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Digitalisation: channels, impacts and implications for monetary policy in the euro area

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No 279, "The need for an inflation buffer in the ECB's price stability objective – the role of nominal rigidities and inflation differentials".
No 280, "Understanding low inflation in the euro area from 2013 to 2019: cyclical and structural drivers".

Contents

Abstract

The digitalisation workstream report analyses the degree of digital adoption across the euro area and EU countries and the implications of digitalisation for measurement, productivity, labour markets and inflation, as well as more recent developments during the coronavirus (COVID-19) pandemic and their implications. Analysis of these key issues and variables is aimed at improving our understanding of the implications of digitalisation for monetary policy and its transmission. The degree of digital adoption differs across the euro area/EU, implying heterogeneous impacts, with most EU economies currently lagging behind the United States and Japan. Rising digitalisation has rendered price measurement more challenging, owing to, among other things, faster changes in products and product quality, but also new ways of price setting, e.g. dynamic or customised pricing, and services that were previously payable but are now “free”. Despite the spread of digital technologies, aggregate productivity growth has decreased in most advanced economies since the 1970s. However, it is likely that without the spread of digital technologies the productivity slowdown would have been even more pronounced, and the recent acceleration in digitalisation is likely to boost future productivity gains from digitalisation. Digitalisation has spurred greater automation, with temporary labour market disruptions, albeit unevenly across sectors. The long-run employment effects of digitalisation can be benign, but its effects on wages and labour share depend on the structure of the economy and its labour market institutions. The pandemic has accelerated the use of teleworking: roughly every third job in the euro area/EU is teleworkable, although there are differences across countries. Over the past two decades, the mechanical contribution of the decline in the prices of information and communication technology (ICT) products to euro area inflation amounted to around minus 0.15 percentage points per year (while annual HICP inflation averaged 1.7% over this period). The effects via indirect channels, such as firms’ pricing behaviour, market power and concentration, as well as firms’ productivity and marginal costs, are ambiguous, but empirical evidence suggests that increased e-commerce may have a small downward effect. Digitalisation affects the environment in which monetary policy operates, so, going forward, digitalisation and its impacts should be regularly reviewed in depth by central banks. Digitalisation may significantly affect the incidence of shocks and their transmission, with heterogeneity across euro area/EU countries, via its impact on key variables – such as productivity, potential output and inflation – and their measurement, and adds to the uncertainty and complexity faced by policymakers. The way digitalisation affects the labour market and firms’ price-setting behaviour may also change the slope of the Phillips curve, with major implications for the conduct and transmission of monetary policy. In a technologically optimistic scenario, productivity growth will rise with increasing digitalisation, raising the natural rate of interest and giving monetary policy more room for manoeuvre.

JEL Codes: E24, E31, E32, O33, O57.

Keywords: measurement, productivity, labour markets, inflation, COVID-19.

Executive summary

Digitalisation is one of the major structural changes transforming the functioning of the euro area and the global economy, together with globalisation and demographic trends. Digitalisation is a long-duration technology shock which has accelerated since the strategy review in 2003, not least in connection with the coronavirus (COVID-19) pandemic.[1] Its overall effects on measurement, productivity, labour market outcomes and inflation need to be closely monitored, combined with further conceptual and empirical work regarding the mechanisms and impact of digitalisation.

Digital adoption and measurement issues

Digital adoption differs across EU countries, implying heterogeneous impacts, with most countries lagging behind the United States and Japan. The heterogeneity across euro area countries can create more divergent economic and monetary conditions and possibly impede the efficient transmission of monetary policy, while the lag in digital adoption compared with the United States and Japan can have an impact on the external position of the euro area, with implications for incomes, exchange rates and inflation.

Digitalisation has exacerbated traditional price index measurement issues, such as dealing with frequent product replacements and adjusting for product quality. Digitalisation also brings new measurement issues such as complex pricing strategies (dynamic pricing, customised pricing, etc.) and “free” services which previously required payment.

Measurement challenges relating to digitalisation have implications for welfare as well as for nominal and real variables. The measurement challenges apply unevenly across different price deflators, with estimates from the literature suggesting upward measurement biases (overestimation of inflation) owing to changes in product quality, depending on the deflator, ranging from 0.2 to 0.5 percentage points (pp) per year in EU countries and in the United States. However, as these methodologies are not undisputed, the magnitude of the bias remains uncertain. The implied underestimation of GDP growth may have contributed to, but cannot explain, the observed productivity slowdown in recent decades, while welfare improvements arising from new product varieties and online services may be significant.

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[1] This report uses a very broad definition of digitalisation, including, inter alia, a wide range of information and communication technologies (ICT), technologies enabling automation and robotisation, and technologies related to the processing and analysis of digital data, including big data, such as artificial intelligence and machine learning, and edge and quantum computing.

Digitalisation and productivity

Digital technologies are pervasive across all sectors of the economy, promising large productivity gains through improved production process efficiency and higher rates of automation and robotisation. Despite the rapid growth in digital technologies, aggregate productivity growth has decreased in most advanced economies since the 1970s, with the notable exception of a productivity revival in the United States between 1995 and 2005. At the global level, the productivity gains induced by digitalisation are still low, but it is likely that without the observed growth in digital innovation, the productivity slowdown would have been even more pronounced. Growth accounting decompositions suggest that it is the declining total factor productivity (TFP) contribution, rather than the ICT capital or robot contributions, that is the main factor behind the productivity slowdown. As TFP is a residual, growth accounting decompositions do not yet really explain the productivity slowdown.

One explanation for the low productivity gains from digitalisation at the aggregate level is that the adoption, diffusion and full operationalisation of digital technologies is too slow, thereby delaying a new wave of potential productivity growth. This slow diffusion results from factors such as resource misallocation, inadequate economic institutions, skills shortages and insufficient infrastructure. Firms' organisational capital and management practices are also important factors in reorganising production and fully reaping the benefits of new digital technologies, which partly explains cross-country productivity divergences across the euro area.

Digitalisation and the labour market

The effects of digitalisation on aggregate employment over the long run appear benign, while evidence remains mixed on the effects on wages and the labour share which depend on the structure of the economy and its labour market institutions.

The ageing of the population may accelerate the adoption of new digital and automation technologies, but long-term productivity growth ultimately rests on the innovation process.

The digitalisation-related reallocation process depends on the balance between the supply of and demand for skills across firms and industries as well as on job-matching efficiency. Education and retraining are crucial to enable the adoption and effective use of digital technologies and mitigate their possible impact on inequality.

Teleworkable jobs account for about one-third of employees in the euro area and are more prevalent among higher-skilled jobs. Digital equipment and skills partly explain the heterogeneity in teleworking across euro area countries, while the pandemic has accelerated the adoption of teleworking.

Digitalisation and inflation

Digitalisation has a direct effect on inflation through the share and prices of ICT products in the household consumption basket and via relative price movements of items purchased online and offline. Over the last two decades, despite the likely upward measurement bias mentioned above, the mechanical contribution of measured ICT product inflation to euro area Harmonised Index of Consumer Prices (HICP) inflation has been negative, amounting to minus 0.15 pp per year, compared with an average inflation rate of 1.7% over the same period.[2]

Digitalisation can change the structure of the economy and influence inflation via indirect channels, such as firms' pricing behaviour, market power and concentration, as well as firms' productivity and marginal costs. Skill heterogeneity and the degree of complementarity among workers, robots and digital technologies may lead to a higher elasticity of output to marginal costs, flattening the Phillips curve.

Conceptually, the indirect effect of digitalisation on inflation is ambiguous: it can reduce search costs and increase price transparency, thereby reducing mark-ups, but it can also increase entry costs for competitors, thereby strengthening the market power of "superstar" firms and increasing mark-ups. Evidence shows that online prices are adjusted more frequently than offline prices, but the extent to which increased flexibility in pricing translates into a steeper Phillips curve is unclear.

Empirical evidence on some of the indirect effects of digitalisation on inflation, such as via e-commerce, points to a small negative effect. However, these estimates are associated with a high degree of uncertainty and many of the possible impacts of the indirect channels have not been empirically assessed. This calls for further empirical investigation, which also requires improved proxy variables for digitalisation in empirical analyses such as Phillips curve estimation, as well as the use of more granular (micro) data on firms and prices.

COVID-19, digitalisation and impacts

Since the onset of the COVID-19 pandemic, there has been an increase in the take-up and use of digital technologies. There are early signs that the more digitalised EU economies (and those with higher teleworking potential) weathered the COVID-19 shock better than the less digitalised economies.

The COVID-19 pandemic and the associated acceleration of digitalisation implies potentially far-reaching structural change which can boost the productivity gains from digitalisation, but there may also be possible temporary labour market disruptions. Product, labour and financial market regulations may

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[2] In other words, all other things being equal, HICP inflation would have averaged 1.85% over this period without the direct downward impact of digitalisation (in principle, any disinflationary impact from digitalisation would be zero if monetary policy were sufficiently responsive to neutralise this effect).

have to be adapted in order to fully reap the potential gains from digital technologies while maintaining inclusiveness.

Job retention schemes and loan guarantees to firms, which are essential in the current circumstances, may eventually impede necessary reallocation. The Next Generation EU package, the Single Market and the public sector can help facilitate the digital transition.

Implications of digitalisation for monetary policy

Digitalisation is affecting the environment in which monetary policy operates via its impact on key variables – such as productivity and inflation – and their measurement. It may also have an impact on monetary policy transmission and contribute to uncertainty and complexity, some aspects of which are beyond the scope of this report. Digitalisation may weaken the credit channel of monetary policy transmission, given that intangible investment is more suited to equity financing than bank lending, but the effects of monetary policy on household consumption and house prices may be strengthened if bank lending is redirected towards property financing.

In a technologically optimistic scenario, productivity growth will increase if digitalisation accelerates, raising the natural rate of interest and giving monetary policy more room for manoeuvre. On the other hand, if the expected productivity gains from digitalisation do not materialise at the aggregate level, and digitalisation and higher savings are associated with rising inequality, then the natural rate of interest may remain subdued.

Deflationary pressure from decreasing prices for technological goods may persist. Furthermore, increases in productivity dispersion across firms could have an impact on optimal trend inflation, which is an important consideration when setting the inflation target.

The way digitalisation affects the labour market and firms' price-setting behaviour may lead to structural changes in the slope of the Phillips curve, which would have major implications for the conduct and transmission of monetary policy.

Digitalisation and its various impacts on economic variables relevant for monetary policy need to be closely monitored and regularly reviewed in depth. In particular, the speed of adoption of digital technologies and their longer-term effects on productivity, the labour market, inflation and the Phillips curve need to be monitored. As the degree of digitalisation differs across countries and sectors, this may significantly affect the incidence of shocks and their transmission, with heterogeneous impacts across euro area economies possibly impeding the efficient transmission of monetary policy.

1 Introduction[3]

Digitalisation can be viewed as a major supply/technology shock affecting many macroeconomic variables that are important for monetary policy, such as productivity, the labour market and inflation, as well as the measurement of various macroeconomic aggregates. This report uses a very broad definition of digitalisation, including, inter alia, a wide range of information and communication technologies (ICT), technologies enabling automation and robotisation, and technologies related to the processing and analysis of digital data, including big data, such as artificial intelligence and machine learning, and edge and quantum computing. Digitalisation is thus a broad phenomenon, which has been ongoing for decades, but has gathered pace in recent years, including in the context of the COVID-19 pandemic.

The digitalisation workstream report reviews the implications of digitalisation for price measurement, productivity, labour markets and inflation, while also describing more recent developments in digitalisation during the COVID-19 shock as well as their implications. Analysis of these key issues and variables is aimed at improving our understanding of the implications of digitalisation for monetary policy and its transmission. The report is organised into chapters : Chapter 1 is this introduction; Chapter 2 examines the different degrees of digitalisation across euro area countries (in terms of adoption and diffusion), as well as the impact of digitalisation on the measurement of deflators and the implications for the measurement of key real variables; Chapter 3 reviews and investigates the possible mechanisms, channels and impacts of digitalisation on productivity growth; Chapter 4 investigates and assesses the impact of digitalisation and automation on euro area labour markets; Chapter 5 assesses the mechanisms and impacts of digitalisation on inflation; and Chapter 6 provides preliminary insights into the ways in which the COVID-19 pandemic may result in an acceleration of digitalisation and the possible implications for growth and productivity, labour markets, measurement and inflation. Chapter 7 concludes by summarising the main findings and outlining the implications for monetary policy.[4]

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[3] This chapter has been prepared by Robert Anderton and Vincent Labhard, with input from workstream members.

[4] Aspects of the digitalisation workstream report also build on Anderton et al. (2020b).

2 Digitalisation, digital adoption and price measurement[5]

The evidence suggests that digital adoption differs across countries and technologies, implying heterogeneous impacts. Based on the 2020 edition of the European Commission’s Digital Economy and Society Index (DESI), the most digital EU economies are Finland, Sweden, Denmark and the Netherlands, and the least digital are Bulgaria, Greece and Romania. While the four most digital EU economies are among the most digital in the world, the EU as a whole lags behind major G7 economies like the United States, Canada and Japan. Uneven adoption of digitalisation across the euro area can exacerbate heterogeneity among euro area countries and, more broadly, weaken economic convergence.

The price measurement challenges posed by digitalisation are not all new, and not all unknown to statistical agencies.[6] *Digitalisation has exacerbated pre-existing price measurement issues. Frequent and disruptive innovations due to digitalisation have led to more frequent product replacements and greater difficulties in deriving price indices adjusted for quality, and the emergence of e-commerce is amplifying measurement issues related to outlet substitution. Digitalisation has also given rise to new measurement issues with new and more complex pricing strategies and the emergence of “free” (non-remunerated) services.*

The measurement challenges (and resulting biases) apply unevenly across deflators. Estimates from the existing literature suggest upward measurement biases (related to ICT products) in the consumption deflator and in the GDP deflator of between 0.2 and 0.5 pp per year in EU countries and in the United States. However, as these methodologies are not undisputed, the magnitude of the bias remains uncertain. Meanwhile, the implied underestimation of GDP growth cannot fully explain the productivity slowdown observed recently in the EU. Even if the measurement bias in prices were accounted for, the implications of digitalisation may be greater for welfare than for GDP, primarily due to new product varieties and free services[7]*.*

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[5] The chapter has been prepared by Erwan Gautier, Stanimira Kosekova and Vincent Labhard. It has benefited from comments from Robert Anderton, Sofia Anyfantaki, Gilbert Cette, Martin Eiglsperger, Annette Fröhling, Celestino Giron, Bernhard Goldhammer, Johannes Hoffmann, Filippos Petroulakis, Riccardo Trezzi and Elisabeth Wieland. While the title of this chapter refers to price measurement, it does not cover HICP measurement issues, which are dealt with in Work stream on inflation measurement (2021). The chapter covers issues related to price measurement as well as issues and implications associated with inflation, the rate of change in the general level of prices (or, more loosely, price changes), and the variables in focus in the central bank and strategy review perspective. The related boxes in the Appendix have been prepared by Stanimira Kosekova (Boxes 8 and 10), Stanimira Kosekova and Celestino Giron (Box 6), and Stanimira Kosekova and Vincent Labhard (Boxes 7 and 9).

[6] Moreover, recommendations regarding the measurement bias in the context of the HICP already exist, but even in this case the issue might not be resolved, owing to, for example, a lack of harmonisation across countries. Therefore, enhanced collaboration and agreed definitions and methodologies among national statistical institutes (NSIs) would be welcome.

[7] Free services in the digital economy are services provided free of charge to users by providers (digital platforms), but these could be measured indirectly.

The COVID-19 pandemic has added to the price measurement challenges related to digitalisation. It has led to a sharp increase in digital adoption and associated changes in spending patterns and price-setting practices. It also makes the collection of prices and the production of official statistics more difficult where a physical human presence or component is involved.

From a monetary policy perspective, monitoring the digital economy and the associated measurement challenges is crucial. This applies in particular to the contribution of digitalisation to cross-country differences in measurement errors and/or the effects on variables that are important from a policy perspective, such as inflation, employment, output, productivity and potential, as well as distribution. The heterogeneity in digital adoption across the euro area could create more divergent economic and monetary conditions and impede the efficient transmission of monetary policy, while the lag in adoption compared to the United States and Japan could have an impact on the external position of the euro area, with implications for incomes, exchange rates and inflation.

2.1 Introduction

Digitalisation affects – often rather directly – almost all areas of official statistics. Digitalisation is a broad phenomenon that has been ongoing for decades[8], but it has gathered pace in recent years, including in the context of the COVID-19 pandemic. Digitalisation and the digital economy involve more than just ICT, particularly in terms of digitally enabled "traditional" products, such as platforms dedicated to accommodation and transport services, and online finance and retailing.

The focus of this chapter is on the implications of digitalisation for the measurement of price changes. This concerns the resulting possible biases in the deflators for ICT products and digital services, consumer expenditure and investment, as well as the implications of digitalisation-related price measurement challenges for the measurement of real activity, investment and productivity. In fact, price measurement is the key to correctly assessing the volume-price split in national accounts (see, for example, Aghion et al., 2019).[9]

To some extent, the price measurement challenges arising from digitalisation are not all new and are not unknown to statistical agencies. The Stigler Commission in the 1960s (Stigler et al., 1961) and the Boskin Commission (Boskin et

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[8] Key milestones include early explorations of machine intelligence in the 1950s; mainframe computers in the 1960s; personal computers and mobile phones in the 1970s; new economy/dot-com firms and search engines in the 1990s; social media, artificial intelligence and machine learning in the 2000s; and edge and quantum computing in the 2010s.

[9] The split between volume and price in national accounts requires the use of the most appropriate price index (unless volumes are calculated in physical terms, e.g. number of pupils). In national accounts, GDP, consumption and investment deflators use product components of consumer price indices (CPIs) to measure changes in prices paid by consumers; producer price indices (PPIs) to measure changes in selling prices achieved by domestic firms for sales in domestic and foreign markets; and import price indices (IPIs) to measure average price changes of imported goods/services. Nominal values of production or consumption can then be deflated by the most appropriate index to obtain a measure of volume.

al., 1997 and 1996) documented the challenges and estimated the associated biases, pointing out the role played by quality adjustments and new products. Later studies found the biases to be somewhat reduced, e.g. Gordon (2000) for the United States, Hoffmann (1998) for Germany, and Lequiller (1997) in the case of France.[10,11]

However, digitalisation may make the measurement of price changes more difficult for two main reasons. First, digitalisation may exacerbate pre-existing price measurement issues. Frequent and disruptive innovations due to digitalisation have led to more frequent product replacements and greater difficulties in computing price indices adjusted for quality. Moreover, the emergence of e-commerce is creating issues related to outlet substitution (just as supermarkets did in the past), and the rapid adoption of internet purchases by consumers may amplify this issue in the future.

Second, digitalisation has brought new measurement challenges. Those challenges include new and more complex price-setting strategies (products/services sold in bundles, pricing models, dynamic and customised pricing) but also the emergence of "free" services (some replacing existing services). Groshen et al. (2017) and Aeberhardt et al. (2020) discuss in detail how statistical agencies in the United States and France tackle measurement issues related to the digitalisation of their economies in practice.

This, in turn, may have important implications, in particular in terms of the possible contribution to the "productivity puzzle", i.e. the pronounced slowdown of productivity growth at a time when digitalisation is gathering pace (for instance, innovations in computer processing power and overall improvements in ICT equipment, communication services, development of free services and consumer platforms). If, as expected, the price measurement bias due to digitalisation is positive, then, once taken into account, inflation would be lower than actually measured, whereas GDP growth would be higher, leading to potentially higher productivity growth, without, however, fully explaining the productivity puzzle.[12]

In this context, there are at least two questions that are important and to which the literature has contributed. First, how large is the possible measurement bias when we measure price changes for digital or digitally enhanced goods and services (whether they are consumed or an investment)? This would imply measurement issues for both the CPI inflation and the consumption and investment deflators. Second, does this mismeasurement issue have relevant implications for the GDP measure? In particular, can the productivity slowdown be explained with this measurement bias? The effect of digitalisation on the broader concepts of welfare/wellbeing is briefly discussed in this report.

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[10] See also G7 Central Bank Digitalisation Working Group (2019).

[11] For an overview of studies on CPI biases, see Work stream on inflation measurement (2021).

[12] In the literature, this has been cast mostly as a debate on the measurement of GDP growth (for a discussion, see Byrne et al., 2016). For example, Feldstein (2017) notes that "*despite the various improvements to statistical methods that have been made through the years, the official data understate the changes of real output and productivity. The official measures provide at best a lower bound on the true real growth rate with no indication of the size of the underestimation*".

The overall impact of the digitalisation-related price measurement challenges is uncertain. On one hand, the rapid adoption of digital goods and services by firms and consumers may have contributed significantly to an increase in the inflation mismeasurement bias. On the other hand, digitalisation may have also contributed to improving price measurement over the recent past, as several major improvements have been introduced by NSIs in the collection of prices and the treatment of quality adjustments, and product replacements may have significantly lowered the possible measurement bias (see Work stream on inflation measurement, 2021).[13]

The remainder of this chapter is structured as follows: Section 2.2 summarises the evidence, across countries and over time, for three measures of digitalisation; Sections 2.3 and 2.4 discuss, respectively, the measurement of price dynamics of digital products[14] and the measurement of ICT and digitalisation-related investment deflators that may be considered to be particularly affected; Section 2.5 discusses the implications of the digitalisation-related price measurement challenges. Digitalisation and price measurement during the COVID-19 pandemic (and possible implications for the future) are discussed at the end of the chapter in Section 2.6.

2.2 Indicators of ICT/digitalisation adoption and diffusion and the degree of heterogeneity across euro area economies

2.2.1 Digital adoption across euro area countries

This section considers three options for measuring digital adoption[15]: (i) the take-up of digital technologies (how much those technologies have spread to the economy); (ii) investment in ICT (a measure of how much is spent on ICT); and (iii) the value added of the sectors considered in general to be the most digital (a measure of how much output is produced in "digital economy" sectors).[16] Each of the three

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[13] It is important to note that some of the measurement issues may be attributed to the fact that digitalisation may allow large firms to benefit from returns of scale and network externalities, with implications for market structure and competition. These issues are discussed in Anderton et al. (2020b).

[14] In the remainder of this chapter, we use 'digital products' to denote products that are either fully digital or have a digitalisation-related component (defined as a nature of transaction) and comprise the digital production (i.e. production that is digital ordered, digitally delivered or both) of an economy in line with Ahmad, N. and Ribarsky, J. (2018) and UNSD (2021).

[15] It should be noted, however, that the process of digitalisation has both intensified existing measurement challenges (e.g. in relation to the frequency of price changes) and created new ones (especially in relation to bundling, and the consequences of algorithm-driven price setting). It is not yet clear whether the resulting challenges are greater for digitalisation than for previous waves of major technological progress. In relation to some of the challenges of measuring inflation, see also Gordon (1981) and Boskin et al. (1996 and 1997).

[16] Other attempts to measure the digital economy include Reinsdorf et al. (2018) and Eurostat (2018a), both of which apply a direct approach to estimating the size of the digital economy in terms of the ICT "digital sector" and found differences across countries. A possible overlap and risk of double counting between ICT services and online platforms when applying the existing classification at the higher aggregate level were noted. Reinsdorf et al. (2018) suggest that in most economies the "digital sector" amounts to less than 10% if measured by value added, income or employment. However, Reinsdorf et al. (2018) do not provide additional data at the same level of detail that the satellite accounts aim to achieve by means of the supply and use tables. Other options also exist, such as measures of e-commerce, ICT usage by households, ICT innovation, etc.

options considered here for measuring digital adoption has its advantages (and drawbacks), which are discussed briefly in the following paragraphs. Digital satellite accounts – a measurement framework within the system of national accounts for capturing the digital economy – are yet to be made available for EU countries.[17]

Indicators of the take-up of specific digital technologies have the advantage of capturing digital adoption. They can also combine measures of potential and actual use, or measures of de jure and de facto digitalisation. Indicators for specific technologies have the drawback of not necessarily being representative of digitalisation as a whole, which is a broad and continuous process. This may be addressed by composite indicators, but these may not have a consistent back run of data, making historical comparisons difficult.

The advantage of using ICT investment as a digitalisation measure is that it can be computed for a large number of countries. Moreover, it is focused on what is a necessary condition for a digital economy – without ICT investment, there is no creation of digital technology and hence no digital economy. On the other hand, it is not clear from the ICT investment measure what the technologies are, or the amount of resources that had to be invested in order to install them and realise the corresponding output, i.e. how efficient the ICT investment is, or what other complementary investments had to be realised in order to make efficient use of this ICT investment (e.g. investment in skills or infrastructure).

The benefit of using ICT value added is that it is readily available from the national accounts. However, sectors (or even products) are never strictly digital or non-digital, and the digital intensity of a sector (or product) varies across countries, which makes the classification somewhat judgemental and cross-country comparisons difficult. Furthermore, for some countries, a high share of value added in the IT manufacturing sector only reflects the outsourcing to that country; hence a high share of value added in that sector does not necessarily indicate that the country is at the forefront of digitalisation.[18]

2.2.1.1 Digital technologies

The first option to measure digital adoption is to consider the diffusion of specific digital technologies. In this section, the focus is on the Digital Economy and Society Index (DESI) published by the European Commission since 2018 (and the international version, the I-DESI, published in 2018 and 2020) as shown in Chart 1. This index summarises digital adoption (or preconditions for it) along five dimensions: (i) connectivity (broadband); (ii) human capital (digital and ICT skills, science and technology); (iii) use of internet; (iv) integration of digital technology in business; and

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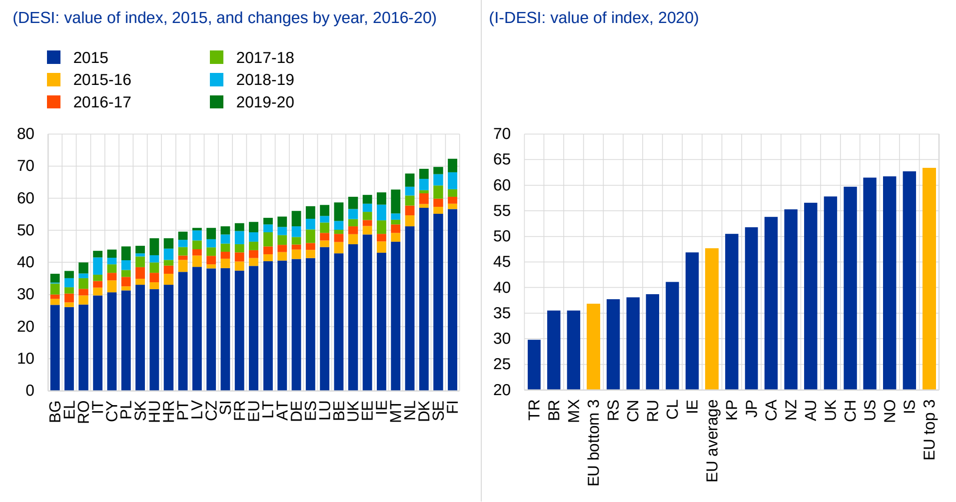
[17] In general, satellite accounts in the national accounts are based on a framework of supply and use tables and focus on a specific aspect of economic or social life, often a sector or set of sectors. They usually include details and/or concepts that are not shown in the core national accounts. Examples include satellite accounts for the health sector, the household sector, the travel and tourism sectors, and the transport sector. Box 9 shows what digital economy satellite accounts would look like for the EU if the key parameters were similar to those in the United States.

[18] For the effects on cross-border trade and investment, see Work stream on globalisation (2021).

(v) integration of digital technology in the public sector. The first two dimensions – connectivity and human capital – may be considered enabling factors, while the other dimensions reflect the actual take-up of digital technologies in the household, corporate and government sectors.

Chart 1

The adoption of ICT technologies in the EU and selected other countries



Source: European Commission (DESI/I-DESI).
Notes: The DESI and I-DESI are both dynamic indices and so not strictly comparable over time, as indicators are added and/or removed each year to reflect new trends. The DESI and I-DESI are also not strictly comparable with each other, as 17 indicators are common to both indices, 20 are specific to the DESI and seven are specific to the I-DESI.

According to the DESI, digital adoption is greatest in Finland, Sweden, Denmark and the Netherlands, and smallest in Bulgaria, Greece, Romania and Italy, as shown in the left panel of Chart 1. As the chart also shows (right panel), the four EU countries with the greatest digital adoption score a little higher than the non-EU countries with the greatest adoption (Iceland, Norway, the United States and Switzerland), while the four EU countries with the lowest adoption score a little higher than the non-EU countries with the lowest adoption. Regarding the evolution over time, the left panel of Chart 1 suggests that the value of the index has increased for all EU countries since 2015, and relatively evenly across countries, with the result that the top four and bottom four countries in 2020 are the same as in 2015, although not in exactly the same order.[19]

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[19] The highest-scoring countries in the 2020 index for the five dimensions are: connectivity (broadband) – Denmark, Sweden, Luxembourg, Latvia; human capital (digital and ICT skills, science and technology) – Finland, Sweden, Estonia, the Netherlands; use of internet – Finland, Sweden, the Netherlands, Denmark; integration of digital technology in business – Ireland, Finland, Belgium, the Netherlands; integration of digital technology in the public sector – Estonia, Spain, Denmark, Finland. As can be seen from this, most countries score relatively consistently across categories, but not all.

2.2.1.2 ICT investment[20]

The second option is to use ICT investment (specifically the capital coefficient). Data for three categories of ICT investment (hardware, software and communication) relative to GDP in current prices are available for the five largest euro area countries for the period from 1960 to 2018. These data are not strictly comparable across countries, as they reflect the methods used in the various national accounts to obtain the ICT investment series. The same applies to comparability over time, as methods have changed over time.[21]

The euro area countries with the highest ICT investment among the big five are the Netherlands and France, while Germany is the one with the lowest rate, as shown in Chart 2.[22] According to this measure, the euro area as a whole had much lower ICT investment (as a percentage of GDP) in 2018 than the United States and Japan but somewhat more than the United Kingdom, having fallen behind the United States and Japan since 1960 (when they had similar ICT capital ratios), while maintaining the higher capital ratio in comparison to the United Kingdom. Over this period, the capital ratios appear to have increased persistently only from 1960 to around 2000, since when they have stalled (or even fallen back slightly).[23]

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[20] This section is based largely on Cette, Devillard and Spiezia (2020), in which ICT investment is obtained by first interpolating backwards the corresponding series in current prices from national accounts, deflating those series with ICT investment deflators built as in Colecchia and Schreyer (2002), and then computing capital in constant prices using a perpetual inventory method (PIM), and capital in current prices by multiplying the constant prices capital series by the corresponding deflator. Finally, the ratio of ICT capital to GDP is computed.

