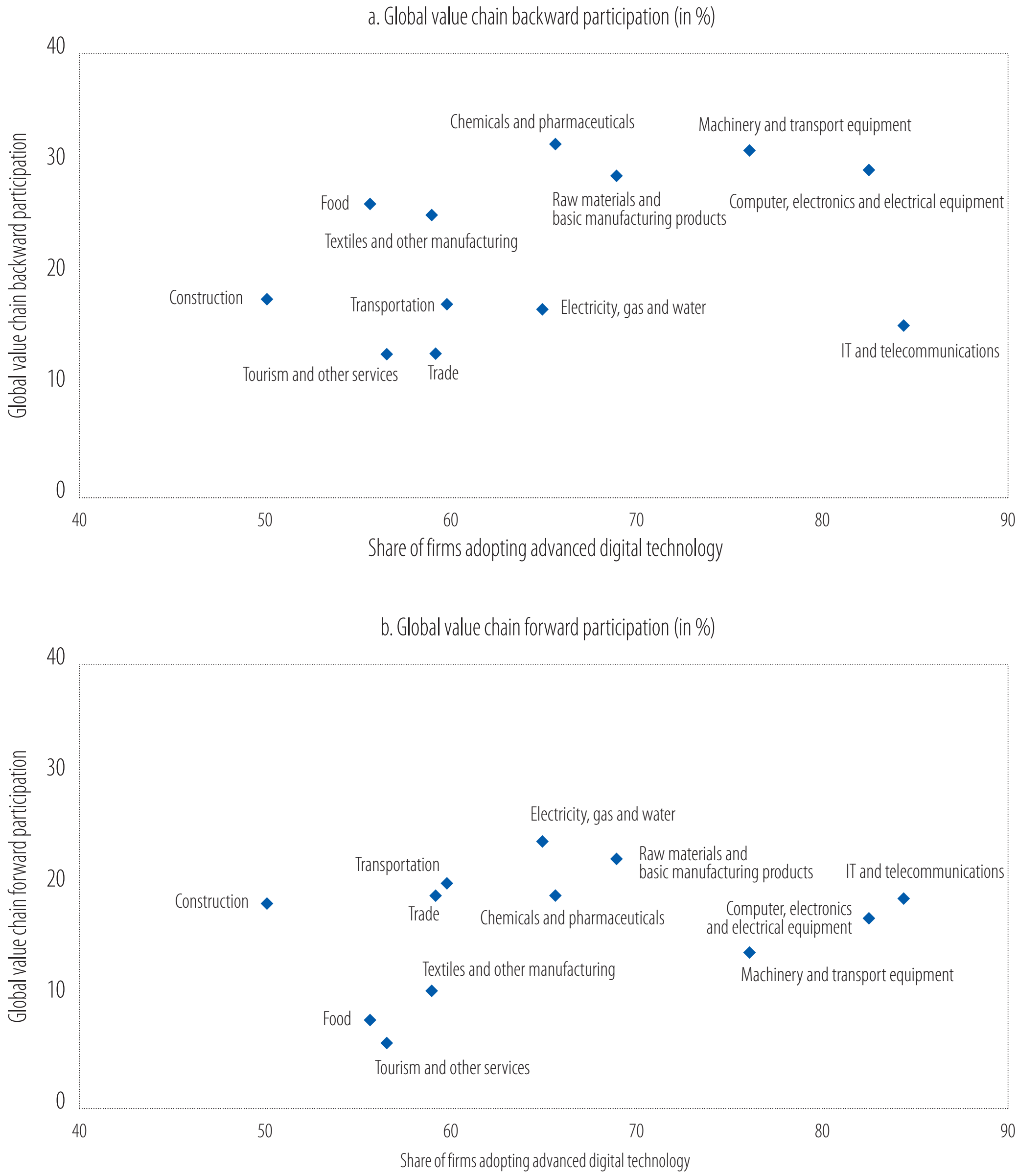


Source: *EIBIS 2022.*
Note: *The bars represent the probability of digitalisation by trade profiles, estimated from logistic regressions. The regressions control for country and sector (27 EU countries and the United States, and 12 sectors).*
Question: *In 2021, did your company export or import goods and/or services? To what extent, if at all, are each of the following digital technologies used within your business? Please, say if you do not use the technology within your business? And as a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital?*