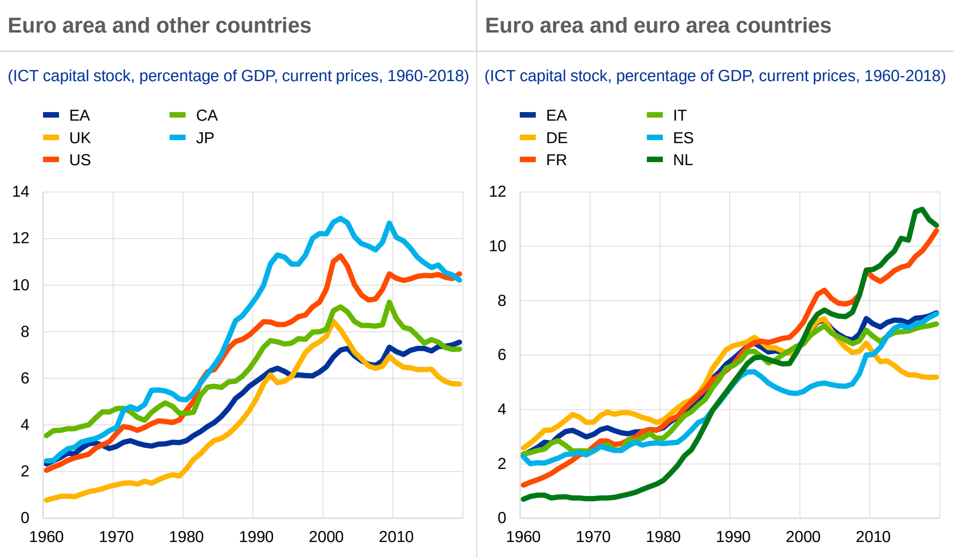
[21] For example, in the case of Germany, the ICT capital coefficient is relatively low, which seems to be explained to some extent by the fact that in the German national accounts spending on software is, to a greater extent than in other countries, considered intermediate consumption rather than investment.

[22] It should be noted that the statistical treatment in Germany is such that own account software spending is not treated as investment to the same extent as other countries.

[23] In the literature, the cross-country differences are generally attributed inter alia to cross-country differences in educational attainment, labour and product market rigidities or the degree of competition. The post-2000 plateau in productivity is often linked to the bursting of the dot-com bubble, after which productivity growth slowed in the most dynamic sectors (including some digital ones).

Chart 2

ICT investment in the euro area and selected countries



Euro area and other countries

(ICT capital stock, percentage of GDP, current prices, 1960-2018)

Euro area and euro area countries

(ICT capital stock, percentage of GDP, current prices, 1960-2018)

Source: Cette, Devillard and Spiezia (2020).
Note: For the computation of ICT investment (ICT capital stock as a percentage of GDP), see footnote 21.

However, there may be substitution between ICT capital and robots in which ICT is incorporated. The reason is that, in the national accounts, ICT embedded in robots is not counted as capital but is considered intermediate inputs of robot producers. This could explain the slowdown and lesser content of ICT in Germany, given the large number of robots in that country.[24] The number of industrial robots[25] is illustrated in Chart 3, with the greatest adoption in Germany and Japan with, respectively, more than 3.5 and nearly 3 robots per million hours worked in 2019, which is far more than other euro area countries or the United States. It should be noted that these data reflect information from sources other than (and outside) the national accounts.

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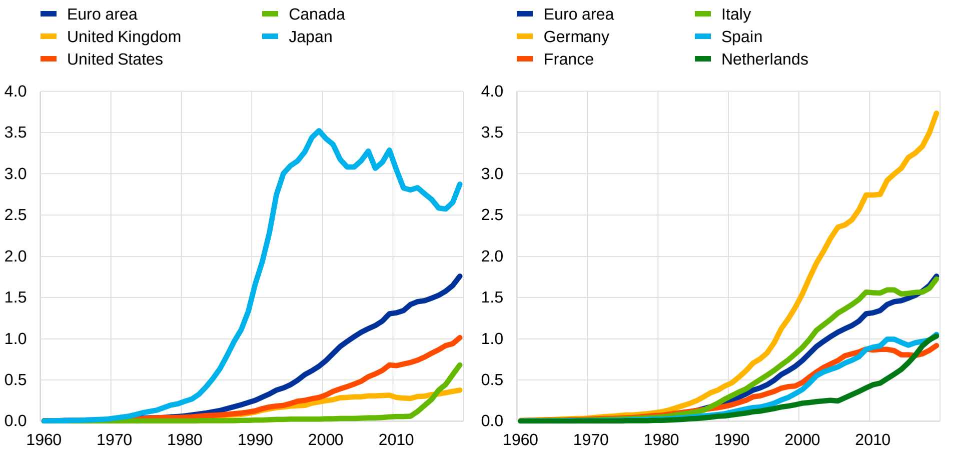
[24] See Anderton et al. (2020b).

[25] For a discussion, see International Federation of Robotics (2017), p. 32. It should be noted that this definition captures only a small proportion of what are currently considered robots and does not adjust for robot quality.

Chart 3

Robot diffusion (1960-2019)

(number of robots per million hours worked)



Sources: International Federation of Robotics and calculations from Cette, Devillard and Spiezia (2020).

2.2.1.3 ICT value added[26]

The value added by digital sectors is a third way of capturing the degree of digitalisation. Chart 4 shows that, according to this measure, the EU countries with the largest digital economy (in percentage of total value added) are Ireland, Finland and the Czech Republic, while those with the smallest are Greece, Portugal and Lithuania.[27] Only Ireland and Finland have a digital economy as large (in percentage of GDP) as the United States. The share of digital economy is much larger in the United States than in the EU or euro area as a whole. It represents more than 8% of total economy value added, compared with only around 6.5% for the EU28 and just over 6% for the euro area. Relative to 2015, most countries seem to have experienced a small increase in the share of the digital economy, but a few (notably among the most digital) have seen the share of the digital economy decline.

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[26] This section draws on Anderton et al. (2020b), which defines the digital sectors on the basis of the latest version of Eurostat's statistical classification of economic activities in the European Community (NACE Rev. 2) as the manufacture of "computer, electronic and optical products" and "electrical equipment" (divisions 26 and 27) and the IT services sector as "information and communication" (Section J, consisting of divisions 58 to 63).

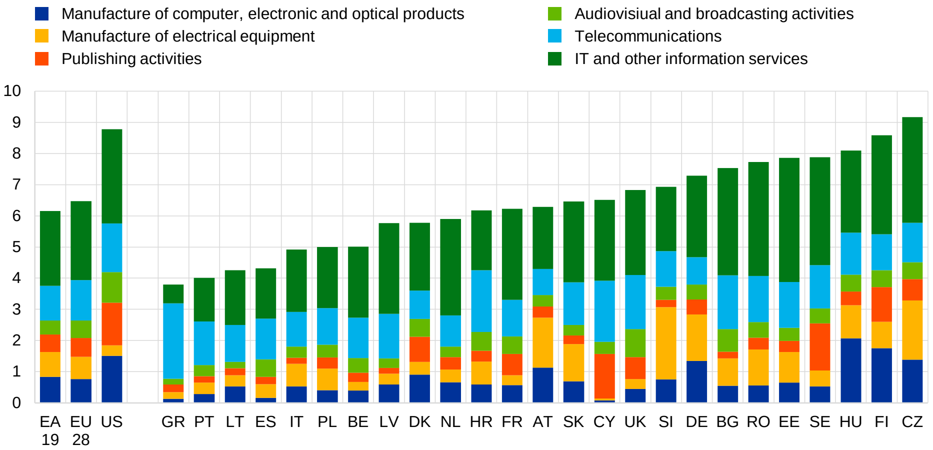
[27] It should be noted that the numbers for Ireland are subject to some caveats (see Anderton et al., 2020).

Chart 4

ICT value added in the euro area and selected countries

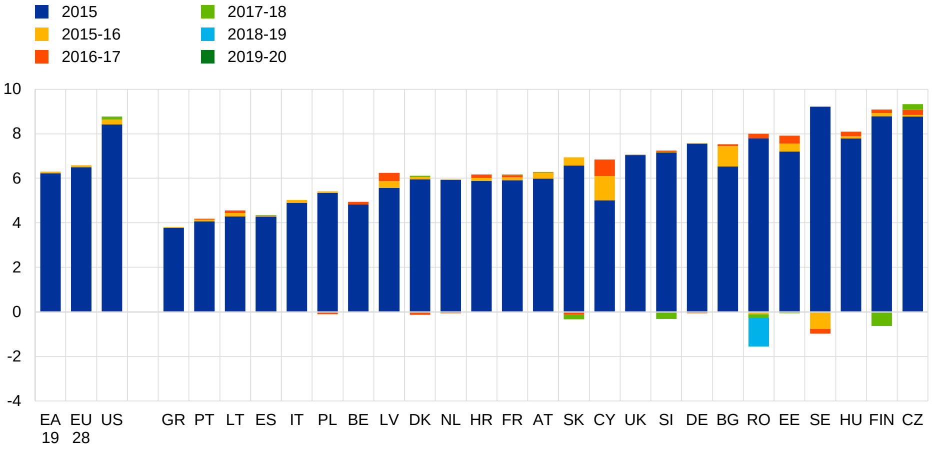
Composition, by NACE sector, 2019

(digital economy value added in percentage of GDP, current prices)



2015, and changes by year, 2016-20

(digital economy value added in percentage of GDP, current prices)



Sources: Organisation for Economic Co-operation and Development (OECD) database and ECB staff calculations.
Notes: The data for AT, BE, CY, DE, EA, ES, EE, EU, HU, IE, IT, LT, LV, PL, PT, RO, SI, SE and US refer to 2018, those for BG, UK, GR, HR and NL to 2017, and EA and EU to 2016. The results for Ireland need to be interpreted with care, as the size of the Irish digital economy is linked to the activities and domiciles of global digitalisation-related firms. In other words, globalisation favoured the relocation of intangible assets, in the form of intellectual property, to Ireland, as well as the outsourcing of the manufacturing of products.

2.2.2 ICT diffusion across euro area countries

This section analyses ICT diffusion and the extent to which pre-existing structural differences across countries (in terms of digital know-how, dependence and composition) may have increased or reduced in recent years.

2.2.2.1 Comparison across measures of ICT adoption

While measures of digital adoption, ICT investment and ICT value added vary greatly, some of them paint a similar picture for some countries. For example, according to the DESI, the Netherlands is one of the countries with the greatest share of ICT investment and is among the countries with the highest adoption. Finland, one of the countries with the largest ICT outputs, has the highest adoption, according to the DESI, while Italy and Greece are among the countries with both the smallest ICT output and lowest adoption.

But the three measures do not all paint the same picture for all countries in all cases. The Netherlands for example shows low adoption in terms of ICT value added (as a percentage of GDP). Belgium, the Czech Republic, Lithuania, Romania and Spain are ranked differently for adoption and ICT output. France has one of the highest levels of ICT investment, but is close to the EU average in terms of adoption and value added. For Luxembourg and Malta, only adoption can be measured, and for several smaller countries, ICT investment is not available, so it is not possible to compare all measures for those countries.

As a result, it is difficult to draw very firm conclusions on the degree of digitalisation and the size of the digital economy across countries. In relation to the efficiency of ICT investment, for example, while it looks as if France could be a country in which ICT investment is not as efficient as in other countries (in the sense of high ICT investment relative to other countries not translating into high ICT output and high adoption of ICT technologies relative to other countries), this may be explained by the way ICT investment is recorded in that country compared to others, and it is not clear whether there are other countries that are similar in this respect.

2.2.2.2 Heterogeneity across euro area countries

The degree of heterogeneity across euro area countries also appears to be broadly similar across the measures considered. While the evidence presented in the previous section suggests that the degree of heterogeneity depends on the specific aspect of digitalisation being considered, all three measures reported in this section suggest that digitalisation and the size of the digital economy may be roughly double in the most digital countries when compared to the least digital countries. Moreover, even where the countries are broadly similar according to a specific measure, they differ (sometimes a lot) in relation to specific aspects, e.g. the various dimensions of the DESI, the three categories of ICT investment, or the different ICT sectors in the case of value added. As a result, it is possible that price measurement challenges may differ across countries.

Technology diffusion and cross-country heterogeneity are driven by a number of factors at the firm and country levels. At the firm level, corporate culture, attitude and agility, staff policies, notably in terms of recruitment, coaching and training, and integration into networks and supply chains are key factors determining how well companies fare in adoption and contribute to diffusion. At the country level, those key factors include policies and frameworks for education, jurisdiction, regulation, market access and structure, competition, and institutions and governance. More generally, socio-economic characteristics like age, gender, educational attainment and income level are also important. Taken together, these factors also account for the gap in digitalisation between the EU as a whole and other countries.

2.3 Measurement of price dynamics of digital products, particularly measurement issues posed by digitalisation

2.3.1 More frequent quality adjustment for digital products

One of the main measurement challenges related to digital products stems from more frequent quality adjustment. The quality adjustment challenge as such is not new and potentially affects prices of all types of goods and services.[28] All other things being equal, this will result in two types of price change: a “pure” price change (for a product otherwise unchanged) and a price change reflecting a change in the characteristics of the product (e.g. quality, service or package) which implies a change in utility to the consumer.[29]

Digitalisation has made the measurement challenge posed by quality adjustment more complex. This is because digital products are by nature (i) more frequently replaced by new products and (ii) more affected by technological progress and innovation. This, in turn, complicates the classification of products, because (i) the faster product cycle requires more frequent adjustments of product classifications and (ii) the application of existing methods of quality adjustment becomes more challenging.

Different methods are used to reduce the measurement bias related to quality improvement. These methods are either explicit (such as hedonic regressions or judgemental quality adjustments) or implicit (bridged overlap for instance). Hedonic quality adjustment methods are appealing because they rely on estimations done on observable characteristics of the products. NSIs that have more experience with a given method tend to use that method more systematically and consistently across the different price statistics areas.[30]

The application of bias-reduction methods, however, is not straightforward, as they have to cope with the rapid pace of innovation and the introduction of completely new characteristics for digital products (for more information on the hedonic method, see, for example, Hausman, 2003, and Bils, 2009). As an alternative, NSIs may use, for example, bridged overlap methods, which assume that the quality-adjusted price difference between the old and the new product can be approximated by the price change observed for similar products which are not replaced. This method may result in a distorted measure of the rate of price change, depending on the pricing policies in

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[28] The quality adjustment issue is discussed in Work stream on inflation measurement (2021).

[29] Price indices are supposed to capture only pure price changes over time and should not reflect changes in quality of goods. Price statistics therefore aim to adjust all price changes for changes in quality.

[30] OECD (2017) provides an overview of the methods used by NSIs to take into account quality adjustments for digital products and services (in both CPIs and PPIs).

the market. Very often, it may underestimate inflation, since most of the price change between the old and the new product will be attributed to quality change.[31]

Digitalisation, however, may also allow quality changes to be measured more accurately. Web-scraping techniques would help statistical agencies to collect information on observable product characteristics and to improve the implementation of hedonic pricing methods (see, for example, Gorodnichenko et al., 2020). Similarly, scanner data (also providing information on product turnover) would enable NSIs to capture the faster product cycle and enhance their ability to control for quality changes, even if this might require more resources to be invested in methodology.[32] This should help reduce a possible "new product bias", where prices of new product varieties decline more rapidly immediately after their introduction, which is not taken into account in a price index in which the product is incorporated with a significant delay (see Ahmad et al., 2016).

2.3.2 Bundling, subscription plans and price measurement[33]

Another measurement challenge arises because some digital products are often combined in bundles/packages. This is notably the case for communication products (mainly comprising services), one of the most prominent digital product items in the consumption basket. Two prime examples are mobile phones combined with service subscriptions, and bundled TV/broadband/phone packages.[34] Providers offer different packages with different service bundles (text messages, data, international/national phone calls, internet access, etc.), and sometimes include another product, such as an additional free or cheaper phone. The main measurement issue comes from the difficulty in assessing the contributions to the price change from the different components of the package. This is further complicated by the classification (and measurement) of the individual products in the statistics, where, in principle, the goods and services should be separated, which is not always possible in practice.[35]

New price structures (e.g. subscription plans) further complicate price measurement. The link between quantities and prices may be nonlinear (e.g. a fixed price for an unlimited number of text messages/duration of calls), complicating the split into quantities and prices. Promotional offers, which refer to several dimensions of a

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[31] Aghion et al. (2019) argue for possible missing growth due to price imputations in the case of "creative destruction" innovative products because NSIs do not manage to adjust correctly for rapid introductions of new products.

[32] One limitation of the use of scanner data is the scope of product coverage, which may not necessarily cover the complete product universe of the specific shop. Web-scraped data, on the other hand, would help to fill in this gap but cannot provide information on turnover.

[33] While similar issues may also exist in "traditional" products (e.g. package holidays), they appear much more widespread in relation to digital products.

[34] In the European Classification of Individual Consumption according to Purpose (ECOICOP), these examples relate to 08.2 Telephone and telefax equipment and 08.3 Telephone and telefax services (including internet access).

[35] If the cost of each item in the bundle is observed, it is feasible to separate equipment from services, but in some cases this is impossible and prices can be assigned to ECOICOP category 08.3.0.4 Bundled telecommunications services.

contract (e.g. price discounts for accepting a longer contract duration), mean that it is not easy to compare prices over time. Moreover, in the case of communication services, quality adjustment techniques are not always appropriate to derive pure price changes. For instance, in the case of phone packages offering unlimited calls, hedonic price techniques cannot capture price evolution in this respect, in particular because consumers do not actually consume an unlimited quantity of phone services.

To tackle the challenge of frequent changes to subscription plans or price tariffs, Eurostat (2018b) recommends using the pre-defined representative consumer profiles method or actual usage/sample of bills method with customers classified by consumption profiles.[36] Such methods aim to capture the evolution of “the minimum cost of a pre-defined and fixed pattern of use” and could be considered a proxy for the constant utility approach. This requires typical patterns of use to be defined for representative consumers and the evolution of the costs for consumers associated with these patterns to be tracked over time. One difficulty in this context is defining constant uses that are representative of all consumers. This requires some external information on the most common use of phones and on the main different categories of households, which might be difficult to obtain. Most NSIs using this approach and following the Eurostat recommendations rely on information from service providers or from telecommunications regulators.

2.3.3 New outlets and the emergence of e-commerce

Further challenges arise from the multiplication of new outlets, such as online retailers and platforms. One challenge relates to the characteristics of a product purchased online relative to the counterpart purchased in a traditional store. The services associated with online and offline options, for example, are different and different prices in traditional outlets may partly reflect the different quality of those services (convenience, advice, etc.). Established consumer price indices compile price changes by outlet type, i.e. prices of the same product are not compared across outlet types which are fundamentally different. In the case of comparisons across outlet types, prices should not only be adjusted for quality differences due to the intrinsic characteristics of the products (see Section 2.3.2) but also for differences related to services provided with the purchase (e.g. delivery, proximity of the outlet).

The price index of an elementary aggregate (the elementary index) is calculated directly from collected prices. In some (usually large) countries, however, the elementary indices at the lowest COICOP aggregate level are compiled using stratifications by outlet and by region within a product category. Thus, only differences in price changes between outlets, and not differences in price levels, are taken into account in the more aggregate product price index. This measurement issue is not completely new: a similar problem was documented when supermarkets entered the market. With respect to bricks-and-mortar shops, the effect of outlet substitution bias

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[36] See Section 12.6 of the methodological manual (Eurostat, 2018c).

was estimated at that time to be between 0.05 and 0.15 pp in France (Lequiller, 1997) and less than 0.1 pp in Germany (Hoffmann, 1998).

Information on differences between online and offline product characteristics is difficult to obtain. Online purchases are associated with possible improvements in quality (e.g. the opportunity to purchase at any time of the day or week or, perhaps, free home delivery) but also with some quality deteriorations (no personal advice, delayed access to the purchased product, possible shipping costs, etc.). In the absence of any information and according to established statistical concepts and methods, statisticians would consider substitutions related to price level differences between outlets as volume changes (see Aeberhardt et al., 2020). In this case, the entire difference in price levels would be attributed to a change in the quality of goods or services, i.e. neutral for the price index.[37]

The spread of e-commerce has also led to the appearance of new products (goods and services) that compete with existing products. Examples include websites offering the printing and sharing of pictures, which are replacing traditional photography; websites for streaming audio and video, which are replacing other media (DVDs and CDs); and websites for rental or other services (e.g. hospitality and transport). These new services are not exactly comparable to the services/goods they are substituting and are therefore treated as completely new services. This implies that if they offer cheaper services, their impact on price statistics will only be measured indirectly, and with a delay, via their impact on competitors' prices. For instance, streaming has contributed to lower prices for DVDs and CDs and will eventually lead to their complete demise (for more examples, see Aeberhardt et al., 2020). In this way, digitalisation is having an impact on price and volume measurement, as there is possible substitution bias arising from the introduction of new digital services, be they retail e-commerce services or peer-to-peer services, such as Airbnb and Uber.

Some transactions may not be captured by some price indices, owing to the nature of the individual indices. For example, consumer-to-consumer ("C2C") sales facilitated by intermediation platforms (e.g. Airbnb) are not yet covered by the HICP. This is because the HICP excludes transactions between private households, such as the sale of a used car by one private household to another (see also Groshen et al., 2017).

2.3.4 New price-setting behaviour and price discrimination

Digital technologies have contributed to changes in price setting and pricing strategies. New processing capacities have enabled online platforms to collect and

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[37] This might be debatable: if consumers tend to buy more online, and possibly the same products that they used to buy at higher prices in bricks-and-mortar stores, this will be interpreted as lower quality and not as lower price. This may lead to an "outlet bias". The overall effect of new outlets in price statistics will only come from the reaction of existing competitors' prices: if new outlets are cheaper and the products are exactly the same, more traditional existing retailers are expected to adjust their prices downwards. Here the treatment should reflect such differences between producer and consumer prices. For producer price indices, prices are measured when leaving the factory and thus do not depend on how products are distributed, whereas for consumer price indices, prices are measured as sold in the outlets and will therefore depend on the type of outlet.

process ever larger quantities of data. New sources of data and new algorithms for processing those data have enabled the platforms to extract more and more information on the behaviour of their customers and the effects of their pricing decisions, and so to develop their customer bases. As a result, pricing decisions may be adjusted (and optimised) essentially in real time and take into account the specific customer they are addressed to. This has the potential to affect a number of properties of prices, including across products, outlets, regions and time (thereby having an impact on inflation measurement).[38]

The spread of online purchases in particular has gone hand-in-hand with the development of more personalised prices and yield-management practices. These practices have developed because internet purchases allow information on buyers to be shared and prices to be adjusted in real time, depending on the characteristics of the demand. This development of customised pricing is particularly significant in the transport sector (train/flight bookings) but also in package holidays and accommodation services.

A better understanding of the changes in price dynamics may require the collection and analysis of a greater number of prices. For example, consumers may pay a different price at different points in time, or at different locations, or depending on other factors (e.g. the device used – smartphone or computer), and the scope of price differentiation has increased considerably with digitalisation. Eurostat (2018b) recommends, for example, that prices of flight tickets are collected "sufficiently in advance of departure to ensure they are representative of consumers' expenditure and behaviour", and this applies in general for all services, but the price should enter the index when the services are actually consumed by the households.

Addressing those issues may also require changes to data collection and processing methodologies. For example, ways may have to be found to deal with the possible shutdown or inaccessibility of websites, both in data processing and in the aggregation of a lot of prices collected on different dates and for different customers. The latter aspect is particularly important, because price differentials observed at different points in time might reflect differences in quality. A last-minute booking might be cheaper but also more restricted than a booking made in advance.

2.3.5 New measurement challenges of free services (free digital content)

New price measurement challenges arise from the free services provided by digital platforms and applications (see also Box 6 in the Appendix). Such services are not explicitly or separately considered within the production boundary of the national accounts[39] and therefore do not entail direct measurement difficulties for official statistics. The issue of free services is already known from free TV channels

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[38] The impact of e-commerce on inflation is discussed more extensively in Chapter 5. We only refer here to the measurement challenges and opportunities related to the emergence of e-commerce.

[39] See Regulation (EU) No 549/2013 of the European Parliament and of the Council of 21 May 2013 on the European system of national and regional accounts in the European Union (OJ L 174, 26.6.2013, p. 1) (ESA 2010), Annex A, paragraphs 3.07 to 3.09.

and free newspapers offering free digital services that are financed via advertising (or the provision of personal data in the case of digital services), and therefore their value is incorporated in the national accounts via intermediate consumption in the price of the final products on which producers incur the corresponding advertisement costs.

The measurement challenges arising from free services on digital platforms are similar to those arising from bundling, the challenge being to identify changes in prices that correspond to the provision of a new free service, or the improvement in quality of an existing free service, somewhere along the value chain from producers to consumers. However, it can be argued that what is included in the prices of the final products are just the counterparts of free services that are still not accounted for and whose exclusion leads to measurement problems at aggregate level, as the price dynamics (and volume dynamics) of a growing part of the economy are missing.

One way to provide a separate estimate of free services not accounted for in national accounts would be to compute a reservation price. The reservation price is the unobserved price which would drive demand for this new good down to zero (or the price consumers would agree to pay to have access to such services) (Reinsdorf and Schreyer, 2018). At the time of introduction, the price decrease would correspond to a large negative jump (from the reservation price to a zero price). However, this method is very difficult to implement in practice. Moreover, the characteristics of the new free service should also be assessed: is the quality of the new free service equivalent to that of existing services?

An important issue in the context of free services is the distinction between GDP and welfare.[40] New free digital services improve consumer welfare irrespective of whether they are considered as part of GDP growth (see Brynjolfsson et al., 2019). This is similar to other services, like do-it-yourself services (e.g. being your own banking or travel services provider) enabled by the online platforms, for which no market price/value is available (see the discussion in Chapter 5).

Note that, in the context of national accounts, the United Nations Statistical Commission (UNSC) has formally launched a review of the System of National Accounts (SNA) in which the issue of the treatment of free services (and the value of data) will be addressed.[41] This work will feed back into the discussion on any systematic mismeasurement associated with the digital economy and will prepare the way for a review of the current statistical standards. Note that this is work in progress and only tentative conclusions could be included in this paper.

An additional challenge is that free services compete with existing services with a (separate) market price. The main issue for price measurement arising from the introduction of free services might be that these new services replace “old” goods

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[40] See also Work stream on inflation measurement (2021). Acquisition-based price indices, like the HICP, refer to actual monetary transactions for purchased products. Products with zero prices are not included, thus their impact on welfare is not accounted for. Cost-of-living indices, however, are aimed at addressing such welfare gains.

[41] See “Treatment of free digital assets and services”, note prepared for the meeting of the Advisory Expert Group on National Accounts working on the SNA research agenda under the auspices of the Intersecretariat Working Group on National Accounts (ISWGNA).

like dictionaries, maps, etc., which we might expect to lead to a decrease in consumer price indices. However, the design of price indices does not permit zero prices, so the effect of free services on existing price indices inflation will be represented by the drop in prices of existing goods with non-zero prices that can be substituted by products with zero prices. Moreover, collaborative consumption arrangements (e.g. Wikipedia), where the providers of free products are not businesses but households, exert a similar effect on prices of standard products via substitution (the prices of traditional encyclopaedias in the case of Wikipedia).

2.4 Measurement of digitalisation-related investment deflators and new growing digital phenomena[42]

2.4.1 Overview

Price measurement issues in the computation of deflators for national accounts are very similar to those for consumer or producer price statistics. In the euro area, these price statistics are implemented by NSIs according to harmonised recommendations made by Eurostat. These price indices are usually fixed-basket price indices: a basket of products is defined with the weights of the products fixed for a certain period, thus the index tracks the price changes of these products over time. If consumption patterns are very stable, this method should be very suitable. A challenge arises when product replacements or changes in consumption patterns occur very frequently (see Aeberhardt et al., 2020).

Therefore, some of the measurement challenges related to investment deflators are no different from the challenges discussed in the previous section. This concerns, for example, quality adjustment, product bundling, and changes to price setting and price dynamics. The principles of measuring price and volume indices in the national accounts are similar to those for other price statistics.[43]

However, there are also challenges specific to investment deflators, such as the measurement of own-account software and own-account research and development (R&D). These specific challenges are the topic of this section. Being aware of these specificities in the statistical measurement of both prices and volumes of the investment – a key concept in the national accounts which is technically referred

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[42] For cloud computing, see Box 7 in the Appendix.

[43] According to ESA 2010, “Volume and price indices can only be derived for variables that have price and quantity elements. The notions of price and quantity are closely linked to that of homogeneous products, i.e. products for which it is possible to define units which are all considered equivalent and which can thus be exchanged for the same monetary value. It is thus possible to define the price of a homogeneous product as the amount of money for which each product unit can be exchanged.” Certain difficulties in price and volume measurement, however, may exist due to the market and non-market distinction of the products/services. This applies, for example, to government education and health services provided as free services to consumers; or own-account production by households. Such services differ from market services in that they are not sold at market prices and their value at current prices is calculated as the sum of the costs incurred. These costs are intermediate consumption, compensation of employees and other taxes less subsidies on production and consumption of fixed capital.

to as gross fixed capital formation[44] (GFCF) – is of relevance when discussing digitalisation in the context of the real economy analysis or the business cycle developments of the economies.

Investment deflators can be measured from either the supply or the demand side. This is done more often from the supply side, although it might be difficult to differentiate between deflators of a capital nature and those that should be considered intermediate or final consumption deflators (i.e. classification issues are possible). The price indices used for deflation of investment (investment deflators) do not directly affect inflation or the private consumption deflator, because they measure price changes of non-financial fixed assets and are, in general, more relevant for capturing digitalisation in GDP, e.g. via non-financial investment.

Investment deflators rely on investment price indices, which should have a number of key characteristics. Investment price indices, which are usually developed for the production of capital goods and often deal with unique products, should capture changes in the purchasers' price of the particular products. As a second best, Eurostat suggests the use of PPIs adjusted to purchasers' prices. Their key characteristics include: (i) being an index covering the precise product or group of products; (ii) taking proper account of changes in the quality of the product or products; (iii) being valued in purchasers' prices including non-deductible VAT; and (iv) that the concepts underlying the index correspond to those of the national accounts.

Even if the product match is exact, the direct use of PPIs is not seen as ideal because PPIs are measured at basic prices. The use of PPIs for the deflation of GFCF assumes that the change in basic prices and purchasers' prices is the same, i.e. taxes, transport, installation and the other costs of ownership remain constant in volume terms. It is therefore recommended in the national accounts that the PPIs be further adjusted to purchasers' prices to qualify as proper investment price indices.

2.4.2 ICT investment deflators

The measurement of ICT investment deflators requires a definition of ICT equipment. As defined in the national accounts, ICT equipment includes devices using electronic controls and the electronic components used in such devices and comprises two subgroups – computer hardware and telecommunications equipment. These products have undergone significant improvements in quality as a result of ongoing technological developments, and quality adjustment therefore plays a central role in their price measurement.