Firms in sectors with more globally integrated value chains tend to be more digital. The most digitalised manufacturing sectors — such as machinery and transport equipment and electronics (Figure 8) — are more likely to rely on inputs produced abroad (backward participation) than less digitalised sectors (Figure 29). In addition, these sectors are more likely to provide inputs to companies in other countries (forward participation).

Figure 29

Digitalisation and global value chain participation



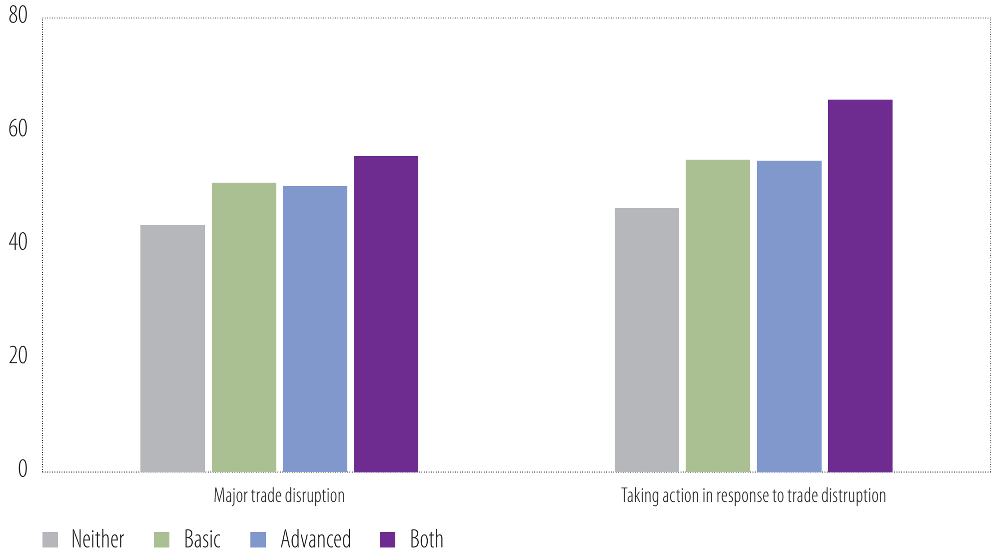
Source: EIB staff calculations based on EIBIS 2022 and OECD TIVA database 2021 edition.

Note: The top panel shows the average backward participation, while the bottom panel shows the average forward participation of a sector against the average share of digitalised companies in the same sector. The backward participation expresses the degree to which a sector's exports relied on imported value added. The forward participation means the degree to which the export value of a sector is used in other countries' production. See note to Figure 2 for the definition of the adoption of advanced digital technologies.

Digital firms are more likely to have reported major trade disruptions since the start of the pandemic. This is not surprising, as firms engaged in international trade are more likely to be affected by disruptions to global value chains, logistics, access to materials or new trade regulations. However, this finding holds even when considering firms' trade engagements. About two in five firms that did not adopt digital technologies or invest in digitalisation (the "neither" category) as a response to the pandemic report experiencing major disruptions in trade, compared with 56% of the companies that can be classified as "both" (the most advanced digital firms that invested to become even more digital during the pandemic) (Figure 30).

Digital firms are more likely to act to mitigate the adverse effects of trade disruptions. The chart on the right-hand side of Figure 30 reveals two patterns related to firms' response to trade disruptions. On the one hand, firms that use advanced digital technologies are more likely to take action to mitigate adverse effects by either diversifying their trade partners or by looking for domestic suppliers and buyers. On the other hand, regardless of whether they are already digital, firms that have responded to the pandemic by investing in digitalisation are more likely to respond to trade shocks. These findings suggest that digitalisation increases the economy's resilience and ability to adapt to large, unexpected economic shocks.

Figure 30
Probability of trade disruption and taking action in response (in %)**, by digital profile**



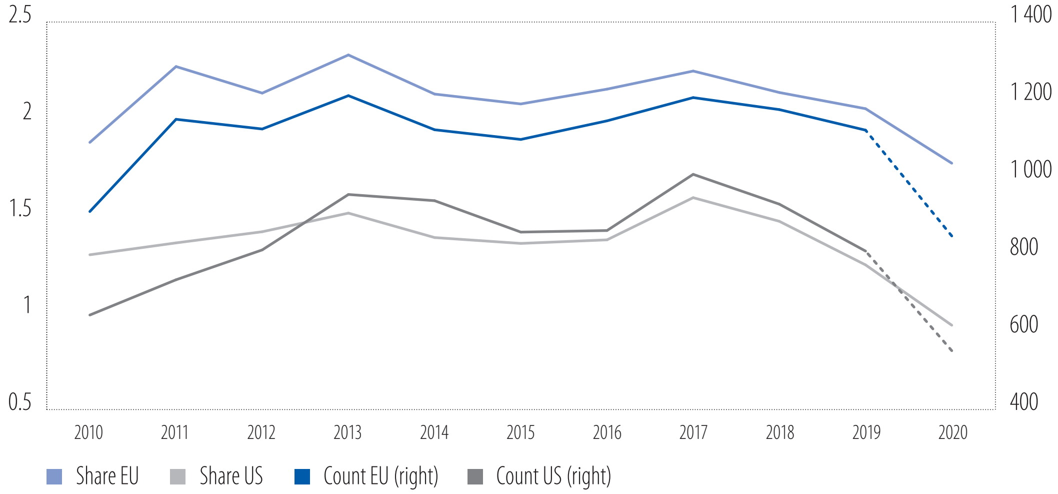
Source: *EIBIS 2022.*
Note: *See Figure 9 for the definition of the digital profiles. The bars represent the probability of a trade disruption (left) and the probability of taking action in response to a trade disruption (right), estimated from logistic regressions. The regressions control for country and sector (27 EU countries and the United States, and 12 sectors). The regressions in the left panel also control for trade status, and the regressions in the right panel for trade status and major disruption reported.*
Question: *In 2021, did your company export or import goods and/or services? To what extent, if at all, are each of the following digital technologies used within your business? Please, say if you do not use the technology within your business? And as a response to the COVID-19 pandemic, have you taken any actions or made investments to become more digital? Since 2021, did any of the following present an obstacle to your business's activities? Is your company taking any actions to mitigate the impact of these disruption?*

Digitalisation and investments in green innovation and climate change

The European Union is a global leader in the development of new technologies that combine digital and green innovations. While Europe lags behind the United States for digital innovation and patenting (see Chapter 2), it is strong in the development of new green technologies. A substantial share of EU patenting activities is concentrated in climate change technology, and it leads on green innovation that incorporates digital technologies (Figure 31).

Figure 31

Green and digital patents in 2010-2020 (left axis: patent share in %; right axis: patent count), **by region**



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

The development of new green and digital technologies is stagnating, however, and policymakers should take notice. If emerging digital technologies are properly employed, they could play a key role in tackling environmental challenges. Examples of such technologies include smart urban mobility, precision agriculture, sustainable supply chains, environmental monitoring and disaster prediction. In addition, digital technologies can be instrumental in monitoring climate change and facilitating the much-needed shift to a circular economy. Data analytics enables companies to better manage resources by matching supply and demand for underused assets and products. Cloud computing, in combination with mobile and social media, can take products or even entire industries fully online. 3-D printing also creates opportunities for manufacturing biodegradable inputs that can be used in production (Lacy and Rutqvist, 2015; Intergovernmental Panel on Climate Change (IPCC), 2022).