The ICT investment deflator accounts for the decline in the share of ICT investment in total investment in the euro area in recent years. The share of ICT investment in the total investment of the euro area has been decreasing since its peak

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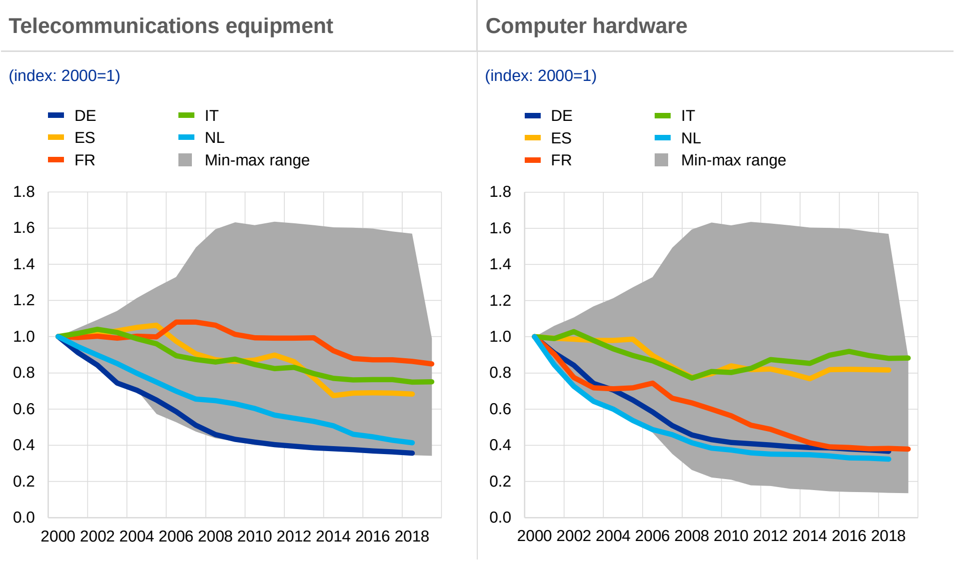
[44] Volume data for changes in inventories, and thus also implicit deflators, are not discussed as these are not readily available in the national accounts.

of 4.4% in 2000 and stood at 3.3% in 2019. This reduction reflects a combination of increasing volume share and decreasing prices (see Chart 5), albeit to a greater extent in Germany and the Netherlands than in Italy and Spain, while for France it depends on the type of ICT investment. This heterogeneity might be due to differences in the quality adjustment practices and/or the update frequency of the baskets.

Chart 5

ICT investment deflators



Telecommunications equipment

(index: 2000=1)

Computer hardware

(index: 2000=1)

Sources: Eurostat and ECB staff calculations.
Note: Latest available data for all EU countries.

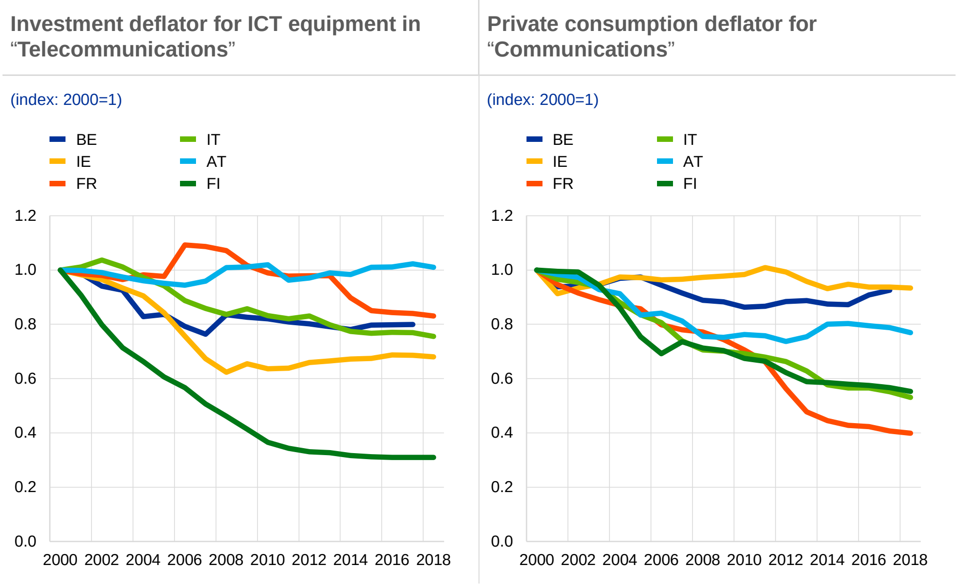
Measuring computer hardware in particular is challenging for a number of reasons. As suggested by the United Nations Statistics Committee (UNSD, 2020), investment is increasingly concentrated in large companies and, owing to lack of data, many countries cannot derive the corresponding deflators (or suitable import price indices), so they often use either unit values or another country's price index such as that of the United States. Furthermore, rapid technology change means that achieving a like-for-like comparison can be difficult, since products do not just change in terms of quality but also in terms of the nature of the product itself (laptops replacing desktops, tablets replacing laptops, etc.) within the product classifications. Owing to specialisation in the manufacture of ICT hardware, many countries, even relatively large ones, find that their domestic production basket may be very different from that which is being consumed. Finally, ICT hardware is often bundled with software products, which makes the price measurement even more challenging.

It has been argued that prices for consumer digital access services would fall at a similar rate as investment prices for the related ICT capital. By combining alternative services indices that they developed, Byrne and Corrado (2020) calculate that, in the case of the United States, prices fell by 12% per year between 1988 and 2018. They also stress the importance of the digital activity that households conduct outside the boundary of the national accounts, e.g. free services on the internet, such as social networking and search engines, and advocate their inclusion in the official statistics (for more detail, see Section 2.3.5).

There are significant differences between implicit national accounts deflators for ICT investment (within the boundary) and the private consumption deflator for ICT products. As shown in Chart 6, there are significant differences in the price changes measured by the two deflators. This might be explained by the use of different price indices to derive the volume measure in the national accounts, but also by the different coverage (business-to-business (B2B) and business-to-consumer (B2C) component in the investment deflators).

Chart 6

Investment and consumption deflators



Sources: Eurostat and ECB/national central bank (NCB) staff calculations.

These differences are behind ongoing discussions on cross-country differences in the evolution of implicit deflators for ICT products, including computing services. As noted in Eurostat (2018a), there might be certain measurement issues across countries that lead to different price developments where more similarity might be expected. ICT products undergo frequent changes in quality and specifications. If the quality improvements embodied in new models were not fully accounted for, this would lead to overestimation of the growth of quality-adjusted prices and underestimation of output volume growth. Prominent examples include bundled telecommunication and other IT products (combining goods and services, such as various pricing plans and bundles) and the necessity to apply quality adjustment for technological changes at the most detailed level.

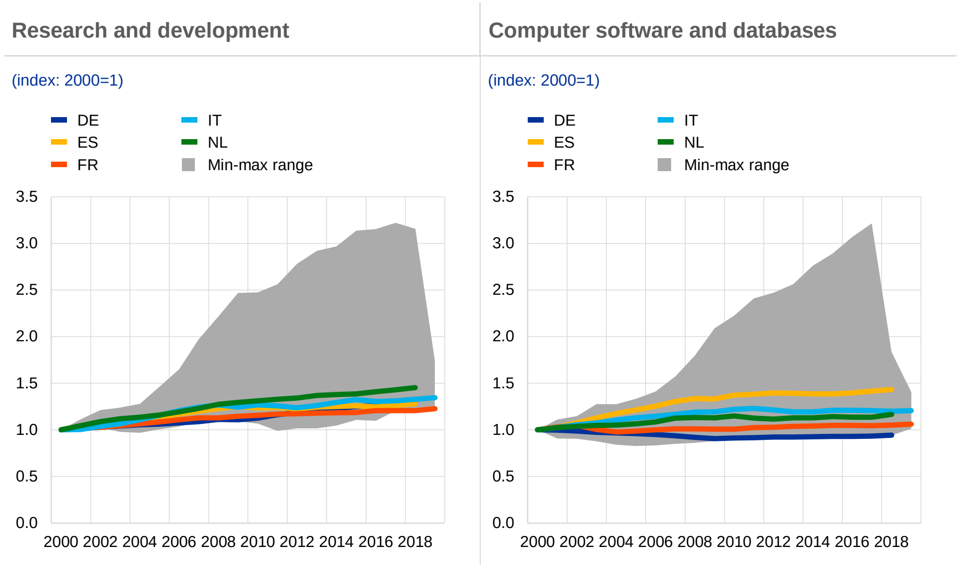
2.4.3 Deflators for other digital products

There are also challenges in the price and volume measurement of intellectual property products (IPP) such as research and development (R&D), databases and computer software. One example is the valuation of own-account (in-house) production of software or R&D because no market value exists and it is difficult to estimate it.[45] Usual methods involve the aggregation of production costs, which implies that quality adjustment for the labour input may be necessary in the volume estimation. Different approaches are sometimes used by different countries, which is also translated into different trends in the implicit deflators.

Specific challenges arise from the cross-border nature of IPP, as discussed in Box 8 in the Appendix. The share of IPP investment in total euro area investment has been growing steadily, from 12.6% in 1996 to 22.4% in 2019, also reflecting the increase in the asset prices which are shown in Chart 7 for R&D and computer software and databases. These investment deflators also reveal that, although the magnitude of the different price developments across EU countries is less heterogeneous than the ICT investment deflators, some clear outliers and possibly questionable developments could be observed for some countries.

Chart 7

IPP investment deflators



Sources: Eurostat and ECB staff calculations.
Note: Latest available data for all EU countries.

2.4.4 Beyond the boundary of GDP: measuring the value of data as an asset

The value of data is a new and extremely complex issue for national accounts. Currently, the value of data, on which many business models are now based, is not included in the production boundary of the national accounts. Discussions about the role of data in the national accounts are ongoing as part of the UNSC review of the SNA. Taking into account recent discussion in that context, it might be possible that expenditure undertaken to collect, store and process data will be capitalised in the national accounts and added as a produced fixed asset (together with “Computer

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[45] There is also an issue of statistical treatment (see footnote 43).

software and databases") in the revised SNA. The value of this new asset would comprise, in the case of data produced on own account and not bought from a third party, the sum of costs plus a margin (which would be difficult to estimate). It would therefore be subject to potential measurement difficulties when distinguishing prices and volume similar to those for IPPs (see above).

2.5 Implications of the digitalisation-related measurement issues

2.5.1 The measurement bias of price changes

2.5.1.1 Digital consumption goods or services

Available results from the literature point to a measurement bias for products in the digital economy. A positive bias is documented for digital goods and services for both consumer goods and investment goods. While available empirical results are abundant for the US economy, only a small number of papers have documented and measured bias for European countries. More definitive conclusions must wait for the results of various studies by researchers and statistical agencies based on European price data.

Among consumption goods, the measurement bias for communication services has been of particular interest. On communication equipment, Hausman (1999) first pointed to a "new product" bias when cellular phones were adopted by households. He summarised his point as follows: "Since their introduction in 1983, cellular phones adoption has grown at 25-35% per year. The BLS did not know that cellular phones exist at least in terms of calculating CPI until 1998". He estimated a "new product" bias of 1.9 pp for telecommunication services in the United States (1.1% in the official time series, but -0.8% once corrected for the bias).

More recent contributions on telecommunication services point to more complex mismeasurement issues and to larger measurement biases. For the

United States and the United Kingdom, the bias is estimated to be about 5 pp per year for inflation of telecommunication services.[46]

Another series of studies focused on extensively analysing internet access services. Greenstein and McDevitt (2011) find that in the United States, the price changes of broadband access is overstated by 3 pp. However, they document that this bias is lower than those estimated for computers and other communication equipment (see also Flamm and Herrera, 2017, for further investigation of the very recent period). More generally, Nakamura et al. (2017) have documented some assessments of the value of "free" internet consumer entertainment and information and find that the free internet content would have lowered personal consumption expenditure (PCE) inflation in the United States by a maximum of 0.1 pp.

Some studies provide alternative estimates of deflators. Byrne and Corrado (2020) constructed alternative consumer price indices for four types of digital services – internet access services, mobile phone services, cable television services and streaming services – over the period 1988-2018. Their method consists of using information on use intensity (i.e. number of users, hours spent by user, quality of an hour of service) to better capture quality adjustment. Combining the four service indices, their aggregate price index for consumer digital access services fell 12% per year from 1988 to 2018, whereas the equivalent official index rose by 1.2% over the same period (see Table 1). They also document that this gap has increased over time from 6 pp in the period from 1988 to 1997 to 19 pp from 2008 to 2018.

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[46] Byrne and Corrado (2015) provide a new price index for communication equipment correcting for quality adjustments using a matched-model technique and without using hedonic price techniques. They find an average bias of 8 pp between their index and the available US Bureau of Economic Analysis (BEA) indices over the period 1985-2009. Combining a hedonic index and a matched-model method, Aizcorbe, Byrne and Sichel (2019) find a rate of price decline closer to, but about 4 pp slower than, the index currently being used by the BEA. They also address the potential measurement bias associated with bundled offers in telecommunications and introduce a method to disentangle price developments related to phones on one hand and phone services on the other. They show that between 2010 and 2017, the adjusted deflator for the PCE category "Cellular Telephone Services" fell by about 4 pp faster than in currently published measures, implying a 4 to 5 pp bias in the aggregate PCE inflation rate. Focusing on telecommunications services, Abdirahman et al. (2017) document bias in the measurement of telecommunication services in the United Kingdom (using work done by the Office for National Statistics, ONS). Using an alternative method based on data usage, they document that the current consumption deflator is upwardly biased and a price decrease of between 35% and 90% between 2010 and 2015, whereas the product deflator for telecommunications services only declined by around 2% over the same period.

Table 1

Consumer digital access services in the United States

	Internet access services	Mobile access services	Cable access services	Streaming services	Total digital access services	Total PCE
A. Alternative price indices (annual average percentage change)						
1988-2018	-35.7	-20.1	0.6	-	-11.9	1.9
1988-1997	-43.8	3.3	0.5	-	-1.7	2.8
1998-2007	-41.3	-20.2	0.2	-	-13.1	1.9
2008-2018	-23.3	-41.2	1.0	-22.8	-20.0	1.1
B. Official price indices (annual average percentage change)						
1988-2018	-2.2	-3.7	4.3	-	1.2	2.1
1988-1997	-4.6	-2.1	6.2	-	4.5	2.9
1998-2007	-2.7	-4.7	4.3	-	-0.2	2.0
2008-2018	0.3	-4.2	2.6	1.9	-0.6	1.5

Source: Byrne and Corrado (2020).

There are also several bottom-up estimates of the measurement bias, derived from the industry level. For the United States, Byrne and Corrado (2020) find that, given that the share of digital services in total consumption was close to 2% over the period 1988-2018, the resulting aggregate bias would be 0.2 pp on PCE inflation (see Table 1, last column). However, since the inflation bias and the share of digital services in consumption have both increased over time, the effect on aggregate PCE was estimated to be close to 0.4 pp in the more recent period (see Table 1, period 2008-2018). Reinsdorf and Schreyer (2020) calculate that the maximum plausible overstatement of price changes in OECD countries due to underestimation of quality changes and cost savings from digital replacements amounted to around 0.7 and 0.6 pp in absolute value in 2005 and 2015, respectively.

2.5.1.2 Intermediate and capital ICT products

As regards investment and intermediate goods, empirical studies have focused on computers, communication equipment and software. The main measurement issues discussed in the literature relate to quality adjustment. Byrne and Corrado (2016) provide a complete picture of the amount of bias for high technology products (see Table 2). The gap between available official price indices and research price indices using more elaborate quality adjustment techniques are larger than 5 pp. For semiconductors, the gap is close to 15 pp (see Byrne, Oliner and Sichel, 2017). Byrne et al. (2013) documented biases of similar orders of magnitude. They concluded that the average bias in IT investment price indices is about 3 to 4 pp.

Table 2

US official and alternative research price indices for high-tech products

(average percentage change, 2004-2015)

	Official index	Alternative research index	Measurement gap (percentage points)
Computing equipment	-11.2	-18.9	7.7
Communications equipment	-2.4	-7.9	5.4
Software	-0.2	-7.0	6.8
Semiconductors	-15.5	-29.1	13.6

Source: Byrne et al. (2017).
Notes: Official indices for computing equipment, communications equipment and software are from the BEA. The official index for semiconductors is from the Bureau of Labor Statistics (BLS). Alternative research indices are from Byrne and Corrado (2016).

2.5.2 Does the mismeasurement of digital goods lead to a significant change in estimates of economic growth?

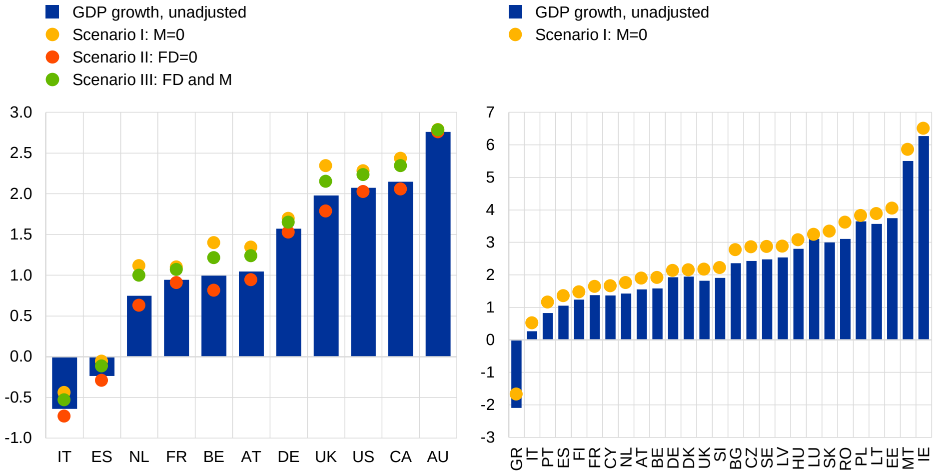
Overall, the mismeasurement of prices does not seem to translate into significant changes in recorded GDP growth. Groshen et al. (2017) calculate the impact of bias in four goods categories on real GDP growth for the United States. These four categories of goods account for about 3 to 4% of US GDP, and these biases would contribute to an overall negative bias of between -0.15 and -0.23 pp over the period 2010-2015. In addition, the contribution of consumption deflators estimated by Groshen et al. (2017) is close to 0.25 pp. The measurement bias due to digital technologies would contribute to an overestimation of the GDP deflator by 0.4 pp and so would underestimate real GDP growth by 0.4 pp. In a different exercise on French data, Aeberhardt et al. (2020) find that if prices were not adjusted for quality changes, inflation for ICT goods and services would be 7.5 pp higher. Since the share of ICT goods and services in total GDP is about 4.6%, the impact of a quality adjustment on the French GDP deflator would be close to 0.3 pp.

This seems to hold in spite of cross-country differences in price and volume developments in ICT products. Chart 8 shows the calculated impact on real GDP of potential mismeasurement of the prices of ICT products and services in the three scenarios assumed by Ahmad et al. (2017) for a subset of countries, and one of the scenarios (M=0) for the EU countries. As argued by Anderton et al. (2020b), “there are a broad range of impacts, with some scenarios generally finding that real GDP growth would have been higher for some countries after taking potential price mismeasurement into account, while other scenarios suggest real GDP growth could have been lower”. The results indicate that measurement errors in GDP growth could range from 0.1 to 0.5 pp per year for EU countries (the average across EU countries being around 0.3 pp), which is in line with estimates available in the literature.

Chart 8

GDP growth: estimated impact of using alternative measures of prices for ICT assets and communication products and services, 2010-2019

(percentages, average annual growth)



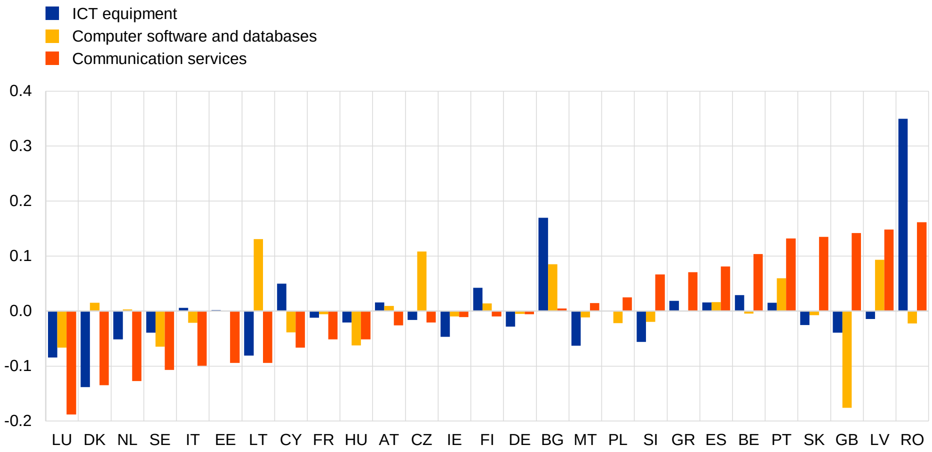
Sources: Ahmad et al. (2017) and ECB staff calculations.
Notes: M = imports; FD = final demand. The left panel shows results from Ahmad et al. (2017), The right panel shows results for all EU28 countries except Croatia calculated by the authors using “lower bound” price indices as defined in Annex 1 of Ahmad et al. (2017) applied to macro data (and not with supply and use tables). The impact of the alternative price measurement in the different scenarios is as follows: in Scenario I it only flows through to final demand, with imports unchanged; in Scenario II it only flows through to imported intermediate products, with final demand unchanged; in Scenario III it flows through to both imports and final demand. Latest observation: 2019 or latest year available.

There is considerable heterogeneity across EU countries. Investigating the same categories of product-level deflators as in Ahmad et al. (2017) (i.e. investment deflators of ICT equipment and computer software and databases, and consumption deflator of communication services), Anderton et al. (2020b) find considerable heterogeneity across EU countries (see Chart 9). Deviations from the mean deflator range from -0.2 pp to about +0.35 pp. Although the depicted divergences in ICT deflators across EU countries do not imply the existence of mismeasurement, they could be used as indicative upper and lower bounds of the possible scale of the potential mismeasurement of GDP growth caused by the potential mismeasurement of deflators.

Chart 9

ICT deflators

(2019; deviation from the mean; index: 2010=1)



Sources: Eurostat and ECB/NCB staff calculations.
Notes: The chart shows each country's deviation from the mean deflator value for all countries considered. Countries are sorted by the country's deviations from the mean deflator in consumption of communication services. Latest observation: 2019. For ICT equipment, the latest available data for BE, DK, ES, LV, PT, SE and SI are from 2018. For computer software and databases, the latest available data for BE, DE, ES, UK, HU, LU, NL, PT, SE, SI and SK are from 2018 and the latest available data for CY, DK, IE, LT, LV, PL and RO are from 2017. For communication services, the latest available data for BE, BG and SE are from 2018 and the latest available data for GR are from 2017. Data for HR are not available.

2.5.3 Does the mismeasurement of digital goods explain the productivity puzzle?

Digitalisation-related measurement issues have been suspected of accounting for the observed slowdown in productivity across advanced economies in recent years. Brynjolfsson and McAfee (2014) argue that since official statistics (i) fail to fully capture quality improvements in new ICT goods and services, (ii) ignore the benefits to consumers from freely available products (e.g. digital photos, social media and online encyclopaedias) and (iii) cannot adequately keep up with the rapid changes in prices owing to the accelerating pace of change in quality and specifications, standard growth accounting effectively overestimates inflation and thus underestimates output volume growth. More recent studies examining the slowdown in GDP and productivity growth since the global financial crisis, such as Cette and de Pommerol (2018), ask whether this drop could be partly explained by an underestimation of the fall in ICT prices.

The empirical literature, however, suggests that the estimates are too small to explain all the productivity slowdown (measured as labour productivity or TFP). For instance, Ahmad et al. (2017) conclude that "even if suspected mismeasurement is occurring, it is not of sufficient scale, at least for now, to significantly depress measured GDP growth or multi-factor productivity growth, nor to explain the recent, near-global slowdown in productivity and GDP growth". Their upper bound estimates of measurement error based on strong assumptions "point to upward revisions [to GDP growth] of around 0.2% per annum in most economies" for the period 2010-2015. Byrne et al. (2017) confirm that the contribution of mismeasurement to the slowdown of productivity is limited. As concluded by Byrne and Sichel (2017), "switching from official price measures to the alternative research series has relatively little effect on the pattern of labour productivity growth over time, as well as the contributions from capital deepening and multi factor productivity (MFP)".

Furthermore, the estimated measurement bias did not increase sufficiently over time to explain the large productivity slowdown. Syverson (2017) suggests that measurement problems have so far not become more problematic over time. Byrne, Fernald and Reinsdorf (2016) note that mismeasurement of IT hardware existed before the productivity slowdown and the measurement issues had not worsened since the early 2000s. In their analysis they correct for the large measurement issues of digital products by using consistent measurement of quality adjusted prices for computers and communication equipment, as well as judgemental corrections to prices of specialised information processing equipment and software and apply a broad measure of intangible investment. As a result, they find that the picture of productivity becomes more plausible, but still cannot fully explain the productivity slowdown.

Finally, the link between the productivity slowdown and ICT intensity appears to be too weak. According to Syverson (2017), there is no link between the productivity slowdown and ICT intensity (see also Cardarelli and Lusinyan, 2015, for US evidence based on differences across states) and there is a large difference between the moderate consumer surplus linked to the internet and the large missing growth that it would imply.

2.5.4 Does it matter more for welfare issues than for GDP measures?

While GDP is a measure of production in the economy, welfare has a broader definition, and its analysis may have different perspectives when done by economists or social, health or environmental scientists. In the field of economics, it specifically refers to utility derived through the consumption of goods and services. In other words, it refers to that part of social welfare that can be fulfilled through economic activity. The distinction between GDP and welfare is quite clear – while the former is central to the national accounts, the latter has many dimensions, most of which are not easily expressed in monetary terms (Blanchet et al., 2018; Brynjolfsson, Collis, Diewert, Eggers and Fox, 2018). Overall, the national accounts framework and its major aggregates are not designed to measure changes in welfare or well-being. These can be developed in the form of a satellite account (see Box 9 in the Appendix).

The implications of digitalisation may be greater for welfare than for GDP. Reinsdorf (2020) defines three sources of unmeasured welfare growth from digitalisation – new free products, the shift from market consumption to home production, and access to more and new varieties. He also notes that the rapid uptake and intensive use of digital services and devices suggest that they generate substantial welfare gains.

Digitalisation may lead to welfare enhancements that by definition are not captured by GDP, for example through free products. Syverson (2017) argues that the price of free products is included via its impact on the prices of complementary products. He also notes that digitalisation (and the productivity slowdown) has led to a GDP-welfare disconnect, although this is not a recent phenomenon. For the United States, he has estimated that if the surplus (the largest estimate being USD 863 billion) was somehow captured in GDP – which is not typically the case – it would still fall considerably short of making up for the GDP lost through the productivity slowdown. On the other hand, while "free" digital services are captured in the national accounts, the distributional aspects might be missing, e.g. the user who purchases the service might not be the final user, which poses difficulties for the volume estimates and consequently for the implicit deflators.

Another important dimension of welfare gains from digitalisation that is beyond the scope of the GDP is the shift between market and household production. Some services that households used to pay for in the market have become "do-it-yourself" services (travel agencies, film developing, open access courses, etc.). This can reduce the monetary cost of a service and potentially increase the quality of the service (access to a much broader variety of services/goods) and so improves the level of welfare by replacing traditional non-household market production by non-market household production. This growing contribution of households to the final production of well-being would seem to be the opposite of the development observed in the period when GDP growth was partly driven by the transfer to the market of activities that were originally domestic activities (Coyle, 2017).

The access to a much wider choice of product varieties is also a major source of welfare gains coming from digitalisation. These gains come from the introduction of new varieties of goods/services that did not previously exist or the replacement of existing goods by new ones. Aghion et al. (2018 and 2019) estimate that the missing growth due to mismeasurement of prices of new goods is about 0.7 pp for the United States and 0.4 pp in France (see Blanchet et al., 2018, for a discussion from the point of view of national accounts). Dolfen et al. (2019) estimate the US consumer surplus derived from a better selection of varieties online and find an overall effect on household consumption growth of 0.05 pp per year over the recent period. However, the resulting welfare gains from accessing new varieties rely on uncertain assumptions about elasticities of substitutions and on modelling assumptions about consumer utility.

3 Digitalisation and productivity[47]

Digital technologies are pervasive across all sectors of the economy. Adoption of these technologies promised large productivity gains through various channels: improved process efficiency, better complementarity between workers and capital and higher rates of automation and robotisation. Such growth, however, has proven elusive. This chapter begins with an overview of the productivity puzzle, the fact that, despite the rapid growth in digital technologies, aggregate productivity growth has decreased in most advanced economies since the 1970s, with the notable exception of the United States between 1995 and 2005. At the global level, the productivity gains induced by digitalisation are still low, but it is likely that, without the digital innovation, the productivity slowdown would have been even more pronounced. Growth accounting decompositions suggest that it is the declining TFP contribution, rather than the ICT capital and robot contributions, which is the main factor behind the productivity slowdown. Accordingly, as TFP is a residual, growth accounting decompositions do not yet really explain the productivity slowdown. The chapter then discusses micro and macro channels through which digitalisation affects growth and considers conditions under which the full productivity potential of digitalisation can be realised. Speeding up the adoption, diffusion and full operationalisation of digital technologies is key, as it is currently too slow and may have delayed a new wave of potential productivity growth. This requires the factors contributing to this slow diffusion, such as resource misallocation, inadequate economic institutions, skill shortages and insufficient infrastructure to be addressed. Firms' organisational capital and management practices are also important factors in reorganising production and fully reaping the benefits of new digital technologies, which partly explains cross-country productivity divergences across the euro area. This is a major challenge for European countries, which on average are lagging behind the United States in terms of digitalisation. The chapter also offers some insights on the future impact of digitalisation on productivity.

3.1 Introduction

Digitalisation is a broad phenomenon involving many different technologies and applications. Adoption of digital technologies had promised, in theory, large productivity gains through various channels. However, in spite of the rapid growth in the quality of ICT-based goods and services, aggregate productivity growth in most advanced economies has decreased since the 1970s and has been essentially stagnant since the mid-2000s, with the notable exception of the United States

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[47] This chapter has been prepared by Sofia Anyfantaki, Antonin Bergeaud, Gilbert Cette and Filippos Petroulakis. It has benefited from comments from Robert Anderton, Gilbert Cette, Hanna Freystatter, Valerie Jarvis, Vincent Labhard, Oke Röhe and Patrick Schulte. For an earlier analysis of digitalisation and productivity, see also Anderton et al. (2020a and 2020b). For a discussion of technical change in a broader sense and implications for productivity, see Work stream on productivity, innovation and technological progress (2021).

between 1995 and 2005. This “productivity puzzle” is the subject of various investigations, and many possible explanations have been suggested.

Digital technologies are at the core of the “fourth industrial revolution”. In many ways, the latter comes hot on the heels of the third industrial revolution, which saw the development of ICTs, which are the bedrock of digital technologies. Therefore, one cannot analyse the impact of digitalisation on growth without considering ICT.

The literature forecasts two antithetical scenarios for the future of productivity growth. The first is a secular stagnation scenario, discussed in Gordon (2012), which assumes that technologies of the third and fourth industrial revolution are not impactful enough to overcome the numerous headwinds that advanced economies are facing. This has resulted in a low productivity growth rate for a prolonged period. The second, technologically-optimistic, scenario posits that artificial intelligence (AI) and other digital technologies will ultimately deliver their full effect on productivity. As discussed by Cette et al. (2016a), both scenarios are in principle possible. In order to understand their potential relevance, it is necessary to investigate the various channels through which digitalisation affects productivity. This is the main purpose of this chapter.

The literature generally acknowledges that, although digital technology adoption generates productivity gains at the micro level, aggregate effects may be slow to materialise and depend on policy choices. Hence, given the uncertainty about the future path of productivity and the recent weak productivity performance, policymakers should (a) exploit the numerous sources of productivity growth, (b) adequately adapt their institutions and policies in order to facilitate the diffusion of existing technologies, and (c) encourage research targeted at breakthroughs in innovation.

The COVID-19 crisis, in addition to its substantial impact and varied effects on public health and the real economy, could force firms to accelerate their adoption of new technologies. One obvious step is the development of teleworking and teleconferencing modalities. The crisis has also highlighted new practices that could have significant effects on productivity and growth in the long run: a rapid increase in online sales and online banking, the development of new management skills, online learning, and, finally, a more efficient diagnosis and tracking system for the health sector.

The structure of this chapter is as follows: Section 3.2 explores the productivity puzzle: the fact that productivity growth remains low in most advanced economies, while ICTs and, more generally, digital technologies are pervasive; Section 3.3 reviews the micro and macro channels through which digitalisation affects growth; Section 3.4 considers the conditions for a full productivity benefit from ICT and digitalisation; Section 3.5 concludes and looks at the future impact of digitalisation on productivity.

3.2 The productivity puzzle

3.2.1 Productivity slowdown in all developed countries

Productivity growth has been slowing in all advanced economies since the 1970s (see Table 3) and has fallen to below 1% per year since the mid-2000s (ECB, 2017). Despite a notable slowdown in the United States during this period, Europe has typically lagged substantially behind the United States in terms of labour productivity growth. The prevalence of the slowdown across all advanced countries has led economists to look for a common underlying force that could explain the global slowdown in productivity in order to better understand this productivity puzzle. In the euro area,[48] labour productivity (LP) growth has declined from an average annual rate of 5.4% in the period 1950-1975, to 2.7% in 1975-1995, 1.2% in 1995-2005, and only 0.7% since 2005. The period following World War II was an exceptional period for productivity growth, fuelled by post-war investment and restructuring which favoured the diffusion and adoption of the new technologies of that period. Since 1975, LP growth has steadily declined in the euro area.

As shown in Chart 10 and Table 3, the recent period has been characterised by very low productivity gains in most countries, compared to long-run averages. Productivity growth rates are now at their lowest level in 150 years (outside periods of war). The global financial crisis could have had a negative effect on growth owing to a temporary tightening of credit constraints that could in turn have a persistent negative effect on growth (Liu and Wang, 2014). In addition, the Great Recession may have slowed technology adoption (Anzoategui et al., 2019; Bianchi et al., 2019; Schmöller and Spitzer, 2020). However, analysis has shown that structural factors are also at play, which led to a significant downward break in productivity that predated the global financial crisis (Fernald et al., 2017).

The productivity slowdown observed since the 1970s seems particularly surprising in the light of the rapid rate of innovation in ICT producing sectors, as well as in digital services. The next section reviews the literature on the causes of the slowdown. At the same time, it should be noted that the large productivity gains observed during the first and second industrial revolutions were mostly concentrated in agriculture and manufacturing. Since the relative importance of these sectors has declined substantially, only a technological revolution that also affects the productivity of the services sector, which is generally lower, can have sizeable effects (Baumol, 1967; Crafts, 2011; Oulton, 2016).

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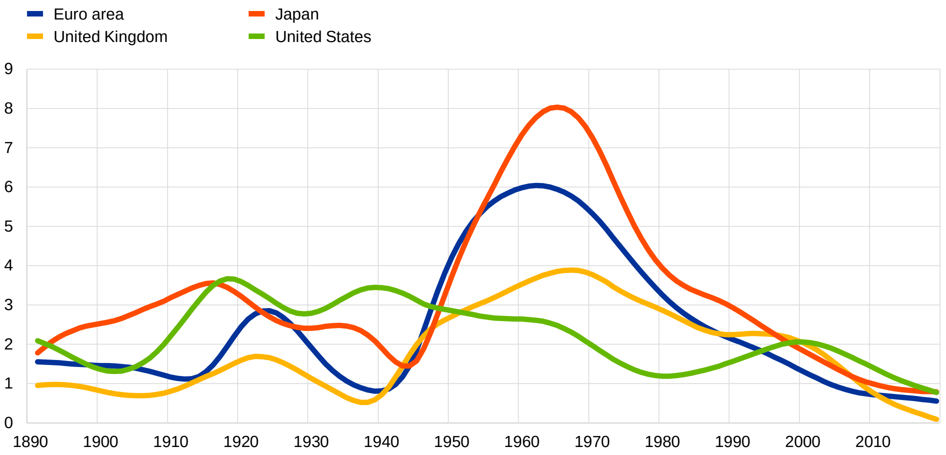
[48] Taken as the aggregate of 11 euro area countries (see Bergeaud et al., 2016).

Chart 10

Average annual growth rate of labour productivity (GDP per hour worked)

(percentages, smoothed indicator, HP filter, λ = 500, whole economy, 1891-2019)



Sources: Banque de France Long-Term Productivity Database and Bergeaud et al. (2016).

Table 3

Average hourly labour productivity growth for selected periods and countries[49]

(GDP per hour worked, annual percentage changes)

	1890-1913	1913-1950	1950-1975	1975-1995	1995-2005	2005-2013	2013-2019
Germany	1.87	0.2	5.78	2.91	1.71	0.6	0.67
Spain	1.1	0.29	6	3.21	-0.52	1.62	0.19
France	1.84	1.79	5.35	2.7	1.87	0.55	0.81
United Kingdom	0.78	1.35	3.29	2.67	2.19	0.46	0.44
Italy	1.54	2.56	6	2.66	0.51	0.07	-0.04

Sources: Banque de France Long-Term Productivity Database and Bergeaud et al. (2016).

3.2.2 Competing explanations for the slowdown in productivity

GDP growth is the sum of the growth of labour productivity and aggregate hours worked. The former can itself be decomposed into capital deepening (the ratio of capital to labour) and TFP. The stock of capital can further be split into different asset categories, including ICT and robots. In a recent exercise, Cette et al. (2020a) performed such an accounting decomposition of GDP for the period 1960-2019. Their results show that the productivity slowdown in advanced countries since the 1970s is mainly explained by a decrease in the contributions of the non-ICT and non-robot components in the capital deepening and the TFP productivity channels (see Chart 11; for the full growth accounting decompositions for the euro area and United States, see Tables 4A and 4B).[50]

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[49] These periods have been chosen to capture global cycles (see Bergeaud et al., 2016).

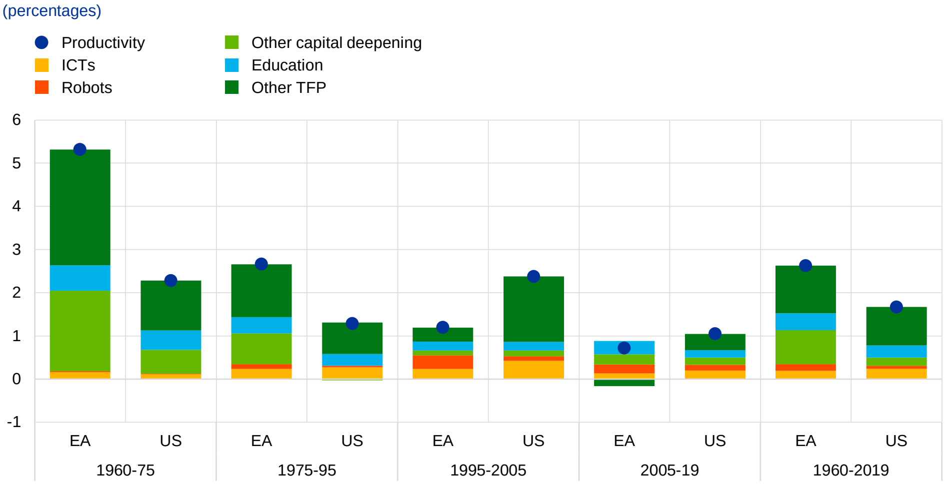
[50] The same result is observed for the 30 developed countries in that analysis.

The slowdown could correspond to an exhaustion of the favourable impact of the second industrial revolution as explained by Bergeaud et al. (2018). The digital revolution and third industrial revolution, of which ICTs and robotisation, among others, are central elements, are not yet the source of a productivity revival, even if they could be expected to make a large contribution to productivity growth, as is shown by firm-level data analyses (see below).

Many potential explanations have been investigated to explain the slowdown in productivity. Particular attention has been paid to the diminishing impact of ICT on growth, and the as yet unobserved effect of digital technologies (see Cette, 2014, for a detailed review). Is low productivity growth the new normal? Is it the result of a measurement error, decreasing competition or increasing misallocation?

Chart 11

Euro area and US productivity: growth accounting decomposition



Source: Cette, Devillard and Spieza (2020).

Table 4a

Growth accounting decomposition – United States

GDP growth (percentages) and contributions (pp)	Period 1		Period 2		Period 3		Period 4		Period 5	
United States	**1960**	**1975**	**1975**	**1995**	**1995**	**2005**	**2005**	**2019**	**1960**	**2019**
GDP (1)		3.66		3.16		3.39		1.76		2.99
Hours (2)		1.38		1.88		1.01		0.71		1.33
Productivity (3) = (1)-(2)		2.28		1.29		2.38		1.05		1.67
Capital deepening (4)		0.67		0.25		0.58		0.40		0.45
ICT capital total (5) = (6)+(7)+(8)		0.12		0.33		0.59		0.35		0.32
Hardware (6)		0.05		0.17		0.28		0.12		0.15
Software and databases (7)		0.03		0.09		0.19		0.16		0.11
Telecommunications equipment (8)		0.04		0.07		0.12		0.07		0.07
Robots (9)		0.00		0.01		0.03		0.03		0.02
Non-ICT capital and non-robot capital (10) = (4)-(5)-(9)		0.55		-0.08		-0.03		0.01		0.11
TFP (11) = (3)-(4)		1.61		1.03		1.79		0.65		1.22
Education (12)		0.45		0.27		0.20		0.17		0.28
Robotisation (13)		0.01		0.03		0.08		0.10		0.05

Source: Cette et al. (2020).

Table 4b

Growth accounting decomposition – euro area

GDP growth (percentages and contributions (pp)	Period 1		Period 2		Period 3		Period 4		Period 5	
Euro area	**1960**	**1975**	**1975**	**1995**	**1995**	**2005**	**2005**	**2019**	**1960**	**2019**
GDP (1)		4.60		2.44		2.12		1.09		2.61
Hours (2)		-0.71		-0.22		0.93		0.37		-0.01
Productivity (3) = (1)-(2)		5.31		2.66		1.19		0.72		2.63
Capital deepening (4)		2.03		0.97		0.43		0.42		1.02
ICT capital total (5) = (6)+(7)+(8)		0.17		0.27		0.34		0.23		0.25
Hardware (6)		0.10		0.13		0.15		0.07		0.11
Software and databases (7)		0.03		0.10		0.14		0.13		0.09
Telecommunications equipment (8)		0.04		0.04		0.06		0.03		0.04
Robots (9)		0.00		0.03		0.08		0.05		0.04
Non-ICT capital and non-robot capital (10) = (4)-(5)-(9)		1.86		0.67		0.01		0.14		0.73
TFP (11) = (3)-(4)		3.28		1.69		0.77		0.30		1.61
Education (12)		0.59		0.38		0.21		0.31		0.39
Robotisation (13)		0.01		0.09		0.24		0.15		0.12

Source: Cette et al. (2020).

Gordon (2012 and 2015) develops a pessimistic view on the future of growth and secular stagnation. He hypothesises that the recent slowdown is a permanent phenomenon, and that the disappointing productivity impact of digital technologies and ICT simply reflects the fact that computerisation is a far less significant technological change than electrification. In addition, he argues, even if potentially promising digital innovations could be found in the future, they are unlikely to deliver significant productivity gains, as economies face major headwinds (such as population ageing, climate sustainability and the need to reduce public debt).

In a similar vein, Jones (2009) and Bloom et al. (2020) suggest that new ideas are simply harder to find and that developing impactful new technologies would be too costly given the decreasing returns on R&D investments. Fernald and Jones (2014) argue that this trend is not so clear given the rise of emerging economies, such as China and India, with large investments in R&D and a large supply of researchers, or even digitalisation itself, in particular AI that could reduce the cost of developing new ideas (see Aghion et al., 2017; Cockburn et al., 2018). This argument is also subject to a more general objection (Aghion and Howitt,1992 and 2009): while in one technological paradigm there are decreasing returns on R&D, a change of paradigm and its creative destruction mechanisms re-initialises the process. The first R&D spending under the new paradigm thus has higher returns than the last R&D spending under the previous paradigm. As such, we should expect high returns on R&D spending in the new digital era, digitalisation corresponding to a change of technological paradigm. The question thus moves from the decreasing R&D return problem to the fact that the digital technology new paradigm appears to be taking time to become visible.

Economists have also considered the possibility that the productivity gains from ICT and digital goods and services are mismeasured. They argue that standard indicators of the size of the economy, such as GDP, underestimate productivity gains because they fail to adequately incorporate the effects of these new technologies. In the case of digital services, one difficulty is that new services are often ostensibly “free” to the user (who often pays by providing private data) and are therefore essentially ignored by national statistics (see Brynjolfsson and McAfee, 2014, and Reinsdorf and Schreyer, 2020, for a review, and Chapter 2 of this report). In addition, the rapid rate of innovation in these new technologies, if accompanied by a higher productivity turnover rate, could lead to biased measures of price indices (Aghion et al., 2019a). However, most quantitative analyses aimed at correcting for these biases conclude that this explanation alone is not enough to explain the productivity slowdown (see Syverson, 2017; and Byrne et al., 2016).[51] See the chapter on digitalisation and price measurement for more detail.

A more subtle explanation of mismeasurement combines implementation lags and the mismeasurement of intangible assets. This idea has been put forward by Brynjolfsson, Rock and Syverson (2018), who argue that, given that intangible assets are used as inputs in and are also outputs of the production process, their inherent mismeasurement problem will give rise to underestimation of productivity gains initially and overestimation later. According to this hypothesis, we may currently be in a stage of underestimation.

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[51] For an overview of measurement issues relating to digitalisation, see Box 2 in Anderton et al. (2020b).

Another possible explanation for the slowdown is the fact that ICT diffusion has disproportionally benefited larger and more productive firms that successfully invested in both intangible and human capital. These firms subsequently became “superstars” (Autor et al., 2020), leading to rising market concentration and distorted competition, which could ultimately discourage innovation and the adoption of new technologies (see Bergeaud, 2019, for a review). Even if these ideas are successful in explaining macroeconomic trends observed in the United States (Akcigit and Ates, 2019; Aghion et al., 2019b; Farhi and Gurio, 2018), studies of European countries suggest more mixed evidence about increasing concentration and market power (Gutiérrez and Philippon, 2017; Döttling et al., 2017; Cavalleri et al., 2019). Other investigations have considered the role of production factor misallocation (Cette et al., 2016b; Gopinath et al., 2017) and, in particular, the fact that financial constraints in the pre-global financial crisis era hindered capital flows to the most efficient firms, especially in southern European countries. This trend has not reversed yet (Gamberoni et al., 2016).

A number of additional explanations have been considered. Although they are not always directly related to the impact of digitalisation and ICT, they can alter the vectors through which these technologies could affect productivity. For example, education duration seems to have reached a plateau and economies are characterised by a skills mismatch, revealing an imbalance between the supply of and demand for skills (Zago, 2020). Such labour market frictions may generate a persistent drag on productivity growth. Another body of work considers the role of the secular decline in real interest rates in explaining the productivity slowdown. Such a decline is the result of various structural drivers, such as demographic change, but also technology (Basso and Jimeno, 2021). Lower real interest rates would have weaker cleansing mechanisms, resulting in increased factor misallocation and a productivity slowdown at the global level (Bergeaud et al., 2019; Liu et al., 2019).

3.2.3 Some stylised facts regarding the productivity slowdown

While the search for a universally accepted reason for the productivity slowdown is not yet conclusive, a number of stylised facts regarding ICT/digital technologies and productivity have been established by the literature. At the microeconomic level, these can be summarised as follows: (i) ICT now acts as a major driver of productivity trends; (ii) a small number of firms have benefited strongly from these new technologies, but most firms have had only moderate productivity gains; and (iii) ICT/digital adoption is still very low, especially among small and medium-sized enterprises (SMEs).

At the macroeconomic level, Bergeaud et al. (2017 and 2018) show that ICT adoption, as measured by the ratio of investment to value added, has played a significant role in explaining productivity growth in OECD countries since the 1970s. Therefore, differences in the adoption of the underlying technologies (software, computers and communications equipment; see Cette et al., 2015) are responsible for a large share of the observed productivity differentials across countries. In particular, Bloom et al. (2012) and Fernald (2015) show that IT-intensive sectors are responsible for the wave of productivity growth observed in the United States, but not experienced in European countries, in the period from 1995 to 2004. Bloom et al. (2012) also argue that management sophistication is crucial to exploiting the opportunities that ICT offers.

Heterogeneity in the adoption and use of ICT technologies is also substantial across sectors within the same country, as shown by Pilat and Lee (2001) and Cette et al. (2017), a phenomenon stretching back to at least the late 1990s. Such differences have been linked to educational disparities, to labour and product market rigidities (Cette and Lopez, 2012) and even to demography (Acemoglu and Restrepo, 2020a). Andrews et al. (2018) relate the dispersion of digital adoption to differences in absorptive capacities and incentives across countries, sectors and firms. DeStefano et al. (2017), who exploit establishment-level data containing detailed information on hardware and software usage for roughly 250,000 entities across 19 countries from 2000 to 2012, document a shift away from physically owning ICT towards renting hardware and cloud computing. For software, results are more heterogeneous across countries. At the firm level, various reports (Abel-Koch et al., 2019; e.g. EIB, 2019) indicate considerable under-investment in digital technologies by SMEs. The structure of the economy may also lead to different aggregate effects of digital technologies on productivity.

Findings by Andrews et al. (2016) and Cette et al. (2018) suggest that frontier firms did not experience a slowdown in productivity, unlike the rest of the economy.[52] This suggests evidence of a diffusion problem and of significant obstacles preventing most of the laggard firms from adopting innovations that are already well-known. This would increase factor misallocation, which could itself be explained by previously discussed related causes common to all developed countries.

3.2.4 Delayed impact of technological revolutions

Long lags between implementation and diffusion of ICT and digitalisation could explain why these technologies have not yet realised their full productivity potential. Lessons from history show that the lag between the invention of a new general purpose technology (GPT) and its impact in the form of large productivity gains can be very long (see David, 1990, in the case of the dynamo). This time lag corresponds to the time needed for the development of new physical and organisational infrastructure and skills, which can considerably slow down the intensive margin of the diffusion of new technologies. Another insight from past industrial revolutions is that productivity waves may happen in two steps. This was, for example, the case in the first industrial revolution in the 19th century (Crafts, 2011).

While it has been established that the contribution of existing ICTs (mainly computers) to growth has declined in developed countries (Cette, 2014; Cette et al., 2020), AI and other nascent digital technologies could still generate a second wave of productivity growth in the near future. In this respect,

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[52] See also Work stream on productivity, innovation and technological progress (2021).

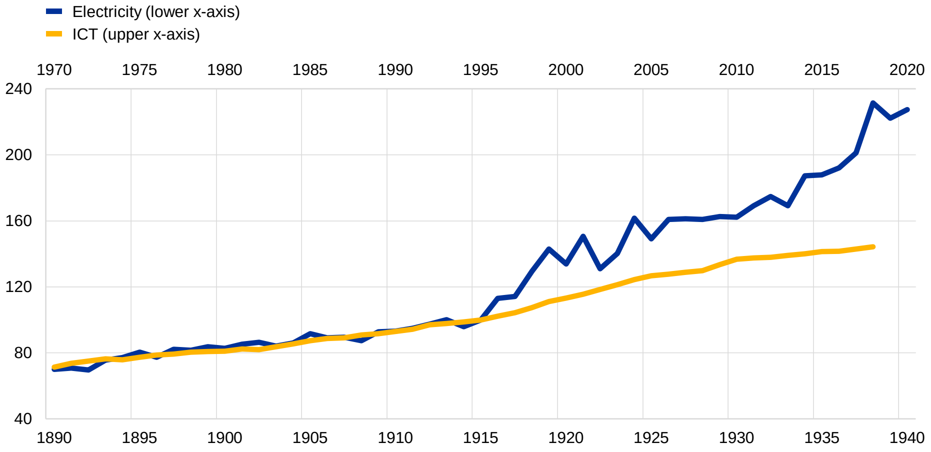
techno-optimists, such as Brynjolfsson, Rock and Syverson (2018), note that the evolution of labour productivity from 1995 until today is very similar to what it was after 1915, i.e. a few decades before the big wave of productivity fuelled by the second industrial revolution. This observation suggests a regular pattern in the impact of GPT on productivity throughout history: it takes many years for the economy to adapt and for a GPT to be sufficiently diffused to generate large productivity gains.

Hence, a number of techno-optimists argue that the current slowdown simply reflects the fact that we are still in the installation phase of ICT (van Ark, 2016) and that the new wave of productivity growth is near (Brynjolfsson and McAfee, 2014). To illustrate the slow materialisation of the impact of GPT on productivity growth, Chart 12 reproduces an exercise from Brynjolfsson et al. (2019). This compares the evolution of productivity over two different periods corresponding to the diffusion of electricity (1890-1940) and ICT (1970-2020).

Chart 12

Productivity growth from two GPTs

(labour productivity; for electricity, 1915 = 100; for ICT, 1995 = 100)



Sources: Banque de France Long-Term Productivity Database, Bergeaud et al. (2016) and ECB staff calculations.
Note: Updated from original.

3.3 The channels of the impact of digitalisation on productivity

3.3.1 The different channels of the labour productivity impact at the macro level

In a simple but useful decomposition, the growth rate of labour productivity can be expressed as a linear combination of the growth rate of TFP and the growth rate of the capital to labour ratio (capital deepening).[53] Theoretically, the impact

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[53] A final element is the growth of human capital, from which we abstract.

of a GPT on labour productivity can be through either TFP or capital deepening. The impact on TFP is, in turn, twofold (Wolff, 1991).

- **First, the development of innovations positively affects TFP in ICT producing sectors.** Fernald (2015) and Aghion et al. (2019b) show that ICT-producing sectors in the United States experienced a very large wave of productivity growth during the 1990s. However, their relatively small size in the overall economy resulted in an average contribution that remained limited. Byrne et al. (2013) estimated this contribution to labour productivity gains in the United States at an average of 0.72 percentage points per year over the decade from 1995 to 2004, when it reached its highest level. It has since declined to a lower trend that they attribute to the offshoring of large segments of the ICT production chain outside the United States.

- **The second TFP effect is through a spillover/externality effect (or a network effect).** For example, in the case of ICT, the adoption of new communication technology by a large number of firms had clear amplifying effects on overall productivity growth. The massive adoption of a new communication technology also facilitates the development of skills in the economy that are complementary to the new capital and thus reduce the cost of training.

The capital deepening effect mainly stems from a decrease in the quality-adjusted price of capital equipment as technology advances. Firms using ICT derive productivity gains by increasing their capital-labour ratio without changing their planned investment expenditure. This capital-deepening effect has been decreasing since 2004 in the United States, and even earlier for some European countries.

It is important to note that these various channels are hard to disentangle from one another in practice. Separating the TFP and capital deepening effects requires precise estimation of the quality-adjusted investment prices. These estimates, however, are quite fragile (in the sense that they differ across sources), in particular in the case of ICT, which is often encompassed in different types of investments (e.g. an automated robot), as explained by Cette et al. (2019). For this reason, it is usually more relevant to consider the impact of digitalisation on productivity in terms of labour productivity as a whole, which reflects an aggregation of these two effects (TFP and capital deepening).

3.3.2 Microeconomic mechanisms

Looking more closely at how ICT and digital technologies can boost productivity at the firm level can shed light on the macroeconomic mechanism. In theory, the development and diffusion of these technologies might have many effects: for instance, they boost workers’ efficiency by complementing their tasks (Gal et al., 2019); they allow the opportunity to grow quickly and achieve scale without mass (Haskel and Westlake, 2017); and they increase competitiveness and market size through the potential of e-commerce (Albani et al., 2019).

Information (IT) and communication (CT) technologies are usually treated jointly but may not have similar effects. Bloom et al. (2014) show that better IT (in particular, better enterprise resource planning) is associated with more autonomy and a wider span of control. Meanwhile, technologies that improve communication decrease autonomy for workers and plant managers. These effects can account for a significant, although hard to quantify, part of the reason why differences in ICT adoption can explain productivity divergence between countries. Malgouyres et al. (2019) highlight an additional mechanism: using the adoption of broadband internet in France, they show that this technological shock resulted in an increase in firm productivity as a result of the ability to access wider choices of import goods.

Recent literature has looked at robots as a specific case of a technology that raises firm-level capital intensity.[54] This mechanically increases labour productivity but also TFP through the spillover channel. Robots (and automation in general) are not ICT per se, but they usually include many electronic components and require various digital technologies to work. At the country level, Cette et al. (2020a) show that the contribution of robots to productivity growth through the capital deepening and TFP channels appears to be significant for the period 1975-1995 in the two most robotised countries, Germany and Japan, for 1995-2005 in France and Italy, and from 2005 onwards in several other countries, mainly those which were not market economies before 1990 (see Chart 13).

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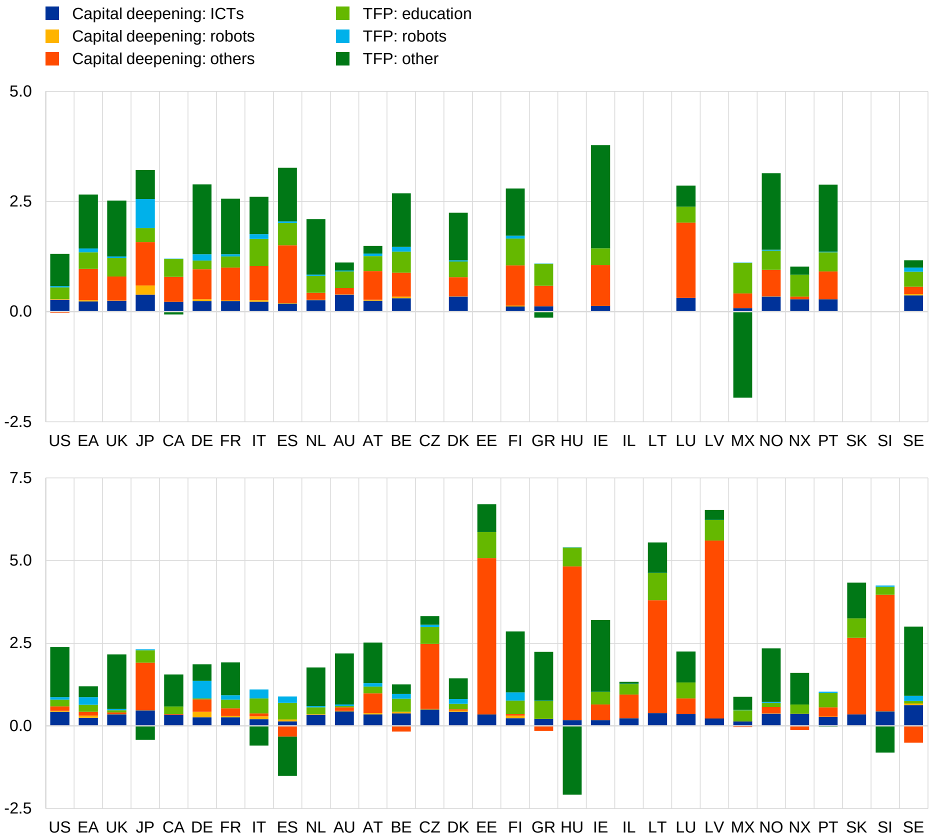
[54] See Acemoglu and Restrepo (2017), Dauth et al. (2017), Graetz and Michaels (2018) and Aghion et al. (2021).

Chart 13
Decomposition of hourly labour productivity

(annual percentage changes and percentage point contributions; upper panel: 1975-1995; lower panel: 1995-2005)



Source: Cette et al. (2020a).

A number of studies have estimated the impact of ICT and digitalisation on firm-level productivity (see Gal et al., 2019 for a detailed review of this literature). This requires microdata on technology adoption and firm-level performance. Although these data are not systematically collected by administrative authorities[55], various sources have been used in the literature.

Empirical results from firm-level studies seem to converge towards a net positive effect of ICT investment on value added. For example, Dhyne et al. (2018) report that, on average, investing an additional €1.00 in IT increases value added by €1.38, albeit with large variations according to firm size. Hall et al. (2013) and Castiglione (2012) both use a survey of manufacturing firms in Italy to show that ICT has a positive impact on productivity and innovation.

Taking advantage of an original firm-level survey conducted by the Banque de France, Cette et al. (2020b) empirically investigate the impact of the employment of ICT specialists (in-house and external) and the use of digital

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[55] However, the use of firm-to-firm datasets reporting VAT transactions can provide direct information regarding (domestic) purchases from IT-producing firms. See Dhyne et al. (2018) for an example using Belgian data.

technologies (cloud and big data) on firm productivity and labour shares. The results point to a large effect: all other things being equal, the employment of ICT specialists and the use of digital technologies would improve a firm's labour productivity by about 23% and its TFP by about 17% compared to firms that do not use ICT.

By contrast, other studies find more limited direct effects of these technologies on productivity at a micro level. Acemoglu et al. (2014) show that ICT has no effect on labour productivity in US manufacturing sectors except ICT-producing sectors. Bartelsman et al. (2017) find no positive effect of ICT adoption at firm level but do report positive effects on aggregate productivity as a result of externalities. DeStefano et al. (2018) show that broadband internet access in the United Kingdom affects firms' size but not their productivity, in contrast to evidence from France.

3.4 Conditions for a full productivity benefit from ICT and digitalisation

The fact that firm-level evidence is not conclusive could reflect an important empirical challenge in estimating the effect of digitalisation or ICT adoption on productivity growth (Gal et al., 2019). This challenge comes from the fact that digital technology adoption translates into productivity through a combination of numerous other factors. ICT requires, to a much larger extent than physical capital, a complex input of labour and managerial and organisational capital to operate efficiently.[56] Bresnahan et al. (2002) point out that "firms do not simply plug in computers or telecommunications equipment and achieve service quality or efficiency gains". Recent research has shown that managerial quality, in particular, is extremely important in driving productivity differences across firms (Bloom et al., 2012); indeed, managerial practices can be vastly different even across establishments of the same firm (Bloom et al., 2019).

Regarding human capital, it has long been established that firms will adopt new technologies if their workers possess the necessary skills to use them in the production process. To develop this technology-specific human capital, firms may need to train existing workers, hire new skilled workers and enhance managerial capacities. This interplay between new technologies and firm capabilities determines both the rate of adoption of technologies, but also their productivity effects.

The European SME Survey[57] conducted by national public development banks highlights a lack of digital skills as one of the main obstacles to the adoption of new technologies by SMEs. This factor could explain the observed lack of adoption of new digital technologies by smaller firms highlighted in OECD (2017). For example, EIB (2020) reports that only 66% of European manufacturing firms have adopted at least one digital technology, compared to 78% in the United States, a gap that is

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[56] See Chapter 4 for a further discussion on these topics.

[57] Abel-Koch et al. (2019)

driven in particular by a very low adoption rate among old small firms. The difference between the United States and the EU is even larger in the construction sector owing to a delay in the adoption of drones and the Internet of Things in the EU. On top of skills shortages, SMEs also report a barrier to investment owing to the lack of appropriate infrastructure, business regulations and financing difficulties.

Cette and Lopez (2012) and Cette et al. (2017) have linked the slow diffusion of ICT and digital technologies to poorly adapted institutions and, in particular, to the existence of regulations that penalise innovation and the adoption of new technologies. Firms are therefore reluctant to make the necessary investment owing to the burden of red tape (see Aghion et al., 2021, for a review and an example of the negative impact of regulations on innovation).