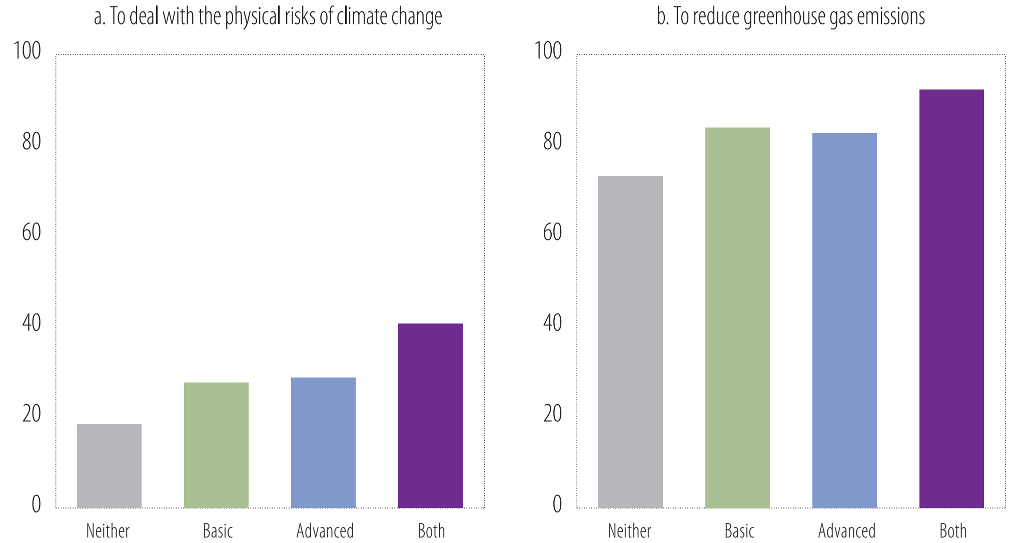
Digital technologies are key enablers of the green transition and can help meet the goals of the European Green Deal. If it is to maintain its long-term competitiveness, the European Union must play a role in combining digital technologies with innovations to address the climate change challenges. Digital technologies are also important to innovations in transport, one of the biggest emitters of greenhouse gas (European Investment Bank, 2022). Europe will need to invest heavily in digital innovation to live up to its green ambitions, especially given the United States' strong head start.

Digitally advanced firms have invested more in building resilience to the physical risks of climate change. 42% of EU firms that fall into the "both" category have invested in adaptation strategies (strategies that involve changing procedures and/or operations to increase the resilience of the organisation), compared with only 20% of firms in the "neither" category (Figure 32a). The association of the companies' digital profiles with investments intended to avoid or reduce exposure to climate risks is more pronounced in the European Union than in the United States.

Digitally advanced firms invest more in measures to reduce greenhouse gas emissions (Figure 32b). 71% of companies in the "both" category have invested in waste minimisation and recycling, compared with 48% of firms in the "neither" category. The gap between digital profiles is most pronounced in energy efficiency investments, where 69% of firms in the "both" category invested, compared with 38% in the "neither" group, as well as for less polluting technologies, where the gap is 28 percentage points.