Institutional adaptation is required in order to reap the full productivity benefit of digitalisation. Institutional arrangements have an impact not only on the diffusion of technologies but also on the way new technologies affect productivity. Acemoglu et al. (2006) emphasised the need to adapt the formation of human capital to the level of technology of an economy. The diffusion of innovation and technologies is also facilitated by greater trade openness and participation in global value chains as well as by the proper functioning of financial markets. In addition, there may be a need for specialised equity financing for intangible investments, which are of central importance in the digital economy but remain hard to collateralise and hence are not suitable for traditional bank-based lending (Haskel and Westlake, 2017). Furthermore, anti-competitive product market regulations are associated with lower rates of adoption and innovation.

Institutional frictions in particular have been singled out as a cause of low growth in Southern Europe. For Italy, Pellegrino and Zingales (2019) show that a range of institutional features, even informal ones, can account for the particularly low productivity growth. Nepotism and cronyism have been shown to be serious impediments to economic development, in particular through their effects on management quality. Schivardi and Schmitz (2018) show that such differences can partially account for differences in productivity growth across European countries.

Regarding labour market regulations, the effect is more ambiguous. While overly protective employment regulations have been shown to deter firm innovation (Gust and Marquez, 2004), raising workers' attachment to a firm may also incentivise the firm to foster the development of firm-specific human capital that is in line with the use of new technologies. Policymakers at country level could do much to encourage further ICT adoption by developing labour employment legislation that favours productivity-enhancing reallocation, while minimising the costs borne by firms and workers (OECD, 2015). One pernicious consequence of overly rigid labour market regulations is the increased risk of a firm adopting new technologies that are not in line with the existing skills level in the firm. See also Chapter 4 for a discussion on this topic.

3.4.1 Decline in the ICT contribution and absence of a second wave

A number of authors have found that the contribution of ICT to labour productivity (through the channels detailed above) has been declining in most countries.[58] However, important differences between countries in terms of ICT and digital technology adoption can be observed (OECD, 2017). This could mean that the technologies of the third industrial revolution have realised their full productivity potential. Nonetheless, a second wave is still expected from the diffusion of new digital technologies in combination with ICT.

Missing this productivity opportunity, which is likely if the right policies are not swiftly implemented, poses considerable risks for a country, even for developed economies. Where a country fails to adopt the right policies, it could be stuck in a low productivity growth trap for a prolonged period of time, similar to Argentina during the 20th century (Taylor, 2018).

3.5 The future impact of digitalisation on productivity

3.5.1 From the effect of ICT to an effect of digital technologies?

As discussed previously, numerous analyses focus on the contribution of ICT to productivity growth.[59] The main results can be summarised as follows: (i) the contribution of ICT to growth became significant and increased from the 1980s and then stabilised or even decreased from the 2000s (see Cette et al., 2020); and (ii) large developed countries are lagging behind the United States in terms of ICT diffusion and ICT contribution to growth. Several analyses (for instance O’Mahony and Vecchi, 2005) emphasise the complexity of the link between technology and productivity. To leverage ICT investment successfully, firms must typically make large complementary investments and innovate in areas such as business organisation, workplace practices, human capital and intangible capital.

These investments take time and require the acquisition of digital skills. In 2020, before the COVID-19 crisis, the degree of digitalisation differed across European countries and was on average lower in the EU than in the United States. It is important to maintain and enhance policies to facilitate the diffusion of digital technologies to close this gap.

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[58] See Cette et al. (2015, 2020); Byrne et al. (2013); and Cette (2014).

[59] In addition to what was already mentioned, prominent examples include Jorgenson and Stiroh (2000); Oliner and Sichel (2000, 2002); Colecchia and Schreyer (2002); Oulton (2002); Van Ark et al. (2002); O’Mahony and Vecchi (2005); Spiezia (2012); and Cette et al. (2015).

3.5.2 Teleworking: a positive productivity effect?

In order to maintain their activities during lockdown, companies had to invest in IT equipment to enable teleworking, but even after the containment measures have ended, it is likely that teleworking will continue to be used more frequently than before, with potential important direct and indirect effects on productivity. Relatively few studies focus on the effect of teleworking on productivity. This could be due to an identification problem: there is a considerable selection bias, since, in normal times, teleworking occurs where both the employer and the employees potentially gain from its use.

In this regard, Bloom et al. (2015) is probably the most important analysis. Based on a random sample drawn from the workforce of a large Chinese firm, the authors find that teleworkers were significantly more productive, happier and less likely to leave the firm (although they are also less likely to be promoted on the basis of performance). Other studies seem to report adverse results: Monteiro et al. (2019) report that teleworking induces productivity losses, a result driven by small firms and consistent with findings in Bartik et al. (2020). Bruggen et al. (2020) report results from a laboratory experiment in which workers who are willing to work from home are typically less honest, but they report no productivity differences by location.

Battiston et al. (2017) stress the importance of face-to-face interactions in collaborative activities. They show that the communication of complex information is more efficient when team members are working in the same room. Based on a laboratory experiment involving students, Dutcher (2012) suggests that teleworking may have a positive impact on the productivity of creative tasks but a negative impact on the productivity of repetitive tasks. These findings are consistent with existing theories of the firm that consider the prevalence of complementarity between workers in some types of tasks (see Autor, 2015, for a review).

Teleworking might induce productivity losses if complementarity between teleworkers and capital (essentially digital capital) is too low. However, such complementarity is likely to increase in the near future. A related question is how are gains from commuting time reallocated? Arntz et al. (2019) exploit a longitudinal panel of German workers and measure a highly heterogeneous increase in working time that varies with the family situation (childless employees work on average an extra hour per week when they telework). This increase in the supply of hours worked is equivalent to an increase in labour productivity per workday. In fact, part of the effect identified by Bloom et al. (2015) comes from a reduction in the number of breaks.

3.5.3 Implications for monetary policy

The effects of digitalisation on productivity, which have been described in this report, can affect monetary policy via a number of channels. The first channel is its impact on potential growth, as productivity is an important driver of the output gap, which in turn influences assessments of inflationary pressures. Ignoring or underestimating the boost to potential growth linked to digitalisation, when it occurs, could lead to an over-evaluation of the risks of inflationary pressures and thus to overly restrictive monetary policies. However, as shown above, these dynamics have not yet been observed, even when the various sources of bias in statistical measurement are taken into account. Productivity growth also affects monetary policy indirectly, through its effect on the natural rate of interest. Low productivity growth implies a low natural rate and hence a higher probability of hitting the lower bound. In a technologically optimistic scenario, productivity growth will increase owing to an acceleration in digitalisation, raising the natural rate and thus giving monetary policy more room for manoeuvre. In addition, digital technologies influence labour market equilibrium and price formation, as detailed in the next two chapters of this report.

4 Digitalisation and the labour market[60]

Digitalisation is one of the major structural changes that has been transforming the functioning of labour markets, together and in interaction with globalisation and demographic trends. The overall effect on labour market outcomes is not yet conclusive and further empirical work is needed. The adoption of automation and digital technologies can lead to short-run labour displacement effects, while general equilibrium effects may differ over time, as productivity enhancement and endogenous growth may stimulate labour demand and create new occupations. Reallocation to these growing tasks and jobs depends, however, on the efficiency of the job-matching process and on the balance between the supply of and demand for skills across firms and industries. Overall, while the effects of digitalisation on aggregate employment appear benign, at least to date and over the long run, the empirical evidence on the effect on wages and on the labour share remains mixed and depends on the structure of the economy and its labour market institutions. Cross-country heterogeneity in digital adoption could also lead to differential impacts on labour market outcomes.

While the ageing of the population may accelerate the adoption of new digital and automation technologies, long-term productivity growth ultimately rests on the innovation process and the ability to exploit technology. The capacity to adjust the quality of labour supply is crucial to enable the adoption of digital technologies and to buffer inequality across labour market outcomes, especially across skills. This includes adequate in-company retraining programmes, in addition to more formal training.

A particularly stark effect of technology on labour markets is the increase in remote working. Teleworkable jobs account for about one third of the total and are less prevalent among low-skilled jobs than other jobs. Differences in social norms and limitations related to digital equipment and skills may explain the heterogeneity in working from home across euro area countries. The pandemic crisis could accelerate the adoption of teleworking and reduce the digital divide across European countries, while the overall effects on long-term productivity and employment growth remain unclear.

The impact of digital and automation technologies on the labour market has important implications for the conduct and the transmission of monetary policy. Both skill heterogeneity and the degree of complementarity among workers, robots and digital technologies may lead to a flattening of the relationship between wages and unemployment.

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[60] This chapter has been prepared by Gaetano Basso, Henrique Basso, Emanuela Ciapanna, Agostino Consolo, Claudia Foroni, Mario Izquierdo Peinado, Matthias Mohr, Filippos Petroulakis and Lara Vivian. It has benefited from comments from Robert Anderton, Sofia Anyfantaki, Gilbert Cette, Valerie Jarvis and Vincent Labhard. Box 1 has been prepared by Claudia Foroni and Matthias Mohr. Box 2 has been prepared by Gaetano Basso. Box 3 has been prepared by Lara Vivian.

4.1 Introduction

Digitalisation is one of the major structural changes that can transform the functioning of labour markets, coupled with other trends, such as globalisation and demographics. The adoption of automation and digitalisation technologies over recent decades has brought new challenges with extraordinary speed amid unprecedented leaps in global connectivity. As in previous industrial revolutions, the impact of these changes has the potential to ripple across industries, businesses and communities. The degree of adoption of digital technologies differs across countries and also depends on the role of countries in a globalised world. Participation in global value chains also matters for labour market outcomes. Demographics, including migration, may complement the relative scarcity or abundance of certain skills or the capacity to innovate, thereby accelerating or slowing down the digitalisation process.

Digitalisation enhances the productivity of jobs, while the efficiency of the job-matching process depends on the balance of available skills across firms and industries. The effect of digital technologies on labour markets hinges on the degree of substitutability or complementarity between production factors (i.e. the specific types of technological capital and labour), productivity spillovers to other industries and compositional effects across sectors. Digital technologies can also reduce search costs and improve job-matching efficiency, while mismatches can still arise from the slower adjustment of the supply of skills.

The adoption of digital technologies typically leads to immediate firm-specific labour substitution, while the general equilibrium effects may differ over time. The available empirical evidence suggests that short-term displacement of labour (low-skilled routine jobs) occurs mainly through the job-finding channel, namely new hires occur away from the automating industry. Nevertheless, in the long run, new technologies lead to (i) the development of new tasks and the creation of new jobs and (ii) higher employment and wages for high-skilled workers which stimulate aggregate consumption. On the cost side, the decline in output prices across industries adopting automating technologies tends to further support household incomes.

The overall effect on aggregate wages and the labour share remains mixed and crucially depends on the occupational structure of the economy, including labour market institutions. Jobs featuring analytical and non-routine tasks have a higher degree of complementarity with machines than routine manual ones, and wages for these jobs are more likely to benefit from a stronger pass-through of higher productivity. At the same time, productivity gains in the labour-intensive services sector translate into price reductions rather than being transferred to workers via higher wages. The structure of the economy in terms of manufacturing and capital-intensive services may thus lead to different aggregate effects of digital technologies on wages. Moreover, employment protection legislation and product market regulation in Europe can also curb the decline of wages and limit the adjustment of the labour share. The digitalisation effect on wages usually depends on the resilience of labour market institutions, and this could make the effects of digitalisation on the labour share more subdued. However, the threat of automation can lower the bargaining power of workers. Going forward, a close look at the development of industrial relations will be key to understanding the evolution of the effects of digital adoption on the labour market.

Firms' organisational capital and management practices have emerged as relevant factors in their propensity to innovate and their ability to extract efficiency gains. This concerns not only the diffusion of technology, but also the complementary investments that firms need to make in skills, organisational changes, process innovation and new business models. As the scale of these investments may make digital transformation particularly difficult for less-technologically advanced firms, which includes many SMEs, this may imply that so far only a few firms have actually benefited from digitalisation.

Population ageing may accelerate the adoption of new digital and automation technologies, but long-term growth rests on the innovation process. Demographic trends (in particular, population ageing) provide a powerful incentive for the adoption of robots. However, higher investment in automation and the adoption of digital technologies may crowd out firms' limited resources in innovation, which is the ultimate driver of long-term growth. Overall, different types of technological advances may lead to different impacts on the labour share.

The capacity to adjust the quality of the labour supply, including adequate in-company retraining programmes, is crucial to enable digital technologies. Automation and AI not only provide opportunities but also pose significant challenges related to changes in the labour market and in employment composition: (a) high demand for soft skills (i.e. social and communication skills, emotional intelligence, ability to work in a team) alongside technical skills (i.e. digital skills); (b) an appreciation of the value of lifelong learning (see Albani et al., 2019). Educational programmes and vocational training are two complementary ways to help labour supply to catch up with new technologies. Given the speed of technological innovation and the implied job reallocation requiring new skills, firms have increased their investment in training after the adoption of new technologies and innovative workplace practices. As a consequence, in the long run, the workers who will be hardest hit by the effects of technological change are those who stay in routine jobs rather than those who switch occupations.

The pandemic crisis has accelerated the adoption of digital technologies, while the overall effects on productivity and employment growth still remain unclear. The COVID-19 shock has helped to speed up the digital transformation, but the lack of appropriate infrastructure (e.g. high-speed internet) and adequate training in new technologies may lead to heterogeneous effects on labour productivity. While working from home has potentially increased flexibility in the supply of labour, new technologies, such as the adoption of AI in the wider services sector, may pose significant challenges for certain occupations.

The impact of digital and automation technologies on the labour market has important implications for the conduct and transmission of monetary policy. Digital and automation technologies lead to non-neutral effects across capital and types of skilled labour. The skill-biased impact on the labour market may affect the relationship between unemployment and inflation – leading to a flattening of the

Phillips curve. In addition, digitalisation and automation may lead to higher income inequality via higher wage premia for high-skilled workers or greater demand for certain types of occupations. Heterogeneous effects could have implications for households' marginal propensity to consume. As a result, consumption behaviour across workers may affect how both standard and non-standard monetary policy measures could ultimately affect household consumption and investment decisions.

This chapter is structured as follows: Section 4.2 looks at the impact of digitalisation and automation on the demand for skills, employment displacement effects and firms' organisational capacity to adopt new technologies; Section 4.3 covers the effects of automation on labour supply, including the role of demographic trends, education and training; Section 4.4 looks at the future of work from a digitalisation perspective.

4.2 Impact of digitalisation and automation on the demand for skills and firms' organisation

4.2.1 Demand for skills

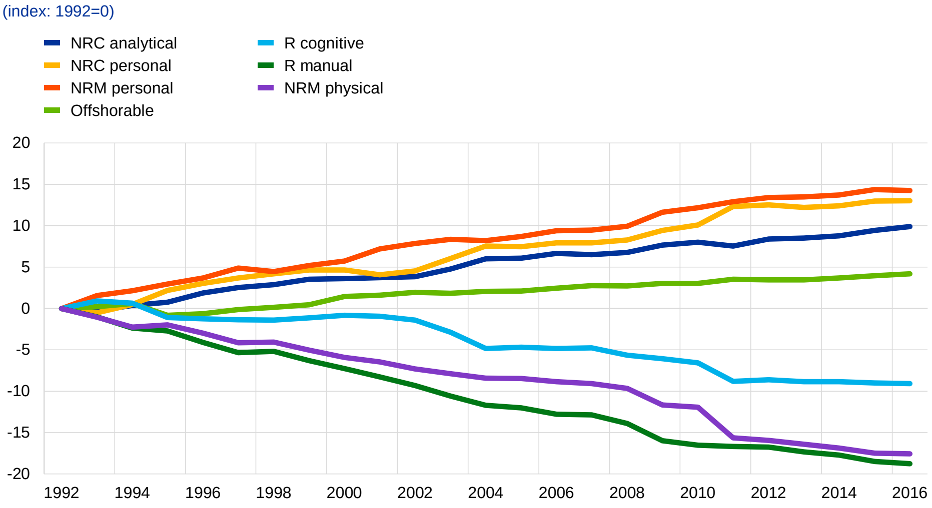
Digital and automation technologies undisputedly influence many aspects of the labour market, from hiring and firing decisions and the skill composition of labour demand to wages and the labour share. However, the channels, magnitudes and directions of these effects are not unambiguously determined, as they vary across countries, at the level of observation – whether it is at the level of the firm or the relevant labour market – and according to the type of technology. Ultimately, the effects on the labour market depend on the degree of substitutability or complementarity between the production factors (i.e. the specific type of technological capital or labour), productivity spillovers to other industries and the compositional effects across sectors of the economy. Moreover, general equilibrium effects operate through changes in the relative prices of tradable goods, and possibly capital gains.

Theories of routine-biased technological change can help rationalise the most recent advances in digitalisation and automation technologies and their impact on the labour market. It has been shown that ICT (Michaels et al., 2014; Akerman et al., 2015), personal computers and automating machines (such as industrial robots) substitute for routine tasks while complementing complex analytical tasks carried out by high-skilled workers (Autor et al., 2003; Autor et al., 2006; Acemoglu and Autor, 2011; Acemoglu and Restrepo, 2018a). Manual, non-automatable tasks performed by low-skilled workers, mainly in the non-tradable services sector (Autor and Dorn, 2013), are weakly complementary to automating and digital technologies: labour demand in these occupations expands mainly because of increases in aggregate productivity and income. These unbalanced changes in the demand for skills induce in turn a polarisation of labour markets: both the low and the high end of the skills distribution increase their employment and share of hours at the expenses of mid-skilled and mid-wage workers. Extensive empirical literature shows that employment polarisation occurs in all advanced economies, including European and euro area countries (see Chart 14), possibly confirming that the diffusion of computerisation, digitalisation and other automating technologies plays a major role (see Box 2; Goos et al., 2009; Goos et al., 2014; Gregory et al., 2016; Dias Da Silva et al., 2019; Anderton et al., 2020a and 2020b).

Evidence on wages is more mixed and points toward a steeper increase at the higher end of the skill and wage distribution than among manual service workers, spurred by three forces. First, routine and analytical tasks tend to have a higher degree of, respectively, substitutability and complementarity with machines than manual ones. Second, up to now productivity gains in the labour-intensive services sector have tended to translate into price reductions rather than increased wages for workers, despite an unprecedented growth in demand for manual services, owing to a large income elasticity (Autor and Dorn, 2013; Mazzolari and Ragusa, 2013). Third, the elasticity of labour supply mitigates wage gains at the low end of the skill distribution (Basso et al., 2020; Mandelman and Zlate, 2020). Moreover, labour protection legislation and product market regulation in Europe could also have curbed the decline in wages, and in the labour share, thereby containing the decrease in wages among routine mid-skilled workers (Goos et al., 2010; Basso, 2019; Dauth et al., 2017).

Chart 14

Evolution of task content in Europe, 1992-2016



Sources: Dias da Silva et al. (2019) and authors' calculations based on EU-LFS data.
Notes: Each line shows the task content of the mean job in the sample for each task. NRC stands for non-routine cognitive, NRM for non-routine manual and R for routine tasks.

In this framework, and in line with empirical evidence, the adoption of labour-substituting technology may cause an increase in overall output and employment through three main channels. First, the rise in productivity per se might have no effect on labour demand in the economy if aggregate consumption also rises, counterbalancing the negative effect within the automating sector. Second, the reallocation of production across sectors can increase the overall demand for labour, compensating for direct labour-saving effects in sectors that experience technological advances.[61] Third, the adoption of new technologies is associated with the development of new tasks and the creation of new jobs that expand the spectrum of labour activities.

Analysis of the overall impact of automation and digitalisation on the labour market requires a general equilibrium perspective. As shown by Graetz and Michaels (2018), output prices decline as industries adopting automating technologies benefit from the lower cost of intermediates. Aghion et al. (2020) document similar declines in producer prices in France for more general automation technology. Macro models allow a generalisation of these findings. Developing a dynamic stochastic general equilibrium (DSGE) model with two skill groups and labour market frictions, Abbritti and Consolo (2021) show that, like a TFP shock, automation leads to productivity growth. Automation, however, displaces the labour factor that it is meant to substitute (low-skilled routine jobs): in line with empirical evidence, such displacement of labour occurs mainly through the job-finding channel, namely as new hires occur outside the automating industry. Relative employment and wages grow for the high-skilled workers whose skills are complementary to the automating technology, but these differences tend to reduce as overall productivity grows and the low-skilled workers are reabsorbed into the workforce (see Chart 15).

A general equilibrium perspective also allows an assessment of the possible implications for the conduct and the transmission of monetary policy. Abbritti and Consolo (2021) highlight that digital and automation technologies favour certain types of occupation, leading to increased income inequality via higher wage premia for high-skilled workers. The heterogeneity in labour income alters households’ marginal propensity to consume, ultimately affecting the transmission of both standard (via interest rates) and non-standard (via balance-sheet expansions) monetary policy measures. As a result, the relationship between unemployment and price and wage growth changes and the Phillips curve is flattened (see Chart 16). Basso and Rachedi (2020) recently developed a New-Keynesian model in which production occurs through either labour or an automating technology, focusing on endogenous changes in the degree of automation. In this setting, automation is also expected to flatten the slope of the Phillips curve, partly because it dampens the wage inflation channel (as with fewer, more productive and high-paying firms advertising vacancies, labour market tightness declines). Wage-to-price pass-through is also reduced with a higher degree of automation, as the labour/machine ratio declines.

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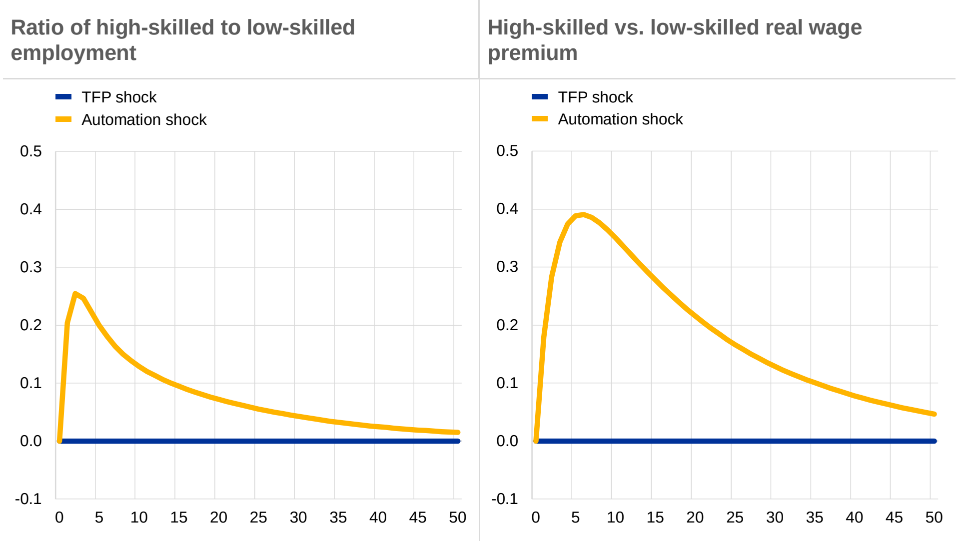
[61] As a special case, reallocation can also be driven by automating sectors. As highlighted in Humlum (2019), automation-adopting firms and industries tend to increase labour demand in occupations that are complementary to technology. If these industries are labour-intensive and expand their market share because of productivity gains spurred by automation, they contribute to an increase in the overall demand for labour.

Chart 15

Response to TFP and automation shocks between skill types



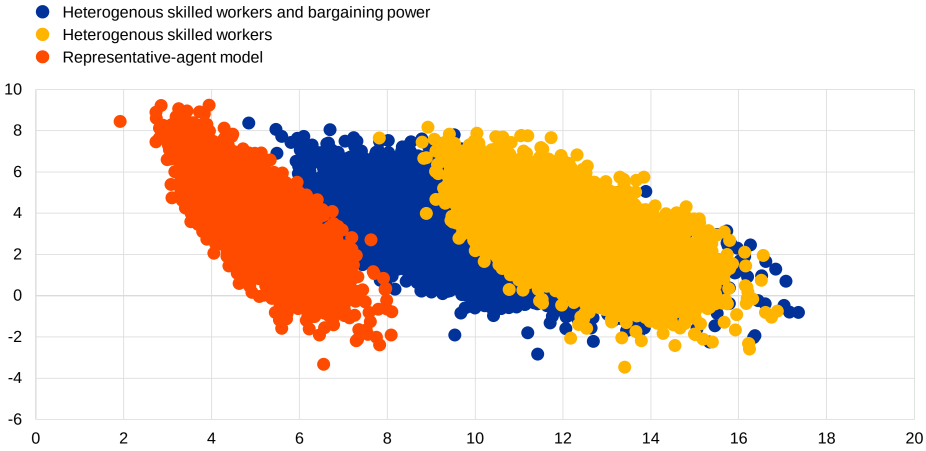
Source: Abbritti and Consolo (2021).

Chart 16

The Phillips curve with labour market skill heterogeneity

The flattening of the Phillips curve after accounting for skill heterogeneity

(percentages; x-axis: unemployment; y-axis: inflation)



Source: Abbritti and Consolo (2021).
Notes: Skill is defined in terms of education attainments: below secondary, secondary and tertiary education. The blue dots are model simulations under no skill heterogeneity. The green dots represent a model calibration in which the supply of skills does not match the demand. The red dots add different bargaining power for low-skilled and high-skilled workers to the labour market mismatch.

In a general equilibrium framework with labour market frictions and automation technology, the threat from the adoption of robots lowers the bargaining power of workers. As shown in Leduc and Liu (2019), the resulting decline in wage growth counterbalances the increase in productivity due to automation and, consequently, the labour share declines. While automation dampens wage growth, it could also generate new vacancies and employment growth. In the model, vacancies carry a positive value even if unfilled: automation is job displacing (workers and robots are perfect substitutes in the model) but also creates incentives for firms to create new jobs, as they can be automated in the future even if they go unfilled.

Bergholt et al. (2019) develop a structural vector autoregression (SVAR) model to examine the relative importance of various determinants of the decline in the US labour share. They find that the rise in automation and a rise in firms' market power explain most of the observed decline in the US labour share, particularly over the last twenty years. They also find that capital deepening is not a major determinant of changes in the labour share, as the implicit elasticity of substitution between capital and labour points to a net complementarity (see Box 1 for a special focus on the euro area).

Box 1
Drivers of labour shares in the euro area

We evaluate the relative importance of a number of factors in explaining the medium-run dynamics of labour shares in the euro area.[62] Once residential income is also taken into account, the labour share in the euro area, as well as in most euro area countries, is not on a historically declining path (as shown by Cette et al., 2019). Nevertheless, medium-term fluctuations are present, which can be analysed on the basis of a structural vector autoregression (SVAR) model. The model used here includes five variables: real GDP per capita, real wages, hours worked per capita, real gross operating surplus per capita and the GDP deflator, which is also the deflator of the other variables. The time frequency is quarterly, and the sample spans the period from the first quarter of 1980 to the fourth quarter of 2018.

The model is aimed at identifying five potentially relevant factors for the labour share dynamics by means of sign restrictions following the identification strategy in Bergholt et al. (2019): wage mark-ups, automation, price mark-ups, investment-specific technology and demand. A wage mark-up shock can be interpreted as any factor that affects the supply side of labour markets (e.g. changes in union power, demographics, leisure preferences). An exogenous increase in the labour supply allows firms to hire more easily, and therefore hours worked and output increase. At the same time, more intense competition among workers exerts downward pressures on wages, which move in the opposite direction. By contrast, a positive automation shock can be interpreted as an increase in the share of tasks that can be performed with capital in production, thereby reducing the need for firms to hire workers. It makes production more capital-intensive at the expense of labour. Automation is therefore a specific (negative) labour demand shock, which implies opposite movements of GDP on the one hand, and hours worked and wages on the other. A positive price mark-up shock can be thought of as any factor that decreases the degree of competition between firms (e.g. increases in market concentration, segmentation and product specialisation). It implies that, on impact, profits on the one hand and GDP and wages on the other move in different directions. An investment-specific technology shock implies that capital becomes cheaper. This leads to an abundance of capital, higher output and higher profits. This translates into GDP, wages and profits moving in the same direction. If labour and capital are substitutes, this will imply a decline in the labour share. If labour and capital are complements, the labour share will increase. Finally, all the shocks mentioned, except automation,

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[62] The labour share variable used here refers to the market sector of the economy and incorporates an imputation of the labour income of self-employed people, assuming that the hourly wage of this group is on average the same as for employees, following the standard definition widely used in the literature.

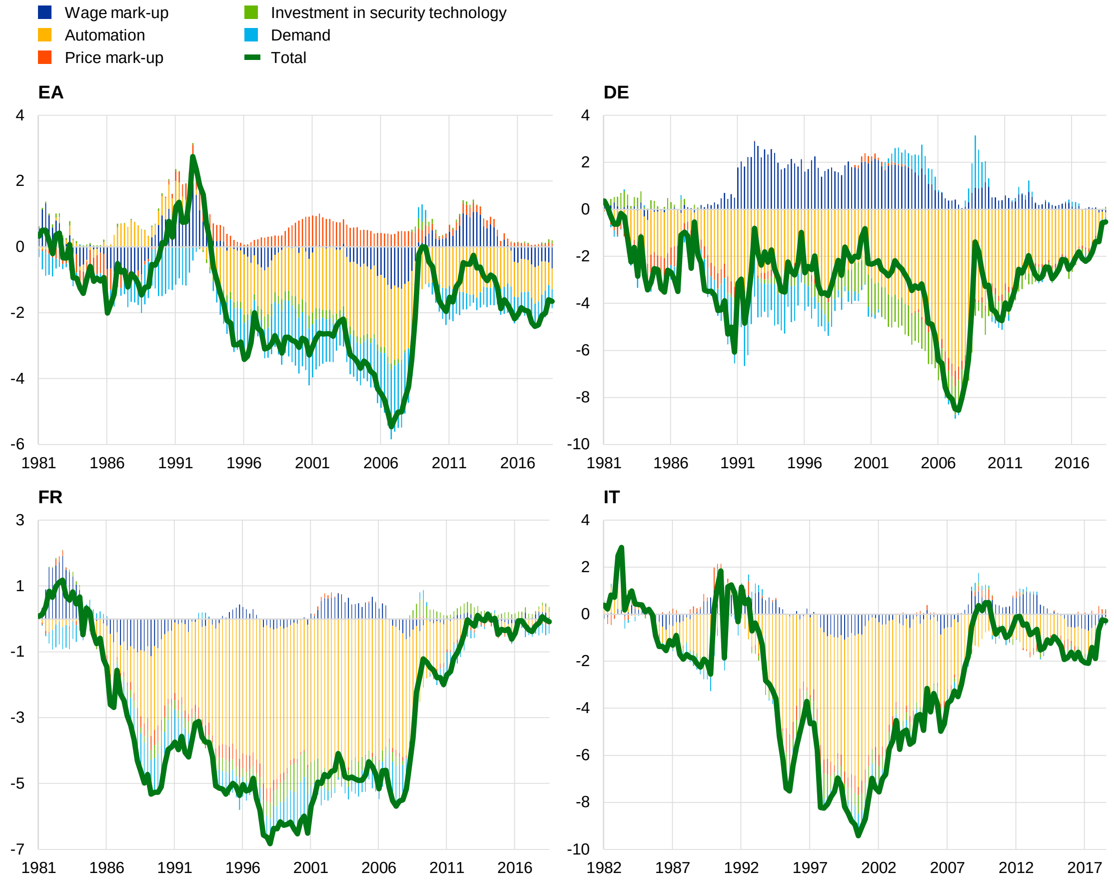
are restricted to having a negative medium-run effect on the GDP deflator. We do not impose any restriction on the response of the GDP deflator to automation, which is theoretically ambiguous in the economic models (see Bergholt et al., 2020). A permanent demand shock, instead, implies parallel movements of GDP, hours worked and the GDP deflator. This shock reflects demand factors that are persistent and could potentially affect labour shares in the medium run.

The estimation results seem to suggest that automation explains a large share of the fluctuations in the labour share for the euro area and the three largest euro area countries. The historical decomposition identifies the contributions of the shocks to the labour share dynamics over the time horizon under analysis (see Chart A). For each country, the black line represents the deviation of the labour share from its deterministic component (i.e. the part unexplained by shocks), while the coloured bars show the contributions of each of the shocks. These are quite large, particularly after the 1990s in the euro area, France and Italy, and over the whole period in Germany. Investment-specific technology and demand shocks seem, overall, to have contributed to downward pressures on the labour share in the euro area, France, Germany and Italy. In France and Italy, the negative impact of the automation shock on the labour share has declined in importance over the last decade. The same holds for Germany at the end of the observation period.

Chart A

Drivers of the labour share in the euro area, Germany, France and Italy

(percentage deviation from deterministic component and percentage point contributions)



Source: Foroni, Maffei-Faccioli and Mohr (2020).

Economic theory, however, allows us to provide conditions under which the labour share does not have to decline even though technological advances may be labour-substituting. On the one hand, as long as the productivity and the reinstatement effects generate enough additional growth and create new tasks in which labour has a comparative advantage, and productivity growth sustains wage dynamics, the labour share does not shrink (Acemoglu and Restrepo, 2018b and 2020a).[63] Furthermore, higher employment protection and more stringent market regulations in Europe may have reduced the extent of the labour share decline in Europe when compared with the United States (Cette et al., 2019; Dauth et al., 2017; Philippon, 2019). On the other hand, the effects of automation may be further amplified when combined with other potential drivers of automation, such as industries that are also experiencing increasing concentration among "superstar" firms with large market power in both the product and the factor markets (Korinek and Ng, 2019; Autor et al., 2020; Azar et al., 2019), and is further associated with offshoring practices (Elsby et al., 2013). Both these factors by themselves contribute to the decline in the labour share.

Digital and automation technologies may interact with other structural factors that also contribute to employment polarisation or to the dampening of wage growth, at least in certain segments of the labour market. The globalisation of economic activities and offshoring also tend to benefit high-skilled labour and non-tradable services, leading to U-shaped employment growth (Goos et al., 2014). Similarly, structural transformation and the reallocation of labour away from manufacturing towards services also generate patterns consistent with labour market polarisation (Bárány and Siegel, 2018; Comin et al., 2020 and 2021). Cyclical factors may play a role as well. The displacement effect of automation on routine jobs seems to occur mainly during recessions, and the pace of recovery could be slowed down by the need of routine workers to relocate to non-routine jobs (Jaimovich et al., 2020). At the same time, automation could contribute to faster growth during expansions, as it dampens wages while increasing productivity (Leduc and Liu, 2019).

In summary, the fast-growing process of digitalisation has shaped labour demand in recent decades without causing discernible labour displacements in the aggregate. On the contrary, digitally-intensive sectors seem to have made important contributions to employment growth, while countries with higher shares of value added accounted for by digital sectors have been those usually associated with lower unemployment rates (Anderton et al., 2020a).[64] Nevertheless, the ICT revolution of the 1980s, 1990s and early 2000s and the more recent wave of industrial robot automation did give rise to adverse employment effects for those in routine tasks and adverse skill-biased effects on wages. The direct negative effects largely operate through lower net inflows into routine-intensive jobs over time. The most recent advances in technology-adopting sectors, however, could have new implications for employment and the labour share, as capital deepening involves higher fixed-cost

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[63] Similarly, growth theory has shown that factor-augmenting technologies and capital deepening are consistent with stable factor shares and the "Kaldor facts" even in the presence of sectoral reallocation (see, for example, Acemoglu, 2003; and Acemoglu and Guerrieri, 2008).

[64] See Box 6 in Anderton et al. (2020b).

investments and the development of digital technology may lead to a winner-takes-all dynamic. Therefore, wages and the labour share could also decline through an increase in the market power of technology-adopting firms that expand their market share and exert monopsony pressure.

In the years to come, low-skilled workers in manual-intensive jobs and high-skilled workers could also suffer employment and wage losses due to automation. New-generation robots and AI technologies are better suited to substitute for certain non-routine tasks, in particular tasks related to prediction. Some are already evident (and indeed widely diffused) in certain high-skilled services sectors and in transport (e.g. self-driving cars; the legal profession) (see Autor and Reynolds, 2020; Anderton et al., 2020a and 2020b).[65] Future labour demand will thus depend on the interplay between the pace of adoption of new technologies, the degree of complementarity of automation with labour, the extent of capital deepening and its impact on aggregate labour productivity, and the ability of the economy to generate new tasks where labour still has comparative advantages (Acemoglu and Restrepo, 2018a).

Box 2

The adoption of robots and other automation technologies: labour market effects across European countries

Recent policy and economic debate about the future of work has centred on automation and the impact of digital advances on labour. In particular, the pace of adoption of industrial robots capable of performing automatically controlled, re-programmable and multi-purpose tasks is unprecedented, raising concerns about the potential for widespread labour substitution and strong rises in unemployment. Several economists show that robot intensity has increased since the mid-1990s in all countries, although at different paces, partly reflecting different starting points (Graetz and Michaels, 2018; Acemoglu and, Restrepo 2020b; Dauth et al., 2017). According to ECB calculations, the number of robots per thousand workers in manufacturing doubled in Germany, France and Italy between 1996 and 2015 and more than tripled in Spain (see Chart A).[66]

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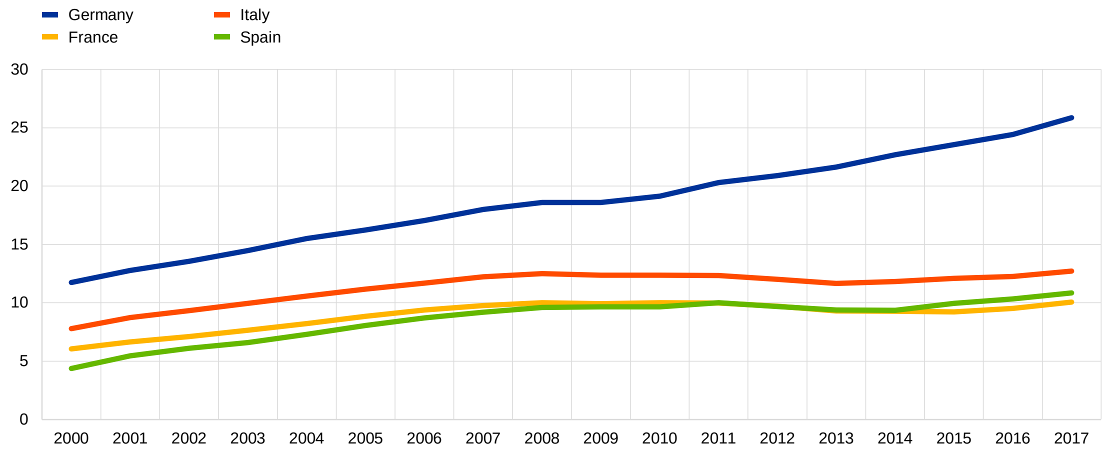
[65] Two ECB podcasts also discuss the implications of digitalisation for European labour markets, including trends in automation and the associated labour market polarisation (see ECB, 2020a and 2020b).

[66] One caveat concerning data on robots is that possible changes in robot quality and their sophistication over the sample period are not accounted for, which implies that comparisons over time should be interpreted with caution.

Chart A

Robots in the manufacturing sectors, 2000-2017

(per thousand workers)



Sources: EU KLEMS and International Federation of Robotics data and author’s calculations.

There is a growing body of literature investigating the effects of industrial robot adoption on employment, wages and the labour share. The seminal work of Graetz and Michaels (2018) finds a positive association between robot adoption and labour (both on employment and on wages) and TFP across countries and industries, albeit with small negative effects on low-skilled employment.

Acemoglu and Restrepo (2020a) show that robots have a three-channel impact on the labour market different from those of capital deepening and factor-augmenting technology: first, they directly displace certain type of jobs; second, they could induce an increase in (non-automated) labour demand in all industries as consequence of lowering the cost of production; third, they result in a sectoral reallocation towards automating industries that expand their activities. Their empirical estimates indicate a negative impact on employment and wages in local labour markets in the United States (one additional robot per worker reduced the employment to population ratio by 0.39 percentage points and wages by 0.77% on average between 1990 and 2007). They further estimate that one additional robot for every 1,000 workers implies an economy-wide employment to population ratio decline of 0.2 percentage points and a 0.42% decline in wages. Such negative aggregate effects depend on the reduced price of tradable goods and capital gains.

Several recent papers adopt the same identification strategy for euro area countries, including the incorporation of further control variables. Dauth et al. (2017) replicate the work of Acemoglu and Restrepo using German data. Common to other European countries, robots are adopted more intensively in automotive and in other manufacturing sectors (including rubber and plastic products, electronic components and domestic appliances) where the displacement effect prevails. They find that the negative effect on wages is also driven by the manufacturing sector. Such direct displacement effects are, however, smaller than those found in the United States. Dauth et al. also find that the positive productivity effects occur within the same firms that adopt industrial robots; incumbent workers tend to retain their employment and move to higher-paying, non-routine tasks and occupations. However, they also find a decline in the aggregate labour share which is consistent with automation reducing the set of tasks performed by labour (Acemoglu and Restrepo, 2018b). Dottori (2020) replicates the study for Italy and finds no overall effect on employment growth or on the employment-to-population ratio. Individual-level evidence shows that incumbent workers exposed to robot adoption remain employed for longer and there is no overall effect on wages, unlike in Germany and the United States. In common with other economies, workers entering the labour market for the first time tend to be employed outside of industries more exposed to robot adoption.

Using a firm-level approach that does not account for general equilibrium effects, Acemoglu et al. (2020) and Bonfiglioli et al. (2020) study samples of French firms and their robot purchases and robot imports, respectively. Acemoglu et al. obtain contrasting results for employment between adopters and non-adopters, but with prevailing negative effects due to both adopters and enhanced competition that drive out non-adopter firms. At the individual firm level, they find that the labour share declines as automation increases. At the industry level, the labour share declines even more because adopters expand their market share while their labour share shrinks. Similarly, Bonfiglioli et al. find that large and growing French firms adopt more robots, but their employment declines following an automation event once the spurious positive correlation induced by demand effects has been netted out (indeed, better-performing firms tend to adopt more industrial robots). Bessen et al. (2019) find displacement effects at individual level on Dutch workers after the firm adopts automation technologies; the effects are, however, small with respect to other displacement events and no wage effects are found.

These firm-level findings contrast with the net positive effects found for France by Aghion et al. (2020), who study the impact of automating technologies (of which robots are only a subset) on employment, product prices and profits. They find positive effects of automation on employment consistent with a positive productivity effect at the firm and industry levels. These translate into lower product prices and higher profits, which they develop in a framework of imperfect competition where demand shifts towards domestic firms with increased productivity and lower prices. Similarly, Koch et al. (2019) find positive employment effects and no impact on wages for a sample of Spanish firms that adopted industrial robots. Finally, Humlum (2019) develops a rich general equilibrium model calibrated to Danish data to investigate the mechanisms of robot adoption. Humlum confirms in particular the strong distributional consequences of robot adoption. This is because welfare losses and wage declines are concentrated among manufacturing production workers and older workers, who represent a small share of the overall workforce. Reallocation towards service and technology-intensive jobs, in which young workers tend to be more prominent, leads to an average wage increase in the economy.

Overall, the evidence for euro area labour markets indicates that the adoption of automating technologies, and of robots in particular, have not induced overall labour displacement effects. Negative impacts on wages and the labour share have been modest, with results mixed across countries. While industrial robots are now common in manufacturing plants, especially in Europe, further diffusion can be expected. As already documented by Graetz and Michaels (2018), robotisation is also likely in the services sector in future. However, if the demand for new and non-automatable tasks does not advance at a similar pace, there may be lower potential for reallocation and reinstatement effects ahead (Acemoglu and Restrepo, 2018a).

4.2.2 Firms’ organisation

This section analyses the relationship between the adoption of digital technologies and firms’ organisation in terms of changes in management

practices and governance. We refer to two main strands in the literature: economics research analysing firm-level complementarities between digital and automation technologies and firms' organisation; and management and business literature on management practices which favour the digital development of firms. The evidence included in this section helps to explain some of the mechanisms behind the results in Section 3.2.1 in the chapter on digitalisation and productivity.

Firms' organisational capital and management practices have emerged as a relevant source of heterogeneity among enterprises. This is often correlated with their propensity to innovate and to extract efficiency gains from the adoption of new technology. Haskel and Westlake (2017) note that digital transformation, like other technological changes, is not just about the diffusion of technology, but also about the complementary investments that firms need to make in skills, organisational changes, process innovation, new systems and new business models. These investments involve a long process of trial and error and take time. In the meantime, productivity growth may be low and can even turn negative.

Brynjolfsson and Hitt (2003) found that productivity benefits arising from firms' IT investments were substantially higher over long horizons than over short horizons, peaking after about seven years. They attributed this pattern to the need for complementary changes in business processes. For instance, when implementing large enterprise planning systems, firms spend several times more on business process redesign and training than on the direct costs of hardware and software. Hiring and other human resources practices often need considerable adjustment to match the firm's human capital to the new structure of production. In fact, Bresnahan et al. (2002) provide evidence of three-way complementarities between IT, human capital and organisational changes in the investment decisions and productivity levels. The authors show that investments in digital technologies and organisational change, coupled with changes in products and services offered by the firm, induce a shift in the demand for labour in favour of skilled over unskilled workers. Thus, digitalisation and organisational change become more productive when they occur in an environment in which skilled labour is more abundant.

Firms' organisational structures that favour more decentralised decision-making work better in environments in which skills are horizontally distributed. As for organisational change, the variables considered by Bresnahan et al. (2002) are: (i) increased delegation of authority to individuals and teams; (ii) a greater level of skill and education in the workforce; and (iii) greater emphasis on pre-employment screening for education and training. Along the same lines, Brynjolfsson et al. (2002) show that firms that combine IT investments with a specific set of organisational practices are not only more productive but also have disproportionately higher market values than firms investing in only one or the other. This pattern in the data is consistent with a long stream of research on the importance of organisational and even cultural change when making IT and technology investments more generally (see, for example, Aral et al., 2012; Brynjolfsson and Hitt, 2002; Orlikowski, 1996; Henderson, 2006). Firms are complex systems that require an extensive set of complementary assets to allow the disrupting effects of general purpose technologies to fully unfold (Bloom et al., 2010). Those attempting radical transformation often have to re-evaluate and re-configure their internal processes, as well as their supply and distribution chains.

Organisational changes are costly and can take time, but managers and entrepreneurs will make direct investments in ways that economise on the most expensive inputs (Acemoglu and Restrepo, 2020a). According to Le Chatelier's principle (Milgrom and Roberts, 1996), elasticities will tend to increase in the long run as and when quasi-fixed factors adjust. Moreover, the scale of these investments may make digital transformation particularly difficult for non-frontier firms, including many SMEs (Brynjolfsson et al., 2017). This implies that, so far, the most productive firms have benefited more from digitalisation than less productive ones (Gal et al., 2019). In line with the complementarity hypothesis, high returns are typically observed when investments in new technologies are coupled and combined with appropriate investments in organisational capital, whereas smaller (or even negative) returns are found when organisational re-engineering efforts are poor or missing.[67] However, identifying complementarities remains a complex endeavour.

The lack of digital adoption may explain poor productivity growth and be related to firms' lack of organisational readiness. While many authors consider firms' organisational capital and management practices crucial in explaining differences in technology adoption and productivity growth, research on this topic has been constrained by the lack of quantitative evidence. In the last decade, however, measurement of management practices has greatly improved, particularly thanks to the World Management Survey (WMS) developed by Bloom et al. (2016)[68] (see Chart 17). In work focused on the United States, Bloom et al. (2016) consider management as a technological factor, able to increase firms' performance as well as to explain part of the productivity gap across enterprises and across countries. Bloom et al. (2019) show that management practices differ massively, even within the same firm (across establishments), accounting for as much variation in productivity as R&D, ICT or human capital.

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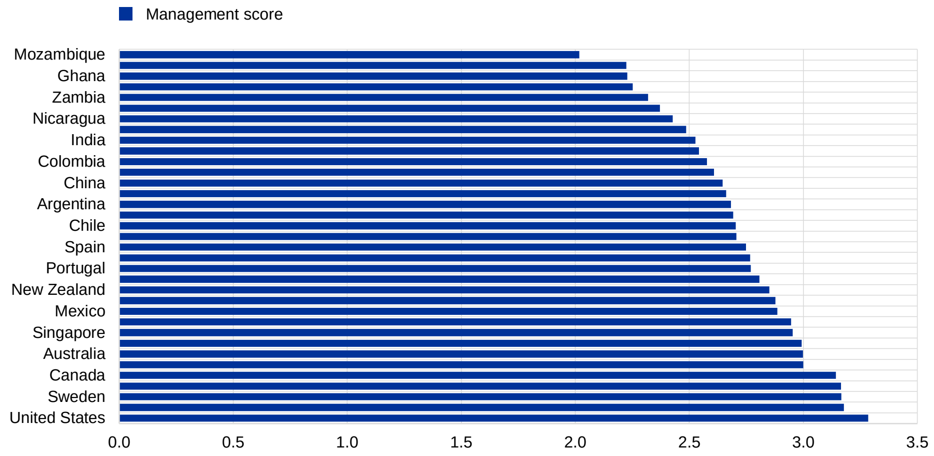
[67] For comprehensive recent reviews, see Arvanitis and Loukis (2009), Biagi (2013), Brynjolfsson and Milgrom (2013); Brynjolsson and Saunders (2010), Dedrick et al. (2003), Ennen and Richter (2010), Hempell (2006), Milgrom and Roberts (1995), Van Reenen et al. (2010) and Zand et al. (2011).

[68] The WMS covers more than 30 countries and focuses on manufacturing firms of intermediate size (between 50 and 5,000 employees). Data are collected in telephone interviews during which a trained interviewer asks plant managers about various management practices (for instance, the setting of goals, performance measurement, or human resource management), and then scores these on a scale ranging from 1 to 5 (lower scores indicating worse practices). A "management score" at the firm level is given by the arithmetic average of the scores for the individual questions, standardised to have a mean of 0 and a standard deviation of 1 across the sample.

Chart 17

Average management score by country in manufacturing



Source: Bloom, Sadun and Van Reenen (2016).
Note: Unweighted average management scores; total number of interviews = 15,489; all rounds pooled (2004-2014).

The productivity gap of some euro area countries may be partly related to firm structure and organisation. Schivardi and Schmitz (2019) find some evidence of this when looking at the poor productivity growth observed since the middle of the 1990s in southern Europe compared to other developed countries. Between 1995 and 2015, productivity increased by only 0.1% per year in Italy and Spain and by 0.5% per year in Portugal, whereas it increased by 1.1% per year in Germany and by 1.4% per year in the United States (see Chart 18).[69]

Schivardi and Schmitz provide quantitative evidence for the complementarity of IT and efficient management practices, in line with the results of the earlier literature. This suggests that inefficient management practices may be responsible for southern Europe's divergence, lowering the productivity gains from IT adoption for southern European firms and reducing their IT demand.

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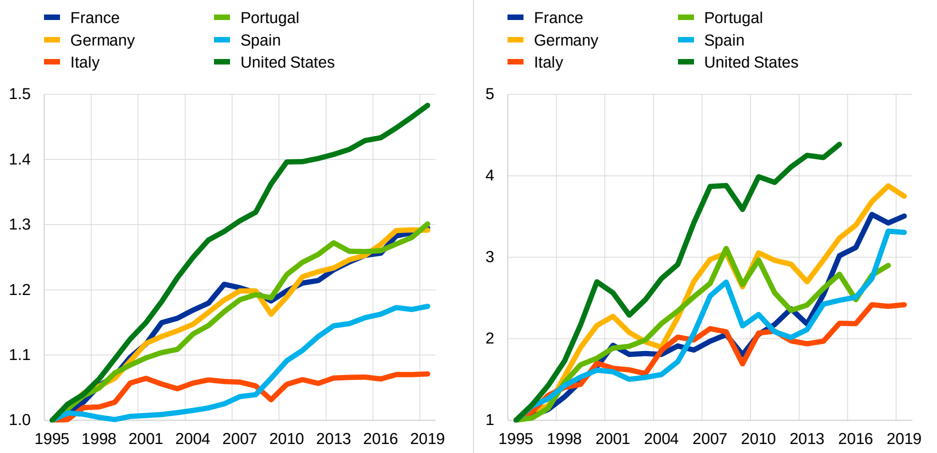
[69] The right panel of Chart 18 indicates that between 1995 and 2014 the real stock of ICT capital increased by a factor of 4.6 in the United States and by a factor of 4 in Germany, but only by a factor of 1.5 in Italy, 2.6 in Portugal and 3.7 in Spain. This suggests two observations: first, the diffusion of IT in southern Europe was limited; second, even in countries that had somewhat faster growth in ICT capital (such as Spain), this seems to have had a negligible impact on productivity.

Chart 18

Productivity growth and ICT capital



Productivity growth

(index: 1995=1)

ICT capital formation

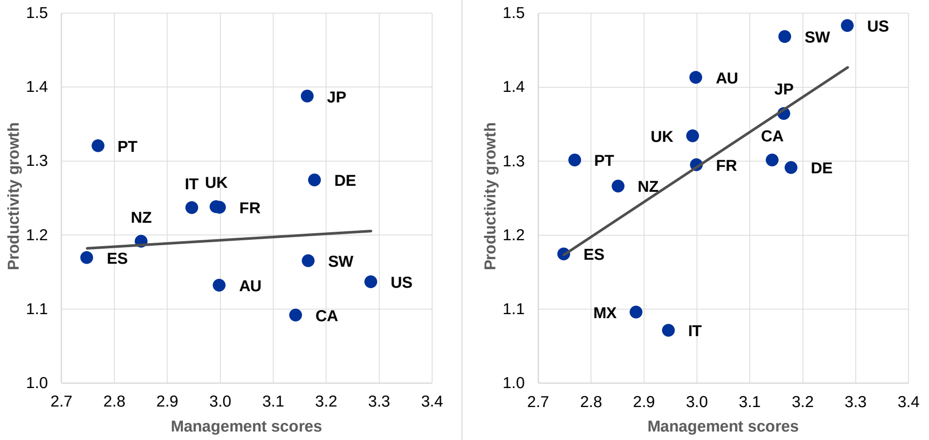
(index: 1995=1)

Sources: Schivardi et al. (2020) using data from the OECD and EU KLEMS.
Note: Panel b: latest observation for United States: 2014.

This, in turn, depressed demand for the high-skilled labour necessary to operate the new technology. Chart 19 provides some evidence on this point. Panel a shows that before 1995 there was no correlation between management scores and productivity growth. However, panel b shows that this changed radically around 1995 and a strong positive correlation emerged. Thus, inefficient management practices started to become a drag on growth after the onset of the IT revolution.

Chart 19

Management scores and productivity growth before and after the IT revolution



1985-1995

(y-axis: index 1985 = 1)

1995-2008

(y-axis: index 1985 = 1)

Sources: Schivardi et al. (2020) using OECD and WMS data.

The quantitative analysis of Schivardi and Schmitz (2020) suggests that strong complementarities between IT adoption and management practices can explain more than one-third of the aggregate productivity divergence between southern Europe and Germany between 1995 and 2008. This result is driven by differences in adoption rates, differences in firm-level productivity gains, and the increase in the importance of management.

The business literature provides evidence of the complementary relationship between digital development and managerial skills – with a focus on the types of organisational structures and management behaviours that prove more suitable to maximise technological gains.

The trade-off between information acquisition and communication costs may require different approaches to the optimal degree of centralisation of the decision-making body. Stucki and Wochner (2019) show that a stronger employee voice increases firm productivity when combined with information technology, but lowers productivity when combined with communication technology. On the other hand, flexible work design is positively associated with communication technology and negatively associated with information technology. This is because IT supports higher levels of decentralised decision-making by lowering information acquisition costs and therefore interacts positively with employee voice. Meanwhile the introduction of non-IT communication technology is of greater benefit to centralised decision-making by decreasing communication costs, which, however, has a negative impact on employee voice. Wrede et al. (2020) explore the role and facilitating actions of senior managers in response to the digital transformation. Building on 27 in-depth interviews with senior managers and close associates from large German firms, they find that senior managers respond to the digital transformation by engaging in three key areas: (i) understanding digitalisation; (ii) setting the formal context for digitalisation; and (iii) leading change.

Organisational practices acting on firms' processes are key for the implementation of new technologies, while human resources practices remain accessory. Agostini and Filippini (2019) examine the relationship between organisational and managerial practices and the adoption of new technologies (Industry 4.0 plans) in the Italian manufacturing industry. Their results show that three clusters of firms can be identified based on their level of adoption of Industry 4.0 technologies (Adopters, Beginners, Non-adopters), which are also characterised by significantly different levels of organisational and managerial practices. A regression analysis suggests that organisational and managerial practices at the firm process and supply chain level have a direct impact on the implementation new technologies, whereas organisational and managerial practices at the human resources level seem to act as a moderator.

Digitalisation has brought about a dramatic shift in performance management for leading companies. Based on interviews with leading industry experts about the future of performance management, Schrage et al. (2019) find that digitalisation has brought about a dramatic shift from compliance to performance. They also point to the central role played by data and platforms that enable communication and collaboration, including dedicated apps and tools (e.g. automated coaches and sociometric badges) which facilitate more continuous feedback sourced from different places and people. This emphasis on data empowers more evidence-based performance management appraisals and conversations, with inputs from a variety of sources. Interdependencies between people, processes, and technologies are becoming increasingly important. As a result, Schrage et al. find that team performance is overtaking individual performance as the workplace's salient unit of analysis. Team performance, coaching ability, and skills development require heightened attention and specific investment. Schrage et al. conclude that digital performance management platforms will make customisation simpler, cheaper, and more scalable, which, in turn, will make performance management an enterprise-wide capability, not just for top performers.

4.3 Effects of automation on labour supply: the role of demographic trends and education

4.3.1 Demographic trends

Demographic change and automation are two structural trends that are having an impact on most advanced economies. Reduced fertility and increased longevity have changed the age profiles of all European economies. Chart 20 depicts the dependency ratio, defined as the ratio of older people (over 65) to the 20-65 year-old population, for the 19 countries within the euro area and shows the degree to which ageing has increased and is expected to continue to increase in the coming decades. The same pattern is observed for the four largest economies in the euro area.[70] During the same period, robot adoption, measured as the stock of robot applications in all industries per thousand employees (based on data from the International Federation of Robotics), has also increased substantially in the euro area (see Chart 21). Although robot adoption varies substantially across countries (ranging from 1.3 in France to 4.8 in Germany in 2016), this measure increased by more than 200% in all euro area countries between 2000 and 2016. This poses the question of whether these trends in demographics and robot adoption are potentially linked.

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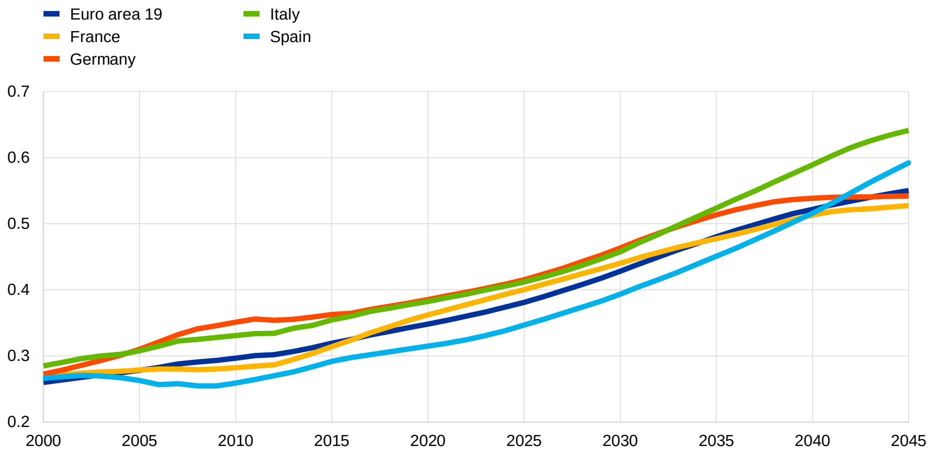
[70] The baseline population projections depicted embed forecasts for fertility and immigration which may be uncertain. Assuming higher immigration or lower fertility (the baseline scenario assumes that fertility generally increases) does not significantly alter the population structure in the euro area.

Chart 20

Age dependency ratio

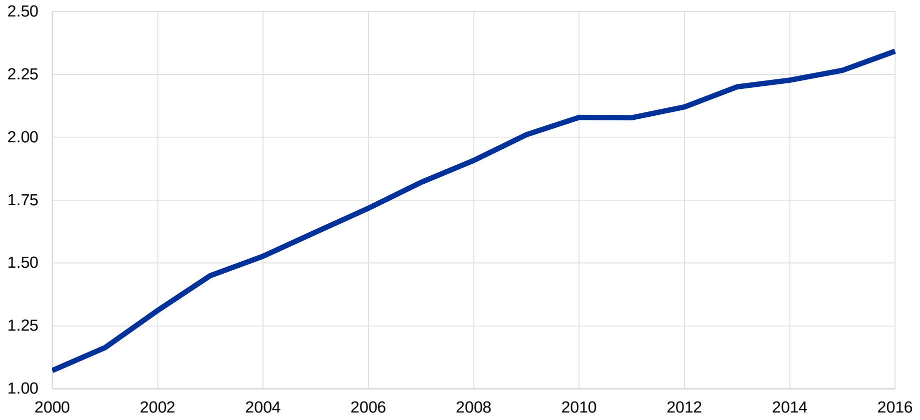


Sources: Eurostat, International Federation of Robotics and EU KLEMS.