Figure 32

Climate investment (% of firms investing in at least one measure), **by digital profile**

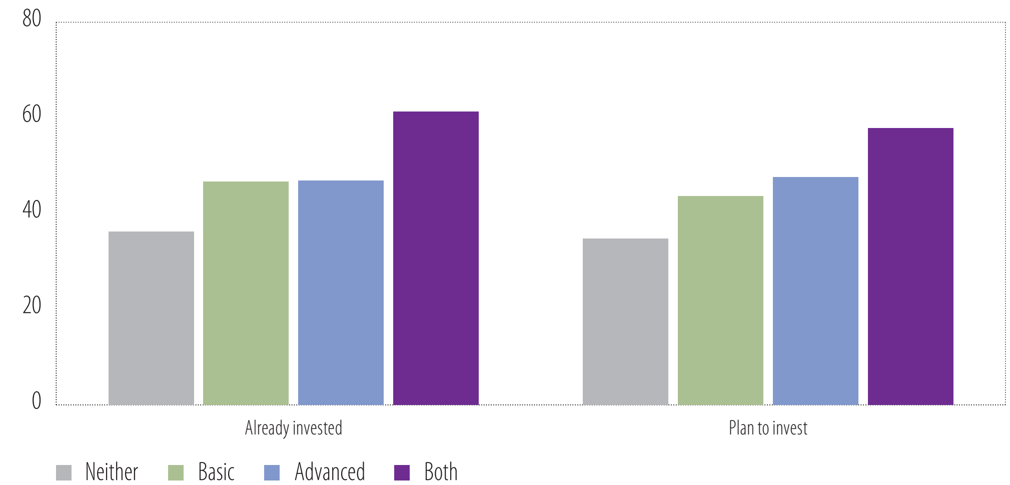


Source: *EIBIS 2022.*
Note: *See Figure 9 for the definition of digital profiles.*
Question: *Has your company developed or invested in any of the following measures to build resilience to the physical risks to your company caused by climate change? Is your company investing or implementing any of the following to reduce greenhouse gas emissions? Less polluting technologies, energy efficiency, renewable energy, waste minimisation, recycling, sustainable transport options.*

More digitally advanced firms tend to invest more frequently in tackling climate change. These firms are more likely to report that they have invested or have plans to invest more in climate adaptation in the next three years than their less digitally advanced counterparts (Figure 33).

Figure 33

Investments to tackle climate change (% of firms)**, by digital profile**



Source: *EIBIS 2022.*
Note: *See Figure 9 for the definition of the digital profiles.*
Question: *Which of the following applies to your company regarding investments to tackle the impacts of weather events and to help reduce carbon emissions? Company has already invested, company invested this year, company intends to invest over the next three years.*

Conclusion and policy recommendations

Digitalisation drives firms' resilience to economic disruption and climate change, and it has helped European businesses adjust at a time of repeated shocks. Digital companies displayed more resilience to the economic and trade disruptions unleashed by the COVID-19 crisis and the war in Ukraine, suggesting that the crisis forced them to find more efficient ways of working. Digital firms generally perform better overall than non-digital firms, tending to be more innovative and productive. They are also more likely to engage in international trade and invest in addressing the physical and transition risks of climate change. Digital technologies will be key to meeting the ambitious goals of the European Green Deal.

Successfully managing the digital transition and taking advantage of its long-term benefits goes beyond technology. The digital transformation is a societal change. Striking the right technological balance is a complex process for the European Union. It is caught between global players that are defining the cutting edge of digital innovation, national preferences and societal and regulatory patterns that set boundaries on the use of digital technologies. To make the most of the digital transformation, the European Union will need to position itself well in the global environment, creating better internal conditions for innovation in technologies that are crucial to European interests and taking full advantage of the benefits of digitalisation, while staying within the boundaries of the European economic model.

Policymakers need to pay equal attention to measures aimed at facilitating the use of digital technologies and to those addressing potential problems, such as the automation of tasks. While potential productivity gains from digital technologies are large and the risk of not keeping up with digital developments high, digitalisation does present potential problems for industries and societies. New technologies tend to reinforce the need for skilled labour and can replace low-skilled workers who perform routine tasks. European policymakers need to foster innovation while also reinforcing a system of lifelong learning for employees. Policy measures also need to address the lack of digital skills in small businesses. More than ever, accomplishing those diverse aims will require finding synergies between private and public investment.

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