Chart 21

Robot adoption – stock of robots in all industries (euro area 19)

(robots per thousand employees)



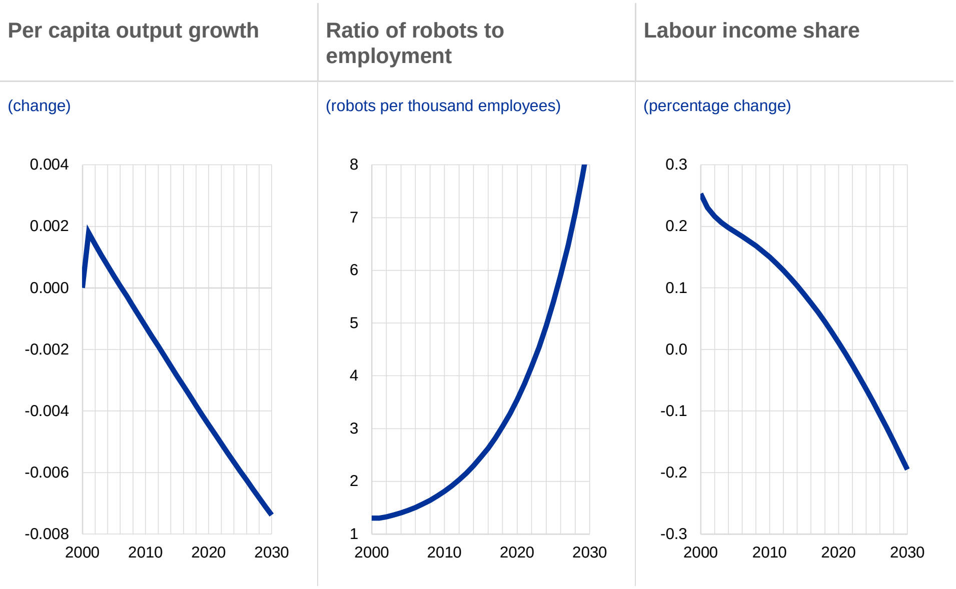
Sources: Eurostat, International Federation of Robotics and EU KLEMS.

Ageing increases the incentives to automate production processes. Acemoglu and Restrepo (2018a) analyse the impact of demographic changes on automation. They argue that demographic changes, by reducing the pool of workers in the population, provide a powerful incentive for the adoption of robots. Country-level data on robot adoption from the International Federation of Robotics, show that countries undergoing more rapid ageing invest more in robotics. The effects are quantitatively large, with demographic changes alone explaining between 40% and 65% of the cross-country variation in the adoption of industrial robots. Finally, using data on exports of automation technologies and patents, they also show that countries ageing faster develop and export more automation technologies.

Demographics may also affect the trade-off between automation and product innovation. Although demographics favour robot adoption and automation-related innovation, Acemoglu and Restrepo (2018a) also show that in countries with more rapidly ageing populations, there is less innovation in product creation (related to computers, software, nanotechnology and pharmaceuticals). Focusing on the interplay between demographics and technological changes, Basso and Jimeno (2021) (see Chart 22) develop an endogenous growth model in which both population dynamics and R&D determine long-run growth. R&D comprises two activities: innovation, which involves the creation of new products, and automation, which is the development of production processes that allow robots to replace labour.

Chart 22

Effects of demographic changes on growth, robot adoption and the labour share



Source: Basso and Jimeno (2020).

The projected ageing of the population in Europe may eventually lead to lower labour income shares and, despite its initial positive effects, to lower growth in the medium run. Embedding euro area demographic changes into the model developed by Basso and Jimeno (2021) illustrates that a decrease in fertility and higher longevity leads to an initial increase in wages and the labour income share, generating incentives for investment in automation. As robot adoption is expected to increase productivity, the initial increase in automation leads to higher per capita output growth. However, automation investment crowds out innovation in product creation and, as automation cannot progress indefinitely without innovation, higher robot adoption alone cannot sustain medium-term growth. Furthermore, as automation displaces labour, wages eventually fall, leading to a decrease in the labour income share. At the aggregate level, the link between the secular fall in the labour income share and automation is also confirmed theoretically and empirically by Martinez (2019) and Bergholt et al. (2019), although as mentioned in Section 4.2.1, the impact of automation on the labour share is heterogeneous across industries and countries and may depend on labour market institutions and productivity spillover effects.

The effects of automation are heterogeneous across the population. Acemoglu and Restrepo (2018a) show that changes in the share of prime-aged workers (age 20 to 55) are particularly relevant, as these have a comparative advantage in production tasks, which require physical activity and dexterity, while older workers tend to specialise in non-production services. Automation is therefore found to displace prime-aged industry workers. Humlum (2019) studies automation in Demark and finds that within the group of workers more heavily affected by automation, the prime-aged workers suffer almost no welfare losses. Young workers who are displaced are less specialised and are more likely to be able to switch to occupations where wage premia rise as robotisation increases, particularly in sectors characterised by greater technological progress. Similar heterogeneity is found when analysing the interplay between technological changes and immigration. Basso et al. (2018) show that unskilled immigration attenuates the drop in routine employment caused by technological change, enhances skills-upgrading for workers, who transition to occupations where wage premia are increasing, and thereby raises economy-wide productivity and welfare.

Greater automation may also be contributing to the persistent decrease in labour participation. As discussed in Jaimovich et al. (2020), workers who were employed in “routine-task-intensive” occupations, who face displacement due the implementation of automation technologies, are more likely to be out of the labour force or employed in low-wage occupations. They conclude that automation leads to a significant polarisation of welfare across different occupations; workers in routine-based occupations experience substantial welfare losses, while non-routine workers experience significant gains.

Gender income differences are also affected by the automation process. Given that occupational differences by gender remain a persistent feature of labour markets, a natural question is how automation may differentially affect the labour market prospects of men and women. Looking at the task composition of work of men and women, Brussevich et al. (2018) find that women, on average, perform more routine or codifiable tasks than men across all sectors and occupations and therefore face a higher risk of being displaced through automation. Moreover, Aksoy et al. (2020), using data from 20 European countries, find that a 10% increase in robotisation leads to a 1.8% increase in the gender pay gap.

4.3.2 Education and human capital

Digital technology and automation require an upgrade of education and human capital endowment. The response of the education system to the increase in the demand for skills resulting from digitalisation and automation is key to explaining the potential effects of digital technology on labour markets. As Acemoglu and Autor (2011) point out, ICT technologies permit the substitution of mostly routine tasks previously performed by low to medium- skilled workers. On the other hand, automation tends to favour highly skilled individuals, as jobs that require analytical skills have a limited automation potential and can benefit from complementarities with new technologies. Overall, a substantial polarisation in labour earnings was found in most advanced economies (Autor et al., 2006; Goos et al., 2009), although the effects on labour depend on the interaction between technology and the skills composition of the workforce (see Anderton et al., 2020a and 2020b, and references therein). Albani et al. (2019) highlight the role of the curriculum in higher education. A well-designed curriculum is an important step in fostering skills and equipping students for success in the labour market. First, certain skills and qualifications, such as STEM subjects (science, technology, engineering, mathematics) and ICT, are critical to innovation and gaining a competitive edge in knowledge-intensive economies. According to the Survey of Adult Skills,[71] higher proficiency in literacy, numeracy and problem solving increases the chances of getting a job and earning a higher wage (controlling for other factors). Second, as machines increasingly take over non-routine tasks as well, future jobs require not only strong digital skills but also other complementary soft skills ranging from cognitive to emotional skills (such as teamwork and problem solving). These soft skills make workers more resilient to change and more willing to experiment, learn quickly and work collaboratively and flexibly in fast-evolving workplaces.

The role of training policies is key to analysing the impact of digitalisation on employment and wages, while supporting workers in a swift transition to non-routine tasks. Humlum (2019) emphasises the role of labour supply responses in order to mitigate the negative impact of robots on production workers. Similarly, Cortes (2016) showed that employment polarisation crucially depends on the types of routines that workers perform. The workers who are hardest hit in the long run by the effects of technological change are those who stay in routine jobs rather than switching occupations. It should be noted that some recent papers, e.g. Arnoud (2018), show that even if a small share of firms automate their tasks, the threat of potential automation decreases workers' bargaining power and can lead to a decrease in wages and, especially, lower returns on experience.

Several studies show that firms increase their investment in training after the adoption of new technologies and innovative workplace practices. Behaghel and Grenan (2010) and Behaghel et al. (2011) find that French firms rely on training at the firm level in order to upgrade the skills level of their workforce. Indeed, Battisti et al. (2017) provide empirical evidence supporting the role of training activities at the firm level in dampening the harmful effects of new technologies on production workers. Using a rich dataset for Germany, they find that, despite technological changes reducing the employment share of routine jobs, workers in routine jobs suffer neither employment losses nor reduced wage growth when they move to more abstract tasks, especially when they receive training provided by their employer. A notable exception is workers over the age of 55, who are more likely to transit into non-employment after the implementation of technological changes at the firm level. These employment losses are also observed among high-skilled older workers in abstract jobs,

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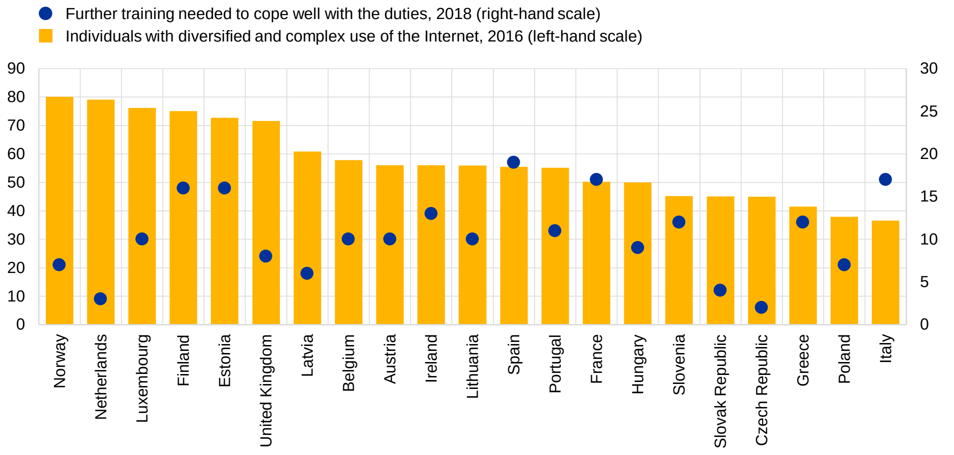
[71] See "The Survey of Adult Skills", OECD, 2019. The survey is part of the OECD's Programme for the International Assessment of Adult Competences (PIAAC).

suggesting general education may be insufficient to protect older workers from the negative effects of technological change.[72]

Chart 23

Internet use in work and skills mismatch



Source: OECD (2019).

Regarding the role of government, current active labour market policies, notably training, may not be sufficient to mitigate the negative impact of automation. Most workers across European countries make diversified and complex use of the internet (OECD, 2019) (see Chart 23). More importantly, this share is higher among the most educated and those in the 25-55 age group. Chart 23 also shows some degree of skills mismatch. In 2018, around 11% of workers in the EU reported needing further training to cope with the ICT-related demands of their job and considerable variation exists between countries. For instance, in Spain, France and Italy, almost 20% of workers need further ICT training. Using PIAAC data, the OECD shows that the probability of participating in training activities is lower among workers in jobs at risk of being automated. In particular, workers in fully automatable jobs are three times less likely to have participated in on-the-job training than workers in non-automatable jobs. This may reflect the fact that training is often provided when occupational tasks are partly automatable, fostering the transition to new tasks within the same firm, but less so when jobs are fully automatable and this transition is less likely. Finally, it is important to enhance the “knowledge triangle” (education, research and innovation) by adopting policies and reforms that support research, technology diffusion and entrepreneurship and foster closer ties between businesses, research centres and universities.

4.4 Artificial intelligence (AI) and the future of work

Going forward, secular forces will continue unabated, with machine learning (ML) being the dominant technology of the new technological wave. While

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[72] Aubert et al. (2006) also found that innovative firms in France show a lower wage bill for older workers in various occupational groups, even those with a higher level of education.

technological anxiety in the past was proved to be unwarranted as regards employment levels (though not necessarily as regards distributional impacts), AI is believed by some to present unique challenges, by making it possible automate even non-routine tasks. It is hence useful to understand exactly what ML algorithms do.

AI systems and ML techniques may trigger a new wave of automation. As argued by Agrawal et al. (2018a, 2018b, 2019a and 2019b), ML algorithms excel in *prediction*: they read massive amounts of data (the training sample) and then use statistics to determine the best course of action given each state of the world.[73] Agrawal et al. (2019b) present a number of actual AI algorithms and discuss ways through which they can affect labour in a task-based framework. These applications show the possibility of automating prediction and even decisions in a wide range of manual (driving, cleaning, warehouse) and cognitive (tax advice, judicial decisions, surgery) tasks. The ultimate net effect on labour depend not only on these direct effects, but also on indirect effects on upstream and downstream sectors. For instance, Brynjolfsson, Hui and Liu (2018) show that improvements in machine translation can lead to sizeable increases in cross-border trade.

Legal, moral or practical reasons can play a role on the decision to automate certain processes. Radiology provides a good example. Even if algorithms acquire an edge in image recognition and decision-making, medical liability concerns may imply that, ultimately, human specialists will still be needed. Recent work has attempted to quantify the threat of automation to existing jobs more precisely. In a widely publicised exercise, Frey and Osborne (2017) asked ML experts to identify specific occupations which can be easily automated in the near future from a random sample of 70 occupations. They mapped the answers to this question to the full range of occupations available in O*NET, using the task content of each occupation, and calculated automation probabilities for each occupation, estimating that 47% of jobs in the United States have high (over 70%) automation risk. Subsequent studies were much less pessimistic. Arntz et al. (2016) point out large differences in task content within occupations and that only considering the average task content may yield misleading estimates. They estimate that only 9% of jobs in the United States face a high automation risk.

One effect of the pandemic that is likely to persist is the shift to remote working. Major technology companies have already signalled their intention to allow some workers to permanently switch to remote working, a move that, if it becomes widespread, could have major implications for cities, industrial relations, and social interactions. Bloom et al. (2020) point to survey data indicating that, in the United States, while only 5% of all workdays were spent at home before the pandemic, this is expected to rise to 20% in the post-pandemic era. To some extent, this may be driven by the removal of stigma. This may be important for productivity as well: Harrington and Emmanuel (2020) show substantial selection effects in connection with teleworking, with less productive workers preferring to telework, although teleworking

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[73] For instance, the job of a human resource specialist who makes decisions on recruitment, promotion and retention can be broken down into tasks of predicting the best candidate to recruit, promote or retain, with only a residual human element in making decisions.

raises productivity substantially. If COVID-19 improves the selection of workers for teleworking, there could be significant productivity gains, as well as the opportunity to increase the incidence of remote working and to have a more broad-based distribution of work across geographical areas.

Box 3
Teleworkable jobs

This box analyses teleworking patterns in the EU and the United Kingdom. In order to disentangle occupations which can be performed from home from those which require presence in the workplace, we combine a teleworking index with individual-level data for 2019 for EU Member States and the United Kingdom.[74] Potentially teleworkable occupations include clerks, information and communication technicians, and most managers and professionals. On the other hand, some jobs in, for example, sales, cleaning and health will still require workplace attendance in order to be carried out.

In 2019 teleworkable jobs accounted for 33% of employees and 46% of annual earnings in the euro area, suggesting that remote working is more prevalent in highly-paid jobs (see Chart A).[75] These shares each increase by one percentage point when also considering other EU countries and the United Kingdom. Despite methodological differences, the results are similar to those for the United States, where 37% of jobs and 46% of wages were identified as suitable for teleworking (Dingel and Neiman, 2020). In the euro area, the share of teleworkable jobs is highest in the information and communication sector and lowest in agriculture. Occupations which are conducive to teleworking account for 83% of employees and 87% of annual earnings in the information and communication sector. In agriculture, by contrast, teleworking is only possible for 7% of workers, but their earnings represent almost one fifth of total earnings in the industry. Sectors where more than 40% of jobs can be performed remotely, namely education, financial activities, public administration, real estate and other administrative activities, account for around 30% of total employees in the euro area. The remaining 70% of employees are spread across industries where remote working is an option for no more than 25% of workers. In addition, less than 10% of potential teleworkers in the euro area report working from home either always or sometimes, meaning that two-thirds of workers might not be familiar with remote working.[76]

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[74] The teleworking index is based on Dingel and Neiman (2020), who assign to occupations a degree of teleworkability ranging from 0 to 1, where 0 implies that no jobs in that occupation can be performed via teleworking, and 1 implies that all jobs in that occupation can be performed via teleworking. In this analysis, the classification is applied to the International Standard Classification of Occupations (ISCO-08) via a crosswalk table provided by the United States Bureau of Labor Statistics (see U.S. Bureau of Labor Statistics, 2012). In addition, we use employee weights to match the index to a broader ISCO-08 aggregate. The purpose of this exercise is to combine the index with individual-level data, namely from the European Labour Force Survey (EU-LFS), European Statistics on Income and Living Conditions (EU-SILC) and the German Socio-Economic Panel (SOEP). For each data source, we consider the most recent survey available – 2019 for EU-LFS and 2018 for the EU-SILC and SOEP (see “Socio-Economic Panel (SOEP), data from 1984-2018”, version 35, SOEP, 2019). Occupations with a teleworkability score above 0.5 are identified as suitable for remote working.

[75] The results are in line with Basso et al. (2020), who show that low-wage workers are over-represented in unsafe jobs.

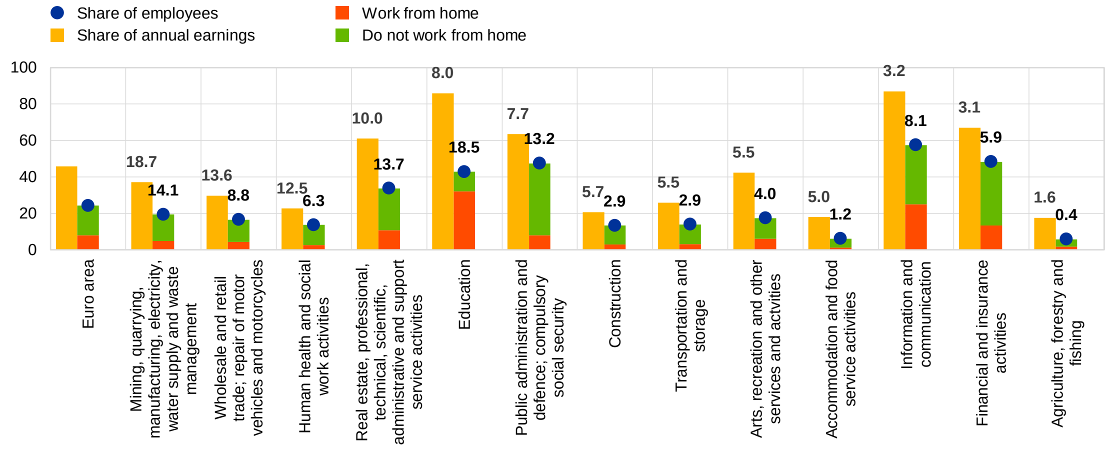
[76] The Labour Force Survey asks respondents whether they work from home. However, an answer of “always” or “sometimes” does not necessarily mean that the individual teleworks or that their job is entirely teleworkable. For instance, teachers might say that they work from home at times to prepare classes, but this does not necessarily mean that they have taught a class from home.

The share of employees in potentially teleworkable jobs is above 50% in the capital regions of the United Kingdom, Belgium, France, Luxembourg and Sweden, while it is around 20% in some regions of Spain, Greece and Romania (see Figure A). Similarly, the share of workers who work from home either regularly or occasionally varies substantially across regions. As many as 70% of potential teleworkers report working from home in Stockholm, while this share is around 45% in Paris and London.

Chart A

Share of annual earnings and employees in potentially teleworkable jobs in the euro area by sector

(percentages)



Sources: Index: Dingel and Neiman (2020); data: EU-LFS 2019, EU-SILC 2018, SOEP (2019); and authors' calculations.
Notes: For the euro area and each sector, the chart shows the share of annual earnings generated by potential teleworking jobs (orange bar) and the share of employees in potential teleworking jobs (blue dot), including those who currently telework (green bar) and those who don't (yellow bar). The figures below the bars show the percentage of the total workforce and the percentage of all potential teleworkers in each sector. Teleworking index aggregated at the ISCO-08 2-digit level using employee weights. Slovakia, Slovenia and Malta are not included.

On the other hand, less than 10% of potential teleworkers engage in remote working in Italy. These pre-pandemic differences in potential and actual take-up rates for teleworking suggest that there were differing degrees of preparedness to promptly deploy remote working as a tool to cope with the pandemic across European regions. Such differences might arise, for instance, from heterogeneous social norms and stigma linked to working from home, as well as from limitations related to digital equipment and skills. The latter refers to a bundle of pre-requisites which would ease remote working, ranging from suitable broadband connections to training aimed at addressing the challenges of remote working environments. Looking ahead, the COVID-19 crisis could accelerate the adoption of teleworking and reduce the digital divide across European countries if countries that are lagging behind invest more in digital technologies.[77]

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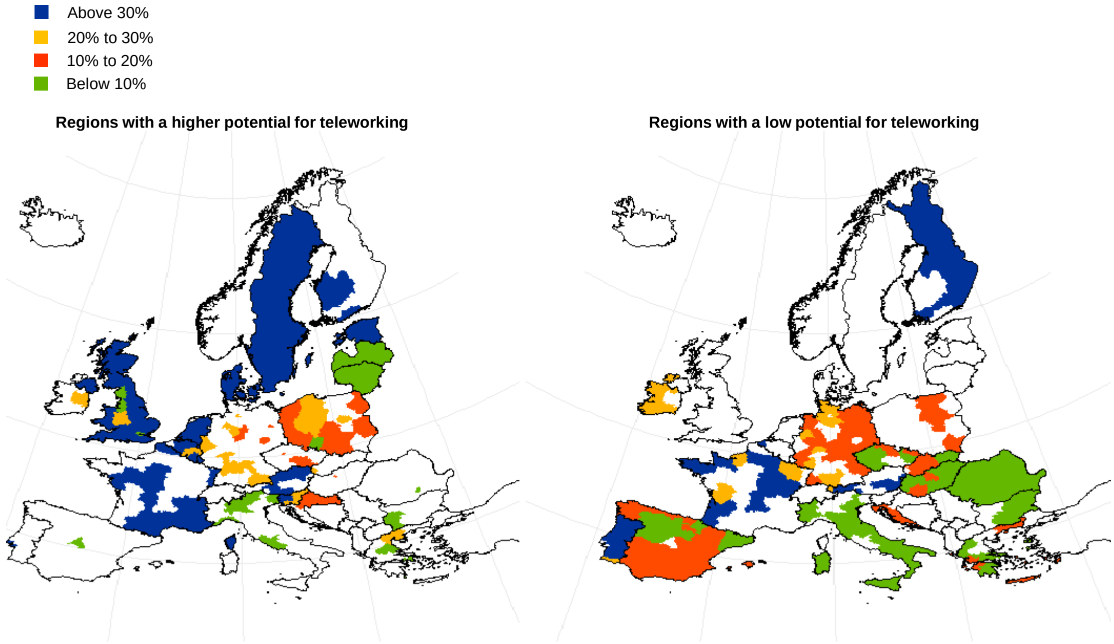
[77] See Anderton et al. (2020a).

Figure A

Share of potential teleworkers who work from home at least sometimes across EU regions



Regions with a higher potential for teleworking

Regions with a low potential for teleworking

Sources: Index: Dingel and Neiman (2020); data: EU-LFS 2019; and authors’ calculations.
Notes: A low potential for teleworking indicates that the share of potentially teleworkable jobs in the area is below 30%. Teleworking index aggregated at the ISCO-08 2-digit level using employee weights. NUTS level is NUTS2, except for the Netherlands (NUTS0), and the United Kingdom (NUTS1). Outermost regions and Malta are not included.

5 Digitalisation and inflation[78]

Digitalisation has a direct effect on inflation through the share and prices of ICT products in the household consumption basket and via relative price movements of items purchased online and offline.

Over the last two decades, euro area inflation for ICT products has been negative and therefore well below average HICP inflation (1.7%) and average HICP excluding food and energy (HICPX) inflation (1.3%). The mechanical contribution of ICT product inflation to euro area HICP (HICPX) inflation has been -15 (-20) basis points per year.

In addition to the direct contribution of digital products to aggregate HICP inflation, digitalisation can change the structure of the economy and influence inflation via indirect channels, such as firms' pricing behaviour, market power and concentration, and firms' productivity and marginal costs. All other things being equal, these indirect effects of digitalisation are important for monetary policy because they may affect the slope of the Phillips curve and can materialise as inflationary or disinflationary forces.

The impact of indirect effects on inflation is manifold and ambiguous. Digitalisation has uncertain effects on the degree of market power (e.g. by increasing price transparency and reducing mark-ups, or by increasing entry costs in terms of R&D investment for competitors of "superstar" firms and thereby increasing the degree of market power and mark-ups).There is also evidence that digitalisation may reduce the costs of changing prices and that online prices are adjusted more frequently than offline prices.

From a theoretical point of view, the indirect effect of digitalisation can be captured by structural parameters, such as the degree of market power and the frequency of price adjustments. These parameters determine the slope of the Phillips curve in a standard New Keynesian model. In this framework, the net effect of these (possibly offsetting) channels remains uncertain.

Empirical evidence on some of the indirect effects of digitalisation on inflation, such as e-commerce, points to a small negative effect, although these estimates are associated with a high degree of uncertainty given that various digitalisation channels are not included in the empirical analyses. This implies that the effects, especially those estimated in the Phillips curve analysis, could be bigger. This stresses the continued need for further investigation with more granular data.

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[78] This chapter has been prepared by Elena Bobeica, Benny Hartwig, Gergő Motyovszki, Anton Nakov, Riccardo Trezzi, Henning Weber and Elisabeth Wieland. It has benefited from comments from Robert Anderton, Sofia Anyfantaki, Gilbert Cette, Luca Dedola, Erwan Gautier, Johannes Hoffman, Vincent Labhard, Chiara Osbat and Filippos Petroulakis. The chapter also draws on Section 7 of Anderton et al. (2020), prepared by Mario Porqueddu and Ieva Rubene. Box 4 has been prepared by Henning Weber. Box 5 has been prepared by Elisabeth Wieland.

5.1 Introduction

When thinking about the impact of digitalisation on inflation, economists typically assume it has a negative impact on both the price level and the relative inflation rate of a sizeable portion of households' consumption items. Digitalisation can be thought of as a process that, through its effects on productivity (and thus costs of production), market structure, price and wage mark-ups, as well as the cost of changing prices, ultimately affects the price level and rate of inflation. This in turn can translate into a persistent and perhaps prolonged, though not permanent, effect on overall inflation. These effects are less obvious than generally assumed and involve several potentially offsetting channels. Despite their potential importance, the empirical evidence on the effects of digitalisation on inflation remains relatively scarce.

In this chapter, we distinguish between "direct" and "indirect" channels of digitalisation on inflation.[79] The former refers to the evolution of the relative prices (and share) of ICT goods and services in the household consumption basket. The latter refers to effects through the supply side of the economy (firms' pricing behaviour, the degree of market competition, and firms' productivity). Overall, empirical findings (both in the literature and in our own exercises) point to a negative, albeit on balance relatively small, impact of digitalisation on inflation so far.[80] Given the importance of the subject, more research is needed and is expected to be carried out in the coming years.

The chapter is organised as follows: Section 5.2 presents the direct channels through which digitalisation affects inflation. Section 5.3 presents the indirect channels through which digitalisation affects inflation, including a qualitative assessment of the impact on the deep parameters of a stylised New Keynesian model. Section 5.4 summarises the empirical literature and presents the results of an ad hoc exercise using an application of the ECB's thick-modelling framework. Finally, Section 5.5 outlines the impact of the COVID-19 pandemic on the spread of digitalisation and its implications for inflation. Section 5.6 concludes.

5.2 Direct channels of impact of digitalisation on inflation

Digitalisation can have a direct effect on inflation through the inclusion of ICT products and products bought online in the household consumption basket. This effect depends on the relative price movements of ICT and non-ICT products and of items purchased online and offline. While the share of ICT items in the household consumption basket has remained broadly stable over time, online sales have

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[79] The definition and measurement challenges of digitalisation proxies (including ICT products) as well as cross-country differences are discussed extensively in Chapter 2. Here, we sidestep these measurement issues and focus on the different economic channels and their impact on inflation. Moreover, we solely focus on inflation as measured by the HICP, which is the underlying measure for the ECB's price stability objective.

[80] These estimates remain quite uncertain for several reasons. First, it is empirically challenging to capture/proxy some of the channels through which digitalisation affects inflation. Second, there is general empirical uncertainty around the main forces driving inflation. Finally, there are measurement issues (see, for instance, Byrne and Corrado, 2020).

increased across euro area countries in the last 20 years. At the same time, while evidence on relative inflation rates for online and offline items is scant and mixed, the relative price of ICT items (both goods and services) has declined. In this section, we present estimates of the direct contribution of ICT items and e-commerce to HICP inflation.[81] The evidence points to a protracted negative mechanical contribution to HICP inflation from the persistent decline in ICT prices.

5.2.1 Evidence of increased e-commerce

Over the last 20 years there has been a large increase in the significance and prevalence of e-commerce. While online sales still make up a relatively small share of total private consumption,[82] the share of people using the internet to obtain information about or buy goods and services has more than doubled over the last 20 years. Panel a in Chart 24 shows the evolution of the use of the internet by households for consumption or information gathering from 2005 to 2019.[83] In 2019 around 70% of households searched for information online, while around 60% made purchases. These shares represent a significant increase compared with 2005, when less than 40% of households were using the internet to gather purchasing information. While most goods and services are purchased from national websites, the share of individuals making cross-border purchases is rising.

On the retailer side, the increased consumer interest in e-commerce corresponded to an increase in online sales. Panel b in Chart 24 shows the share of online sales in retail trade turnover across euro area countries. The yellow bars in panel b show the 2018 level, while the blue dots show the level in 2010. The share of online sales varies by country, with some countries lagging substantially behind. Nevertheless, all euro area countries have shown a rising trend of individuals searching for information and purchasing items online. Overall, the available online shopping data suggest that there has been a significant increase in e-commerce over the last two decades.[84] The indirect effect of e-commerce on inflation, e.g. via increased price transparency, is discussed in Section 5.3.

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[81] Empirical evidence about online and offline prices is presented in Section 5.4.

[82] According to data from Eurostat and Ecommerce Europe (an association of European online retailers), online sales to consumers account for about 15% of total retail sales (excluding cars and motorcycles) in the euro area. Over the last ten years, the growth in online sales to consumers has substantially exceeded the growth in sales in bricks-and-mortar shops. As a result, for most euro area countries, the share of online sales in total retail turnover has more than doubled over the last ten years. The items most frequently purchased on the internet are clothing, accommodation and travel.

[83] The presence of e-commerce can be measured using a number of different indicators on the retailer side (such as the number of websites and the percentage of sales via online channels) and on the consumer side (such as the percentage of consumers buying online). For brevity, in this chapter we show two selected indicators. For more detail, see Anderton et al. (2020b).

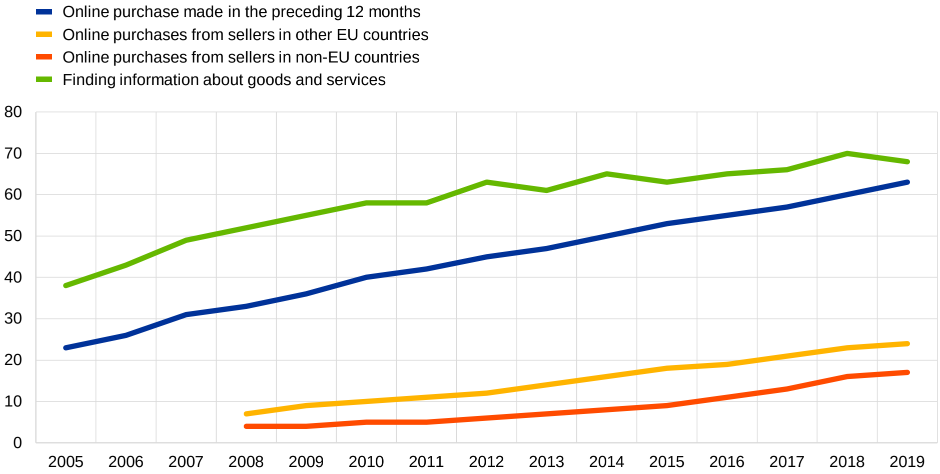
[84] The effect of online purchases on inflation remains hard to quantify because data on relative price movements for online and offline goods and services are available only for case studies. We present the empirical evidence on the subject in Section 5.4, as well as a case study using German CPI microdata.

Chart 24

Households’ use of the internet to purchase and find information on goods and services

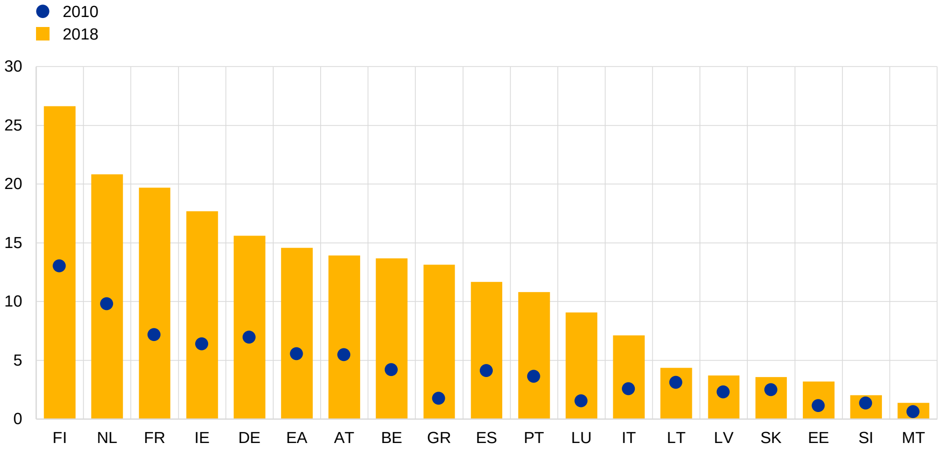
a) Euro area households’ internet use

(percentages)



b) Share of online sales in retail trade turnover

(percentages)



Sources: Eurostat, Ecommerce Europe and ECB staff calculations.
Notes: Retail trade turnover excludes cars and motorcycles; data for online sales to consumers are not available for Cyprus. Panel b: 2010 data for Latvia, Lithuania, Slovenia and Slovakia refer to 2013. The share in retail trade turnover for the euro area (EA) (about 15%) is an aggregation of the available country data.

5.2.2 Direct effect of digitalisation on HICP inflation[85]

Digitalisation has a direct impact on consumer inflation via the prices of ICT products purchased by households. ICT products are among the goods and services regularly purchased by European households and are included in the basket

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[85] This section draws extensively on Anderton et al. (2020b), in particular on Chapter 7 prepared by Mario Porqueddu and Ieva Rubene.

of goods and services used to compute the HICP inflation rate.[86] Therefore, price movements of these items have a direct effect on the overall index.[87]

Over the last two decades, prices of ICT products have fallen, exerting a negative effect on overall HICP inflation. Panel a in Chart 25 shows the ICT inflation rate (in blue) between January 2000 and October 2020. In the last 20 years, ICT prices have, on average, contracted by 3.6% per year, and this contraction was particularly pronounced in the first half of the sample period. The yellow and orange lines in panel a of Chart 25 show the contributions of ICT items to headline HICP inflation and the "core" rate (HICPX inflation), respectively.[88] From an inflation accounting perspective, the decline in the prices of ICT products has contributed negatively to the euro area annual HICP inflation rate by 0.15 percentage points per year, although in the past five years the negative contribution has roughly halved. The contribution to HICPX inflation is slightly more negative (around 0.2 percentage points per year), given the larger weight of ICT items in this index.[89]

ICT inflation has had a heterogeneous impact on inflation rates in individual euro area countries, mainly driven by developments in telecommunication services.[90] Panel b in Chart 25 shows the ICT contribution to the headline HICP annual inflation rate across euro area countries. Specifically, panel b shows the ICT contribution to headline inflation for Germany (yellow), France (orange), Spain (green), Italy (light blue), the euro area (blue) and the range for euro area countries (grey-shaded area). The contours of the lines in panel b are broadly similar, although some countries (such as Germany in around 2001 and France in around 2013)[91] show large negative readings. Differences across countries in the contributions of ICT products to headline HICP inflation mainly reflect different inflation rates for telecommunication services, a sector historically more concentrated and with a higher

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[86] In an ever more technology-intensive world it is difficult to clearly define what a digital product is. ICT products are subject to sudden and rapid technological development which creates challenges for their inclusion in the HICP basket in terms of proper quality adjustment, replacement or expansion of the basket. For this reason, we follow Anderton et al. (2020b) in defining "digital items" using the Eurostat (ECOICOP) classification. The list of ICT items includes: "Audio-visual, photographic and information processing equipment" (09.1), "Telephone and telefax equipment" (08.2), "Telephone and telefax services" (08.3), and "Clocks and watches" (12.3.1.2). The weight of these items is about 4% of total consumption. The weight of ICT items has remained broadly constant over time owing to a combination of two offsetting factors: the increase in the number of ICT items sold and the decrease in their nominal prices. As a result, nominal spending on ICT items relative to total household spending has also remained broadly constant. Nonetheless, as mentioned above, the product classifications are rather broad. In particular, "telephone equipment" includes both mobile and older landline phones. The same applies to the code 09.1, which includes new digital products but also older products replaced by new ICT products. In other words, at this level of aggregation, the apparent stability of the ICT consumption weights hides a compositional shift from older to newer technologies.

[87] In the euro area, consumer price inflation is measured by the HICP, which measures the change over time in the prices of consumer goods and services purchased, used or paid for by euro area households.

[88] Over the sample period 2000-2020, euro area HICP and HICPX inflation were 1.7% and 1.3%, respectively.

[89] These contributions are based on a decomposition of headline inflation across categories, where categories with higher (lower) inflation rates than the average across sectors contribute positively (negatively) to headline inflation. Outside the very short run, these mechanical contributions should not be interpreted as implying that inflation would have been higher without the ICT contribution.

[90] The weight of "communication services" in HICP is currently about 2.5%.

[91] In France, this drop is due to the market entry of a new mobile phone provider offering very low prices.

market power than other sectors.[92] Importantly, HICP inflation rates are computed using quality-adjusted indices for some sub-categories, and this adjustment can be substantial in the case of ICT goods. How such quality-adjusted indices are compiled varies across countries, and this can itself lead to deviations in inflation rates, which in turn could lead to substantial cross-country divergences in the HICP sub-index over longer horizons.[93]

The estimates of the direct impact of ICT price developments on HICP inflation are surrounded by high uncertainty, which is due to several factors. First, some product categories in the underlying consumer basket of the HICP have very high IT intensity (for example, household appliances and cars), but it is difficult to measure and rank such intensity. Therefore, we have used a rather narrow definition of ICT products. Second, several digital products in the consumer basket were not considered in this analysis.[94] Because ICT items tend to contribute negatively to the overall HICP index, our estimate can be interpreted as a lower bound of the direct effect of relative ICT price movements on overall inflation. In other words, the negative impact of ICT items on HICP inflation is presumably a bit larger than estimated here. Finally, ICT products (or electronic goods) are subject to rapid technological change, which creates measurement challenges in terms of quality adjustment, replacement or expansion of the basket.[95]

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[92] For the United States, Byrne and Corrado (2020) construct an alternative price index for consumer digital services and find that the increase in the total PCE price index would have been nearly 0.5 pp lower than the official index since 2008. Differences across countries might also come from different methodologies used to deal with measurement issues.

[93] Work stream on inflation measurement (2021) contains a detailed discussion of issues related to heterogeneity in quality adjustment practices for the HICP.

[94] The reason is that a more disaggregated estimate can only start in December 2016, which is when indices based on the new ECOICOP classification became available.

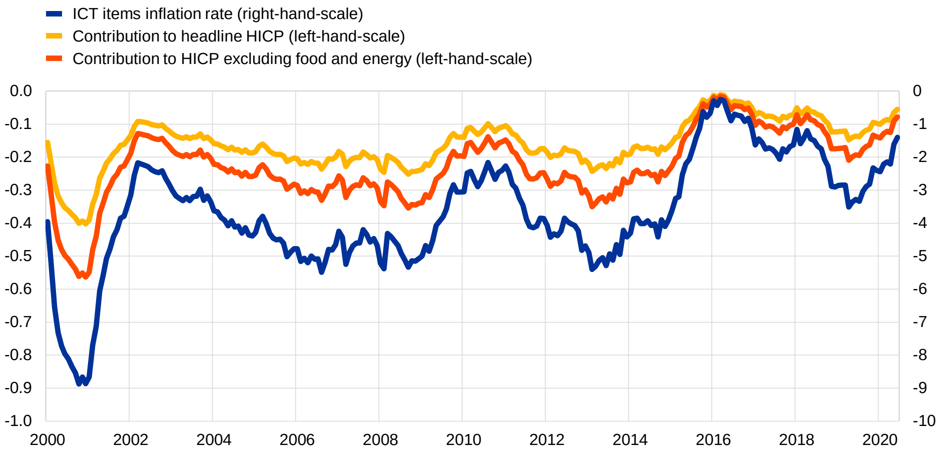
[95] For a detailed discussion on this point, see Chapter 2.

Chart 25

ICT consumer product price developments and their impact on inflation

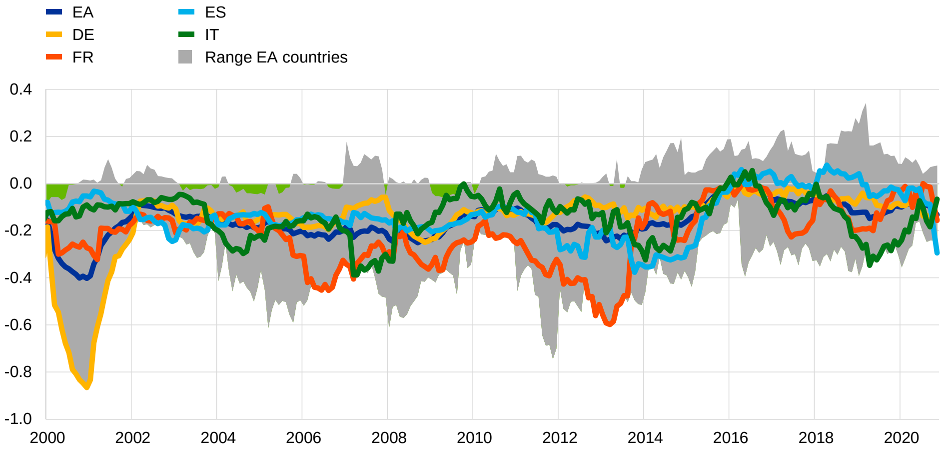
a) ICT product price developments in euro area countries

(left-hand scale: percentage point contributions; right-hand scale: percentages)



b) ICT product contribution to headline HICP annual inflation rate

(percentage point contributions)



Source: ECB staff calculations based on Eurostat data.
Notes: ICT products include audio-visual, photographic and information processing equipment and telephone and telefax equipment and services. Inflation rates for 2000 and 2001 are distorted as they reflect the methodological impact of the inclusion of internet services in Germany's HICP. The range is based on a changing group of countries reflecting the composition of the euro area.

5.3 Indirect channels of impact of digitalisation on inflation

The indirect impact of digitalisation on prices and inflation is more challenging to define and estimate than the direct channel. Chapter 4 on digitalisation and the labour market discusses important indirect channels, such as automation (and the related channel of productivity growth) and the effects of skill heterogeneity and mismatch on wage growth and inequality. A very important result when considering the impact of digitalisation on inflation via the labour market is that when skills are heterogeneous in terms of complementarity or substitutability to capital, the Phillips curve becomes flatter. Moreover, wage premia for high-skilled workers relative to low-skilled workers lead to income inequality and heterogeneous consumption behaviour. This section adds to that analysis by reviewing three main indirect channels originating in product markets, all of which operate on the supply side of the economy: (i) firms' pricing behaviour; (ii) market concentration and firms' mark-ups; and (iii) firms' productivity. After reviewing each channel in turn qualitatively, we look at them through the lens of a standard New Keynesian model to understand how digitalisation operates by affecting the deep parameters of that model.

5.3.1 Pricing behaviour

Digitalisation can affect inflation by increasing price flexibility. Higher price flexibility increases the responsiveness of prices to shocks and may lead to higher volatility of inflation. Digitalisation can reduce price adjustment costs for both online stores and bricks-and-mortar shops. Changing prices in online stores is technologically easier than in bricks-and-mortar shops, but technology can also reduce the cost of changing prices in bricks-and-mortar shops, especially if prices are displayed on electronic devices. Beyond this practical impact on menu costs, more important is the reduction in information costs, i.e. the cognitive resources necessary to optimise prices in a non-stylised business context in which firms produce many different goods and services.[96]

Furthermore, digital algorithms facilitate dynamic pricing practices, whereby prices react automatically to changing market conditions, potentially within a day (surge pricing). From a theoretical point of view, in a standard "menu cost" model this would be captured via a permanent reduction in the menu cost parameter. In models where nominal stickiness arises due to information friction (e.g. models of "rational inattention"), this would instead manifest itself in a lower cost of information processing. In either case, the frequency of price changes increases and so does the size of the "selection effect" for a given frequency.[97] Microeconomic features of pricing can have macroeconomic consequences, potentially improving price responsiveness at macro levels and frequencies too, which is why exploring this potential effect of digitalisation is relevant for central banks. In general, higher price flexibility makes inflation more responsive to aggregate demand pressures. In other words, higher price flexibility steepens the Phillips curve. One complication, however, is the relationship between very high frequency price changes and what macroeconomists call "price flexibility". The extent to which very high-frequency price fluctuations are related to the responsiveness of the general price level to aggregate demand at lower frequencies is the subject of ongoing debate.[98]

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[96] See Costain et al. (2018).

[97] The selection effect is the positive covariance between the absolute size and the probability of price changes in a setting with idiosyncratic shocks. When selection increases, prices become more aligned with fundamentals and inefficient price dispersion decreases, with positive allocative effects, similar to a favourable productivity shift.

[98] For example, outlets may pursue a policy of charging high prices most of the time and low prices intermittently, thereby trying to capture some of the consumer surplus by discriminating between informed and uninformed buyers.

5.3.2 Mark-ups and concentration

The effect of digitalisation on inflation via market concentration and firms' mark-ups is ambiguous because it influences the degree of market competition via several channels, with impacts in opposing directions.[99] On the one hand, digitalisation can increase the degree of market competition and reduce firms' mark-ups, for example by increasing price transparency or by "commoditising" more efficient production practices that were previously only accessible to very large firms. On the other hand, digitalisation can increase entry costs in terms of investment in R&D and reduce the degree of market competition. Data from users can be a valuable competitive asset: new entrants may find that data constitute a substantial barrier to entry into digital markets.[100] Which factor dominates depends on the structure of a given market, and the net effect remains uncertain. We look more closely at each factor below.

Digitalisation can reduce the degree of market concentration and reduce firms' mark-ups. Online stores increase competition among firms by widening the relevant market in which firms compete. Digitalisation can also reduce entry costs, as digital technologies, platforms and services reduce entry barriers and customer acquisition costs. In addition, digital technologies facilitate price comparison across products, reducing information frictions. In other words, digital technologies increase the degree of substitutability across similar products. This higher substitutability of goods due to easier price comparison mitigates the market power of firms and results in greater competition. On the other hand, recent research indicates that digitalisation and, more specifically, algorithmic pricing strategies can have the opposite effect, as these algorithms can learn to "collude" with one another, charging prices above competitive levels.[101]

Digitalisation can also be a vehicle for higher market concentration and higher mark-ups.[102] The large initial investment necessary for the development of digital technologies and the subsequent low cost of scaling up imply that tech firms operate with relatively high fixed costs compared to marginal costs. High fixed costs tend to induce higher market concentration and the emergence of natural monopolies or "superstar" firms, as they increase entry barriers and limit the number of firms. In addition, higher market concentration can be reinforced by network effects associated with digital technologies, as first movers tend to dominate their markets.

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[99] This is subject to ongoing research on both sides of the Atlantic. In the United States, some studies have underlined the increasing power of "superstar" firms, while ECB research (see Cavalleri et al., 2019, and Praet, 2019) has found that in the euro area mark-ups did not increase as much or as recently.

[100] A very interesting discussion on "digital value chains" and interdependencies initiated through data connectivity can be found in Subramaniam (2020) and Lianos (2019).

[101] See Calvano et al. (2020).

[102] There is a debate about the extent to which higher market power stemming from higher concentration leads to higher mark-ups, as firms may become large precisely by strategically keeping mark-ups low and attracting market share. Nevertheless, there is broad agreement that concentration and average mark-ups move together, indicating that larger firms can afford to use their large average mark-ups as a cushion against temporary increases in marginal costs to retain market shares. This in turn reduces the sensitivity of inflation to demand pressures, thereby flattening the Phillips curve.

Whether the net effect of digitalisation is to increase or decrease firms' market power in a given sector or on aggregate across sectors, it can lead to macroeconomic effects via several channels. For instance, consider the case of reduced competition. By reducing the number of firms and hence the substitutability of goods, digitalisation lowers the price elasticity of demand (which is in general an important measure of market power). This in turn raises firms' market power and the mark-up that firms would optimally like to charge over their marginal costs. Digitalisation can also affect the pricing behaviour of firms in other ways that alter the responsiveness of inflation to changes in their marginal costs (i.e. the slope of the Phillips curve).[103] The overall effect of this channel depends on the nature of nominal rigidities and the existence of strategic complementarities across firms (i.e. reduced competition can either steepen or flatten the Phillips curve). Shocks to desired mark-ups also matter: falling mark-ups could reflect a changing degree of product market competition and firm market power brought about by digital change. This kind of shock is likely to introduce a welfare-relevant trade-off between inflation and an appropriately defined output gap; in other words, it is likely to break the "divine coincidence" (Blanchard and Galí, 2010).

5.3.3 Firms' productivity

The impact of digitalisation unfolds over time because firms adopt new digital technologies gradually. The chapter on digitalisation and productivity discusses the possible impact of digitalisation on productivity and the extent to which the impact on aggregate productivity may take a long time to be fully manifested. A stylised fact across advanced economies is that their aggregate productivity has slowed down at the same time that digital innovation has accelerated. This has raised the question of whether the digitalisation drive was not sufficient to compensate the slowdown in productivity in other sectors, or whether the digital transformation was so deep that it exceeded the scope of traditional statistical measurement. The chapter on productivity discusses three main stylised facts: (i) ICT drives productivity trends; (ii) there is an asymmetry in the benefits from innovation (that is, a small number of firms benefit greatly, while most firms see only moderate productivity gains); and (iii) digital adoption is still low overall, especially among SMEs.

The implications of these three stylised facts for inflation can be thought of as stemming from a persistent supply shock. Shocks to aggregate productivity or intermediate inputs embedded in ICT could reflect the productivity-enhancing effects of digitalisation across firms. A positive shock lowers marginal costs, leading to disinflationary pressures. The persistence of this effect is due to the continuous pace of innovation, but also to its slow adoption. If wage growth is indexed to productivity, and if productivity accelerates as digitalisation becomes more diffused, there would

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[103] Potentially changing market concentration could alter the market structure and the nature of competition in a way that affects the market power of firms even if the underlying price elasticity of demand is unchanged. A continuum of small monopolistically competitive firms has different implications for pricing behaviour and desired mark-ups than a handful of larger oligopolistic competitors in the same market, who must also strategically consider the effect of their own actions on aggregate market outcomes, thereby altering the effective price elasticity of demand they face.

be, all other things being equal, a transitory negative impact on inflation. However, given its nature, digitalisation may contribute to the separation of firms into early/full adopters and laggards, potentially affecting not only wage dynamics but also market structure in some of the ways described above, with direct implications for market concentration and firms' pricing behaviour.

The previous sections exposed how complex it is to derive even qualitatively the impact of digitalisation on inflation through various channels. It is even more difficult to analyse the interplay between the aforementioned channels. For this reason, in the next section we look at them systematically through the lens of a stylised New Keynesian model.

5.3.4 Digitalisation in a stylised New Keynesian model[104]

This section explores the impact of digitalisation on inflation and on the monetary policy transmission mechanism via firm pricing behaviour, market concentration and firms' productivity using a standard New Keynesian model with monopolistic competition in the goods market. The box at the end of this section shows that the addition of heterogeneity in productivity across firms, which could be characterised as "digital" and "analogue" firms, introduces a possibly "surprising" effect of digitalisation on trend inflation via its effect on the dynamics of productivity dispersion.

Digitalisation can be captured by several parameters in a standard New Keynesian model. We look at the channels outlined above through the lens of the standard Calvo model, as described in Galí (2008) and Woodford (2003). The basic ingredients of this standard framework are the consumption preferences of households and the profit optimisation choices of firms. Households have a preference for consuming different varieties of each type of good, and this is reflected on the production side by a large number of firms, each producing a variety, giving rise to monopolistic competition. Firms are assumed to have similar trends in productivity, while demand for differentiated products is aggregated as in Kimball (1995).[105] Our aim is to understand how digitalisation can affect the monetary policy transmission mechanism via changes in the parameters of the model. Up to a first-order approximation, the supply side of this framework is described by the New Keynesian Phillips curve (NKPC): firms would like to charge an optimal time-varying mark-up over marginal costs, but staggered price stickiness occasionally prevents them from adjusting their prices and maintaining their desired mark-up, leading to persistent deviations of the actual mark-up from its desired level. If actual mark-ups are lower than desired ones, there is upward pressure on inflation. An important composite parameter in the Phillips curve is its "slope coefficient". The slope coefficient depends

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[104] The Calvo framework is used here for analytical convenience. We do not cover the Rotemberg adjustment cost model because it is inconsistent with micro evidence on the nominal stickiness of individual prices.

[105] While the Dixit-Stiglitz aggregator is characterised by a constant elasticity of substitution, the Kimball (1995) aggregator allows for the elasticity of substitution among goods to be a function of their relative market share. See also Sbordone (2010).

on the degree of nominal rigidities, firms' elasticity of demand ($\bar{\varepsilon}$), the elasticity of marginal cost to sales and the elasticity of firms' mark-up.

In this stylised framework, the indirect channels of digitalisation are captured by the model parameters or by shocks affecting the behaviour of marginal costs. Table 5 shows the slope of the NKPC under alternative model specifications. In the special case of the Dixit-Stiglitz aggregator, the determinants of the slope of the NKPC are summarised in the second and third columns of Table 5.

Table 5

Slope of the NKPC under alternative model specifications

Kimball aggregator	Dixit-Stiglitz aggregator	Dixit-Stiglitz aggregator
Sbordone (2010):	Galí (2008):	Woodford (2003):
$= \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1}{1+\bar{\varepsilon}(s_y+\epsilon_\mu)}$	$= \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1}{1+\varepsilon\left(\frac{\alpha}{1-\alpha}\right)}$	$= \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1}{1+\varepsilon\left(\frac{\alpha+\varphi}{1-\alpha}\right)}$

Note: 1-α is the labour elasticity of output in the production function; φ is the elasticity of labour supply; θ is the probability of not changing the nominal price; β is the time discount factor; $\bar{\varepsilon}$ is the steady state elasticity of demand; s_y is the steady state elasticity of marginal cost with respect to sales; and ϵ_μ is the price elasticity of demand.

The impact of digitalisation on parameters like demand elasticity and the degree of nominal rigidities will manifest itself in the slope of the Phillips curve, while the impact of digitalisation on aggregate productivity will transmit through the Phillips curve via marginal costs.

The impact of digitalisation via factors affecting the slope of the NKPC can lead to either a flattening or a steepening. We first consider the degree of nominal rigidity under Calvo pricing (the parameter θ), which represents the fraction of firms not adjusting prices in any given period. Digitalisation can reduce θ, making prices more flexible and leading to a steeper Phillips curve (also making prices more responsive to change in utilisation). This is likely to have a first-order effect on monetary policy transmission: there will probably be faster transmission to prices but less effect on real output. Switching to the demand elasticity ($\bar{\varepsilon}$), this parameter affects the desired mark-up ($\mu = \frac{\bar{\varepsilon}}{\bar{\varepsilon}-1}$). If digitalisation reduces the mark-up by increasing $\bar{\varepsilon}$, it will tend to flatten the NKPC. The elasticity of the mark-up function (ϵ_μ), which is a decreasing function of the number of goods, also plays a role. If digitalisation increases the number of products, this channel in isolation will tend to steepen the NKPC. The final parameter is the elasticity of marginal cost with respect to sales (s_y), which depends on, among other things, the labour elasticity in production. As also discussed in the note on the labour market, digitalisation may reduce the "labour share", leading to a higher s_y and hence a flatter NKPC, all other things being equal.

The theoretical framework sketched above is relatively simple, but even within this highly stylised model there remains ambiguity regarding the impact of digitalisation via the various channels. This simple overview showed that a quantification of the indirect impact of digitalisation on inflation and monetary policy transmission is very complicated, but it also indicated important directions of research that can lead to this quantification: understanding what the dominant market structure in each economy is and if it has changed, understanding the pricing behaviour of firms within that market structure, and understanding the impact of digitalisation on productivity. These “ingredients”, whose quantification largely hinges on the availability of microdata, can then inform the specification and estimation of structural models.

As discussed above, looking at digitalisation from the perspective of the deep parameters of alternative NKPC models shows that the impact of digitalisation is theoretically uncertain. The issue remains an empirical question, but the sketch of theoretical channels presented in this section can help orient the empirical work agenda. The next section focuses on the results of the – as yet rather scant – empirical literature.

Box 4
An additional channel of impact of digitalisation on inflation: productivity dispersion

Productivity dispersion affects inflation and the optimal central bank target. According to a stylised New Keynesian model accounting for productivity dispersion, when digital technologies and automation lead to permanently higher structural productivity dispersion, this can affect monetary policy transmission and, depending on the monetary policy rule, also the average level of inflation.

While the newly adopted technologies are expected to raise firm-level productivity, technology diffusion and adoption speeds are likely to differ across firms. For instance, young firms may find it easier to adopt digital technologies, and start-ups may base their entire business model on these technologies. By contrast, older firms may lack the sophisticated management and skilled workforce required to adopt digital technologies swiftly and successfully. On the other hand, older firms may find it easier than younger firms to finance the necessary investment to adopt new technologies. Indeed, the years before the current pandemic saw an increase in productivity dispersion: the productivity gap between firms on the technology frontier and other firms has widened in firm-level data.[106] In what follows, we present another stylised New Keynesian model to understand how productivity dispersion can affect the inflation rate.

Adam and Weber (2019) developed a stylised model to consider the effect of the evolution of productivity dispersion on inflation. Their New Keynesian framework incorporates firm turnover and firm-level productivity dynamics in addition to nominally sticky product prices.[107] Higher firm-level productivity complements labour and hence translates into a lower cost of production.[108] In the framework, aggregate productivity growth consists of three components: one common to all firms; one specific to incumbent firms, and another specific to firms newly entering the economy. In principle, digitalisation can affect all three components. While its impact on the first one can be

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[106] See Andrews et al. (2016).

[107] Despite firm turnover, the mass of firms is kept constant such that firm turnover does not alter the competitive structure of the product market, unlike the effects considered in the previous section.

[108] Two models discussed in the note on digitalisation and the labour market, by Abbritti and Consolo (2019) and Basso and Rachedi (2020), show the effects of releasing the modelling simplification that the labour input is homogeneous and all productivity change is labour-enhancing. These modelling decisions in turn have consequences for the predicted impact on inflation. Abbritti and Consolo (2019) introduce high and low-skilled workers, introducing job displacements effects for the latter and an increase in the relative employment and wages of the former in the short run. Simulations show that, all other things being equal, the Phillips curve flattens when heterogeneity in skill levels is introduced in this model. Basso and Rachedi (2020) model labour and automating technology as substitutes and find that automation flattens the slope of the Phillips curve by reducing the labour elasticity of output. Also, wage pass-through falls as the relative importance of the labour factor declines relative to that of machines.

analysed in a textbook New Keynesian model, the consequences of its impact on the second and third components for the determination of inflation can be better understood in the model framework in Adam and Weber (2019). Up to a first-order approximation, the production side in this framework can be summarised by an augmented New Keynesian Phillips curve (NKPC):

$$\pi_t - \pi^* = \beta E_t(\pi_{t+1} - \pi^*) + \mu\, y_t, \qquad (1)$$

where π_t denotes inflation, π^* denotes the optimal level of trend inflation, and y_t is the welfare-relevant output gap. Optimal trend inflation is defined as the level of inflation that the central bank should target to set the output gap at zero.[109] Thus, while in the standard NKPC the inflation rate and the inflation gap $\pi_t - \pi^*$ exactly coincide, the two variables differ in the augmented NKPC. Optimal trend inflation $\pi^* = g/q$, where g denotes the steady state productivity growth specific to incumbent firms and q denotes the steady state productivity growth specific to newly entering firms.

Productivity dispersion affects optimal trend inflation and hence the NKPC via these two growth rates. Changes in relative productivity among firms also require inverse changes in relative product prices. For example, raising q also raises the productivity of the current cohort of new firms relative to the productivity of the average incumbent such that relative prices of new firms should decline to restore allocative efficiency. With sticky prices of incumbent firms, new firms should enter the economy with relatively low prices, reducing optimal trend inflation. Along these lines, optimal trend inflation is not affected by the common productivity component, because changes in productivity common to all firms require that relative product prices remain unchanged.

This augmented NKPC suggests two important channels through which long-lasting changes in productivity dispersion can affect inflation dynamics.

First, structurally higher productivity dispersion can affect inflation dynamics via the slope of the augmented NKPC. A long-lasting, structural increase in productivity dispersion has ambiguous effects on this slope depending on which firms improve in terms of productivity growth: the new or the old ones. In the case where productivity dispersion increases because the entry productivity level of new firms grows faster (higher q), incumbent firms would see their market share decline going forward. Therefore, incumbents emphasise current cost conditions more than future cost conditions, which raises the slope of the NKPC. In contrast, when higher productivity dispersion results from higher productivity growth in incumbent firms, these firms see their market share expand going forward, which leads to a decline in the slope.

A second channel through which long-lasting changes in productivity dispersion can affect inflation is via monetary policy itself. Suppose that optimal trend inflation experiences a long-lasting decline in a scenario in which monetary policy reacts to both deviations in inflation from target and the output gap and is not constrained by the effective lower bound. In this scenario, the decline in optimal trend inflation constitutes a permanent shift in the augmented NKPC that exerts downward pressure on inflation. The central bank partly offsets this downward pressure, but also accepts some below-target inflation to prevent the output gap from opening excessively. To avoid this predicament, the central bank should adjust its target to optimal trend inflation.

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[109] This concept of trend inflation differs from the one employed in Ascari and Sbordone (2014), where trend inflation is not associated with a closed output gap.

5.4 Empirical assessment of the indirect impact of digitalisation on inflation

The existing empirical literature has investigated two main aspects: (i) the impact of e-commerce on consumer price inflation; and (ii) relative online and offline price movements. After reviewing the existing literature[110], we provide an empirical estimate of the impact of digitalisation on euro area inflation dynamics. Overall, the empirical evidence suggests a negative impact of digitalisation on inflation, although the estimates are quite uncertain.

5.4.1 Literature review of the empirical indirect impacts of digitalisation on inflation

Empirical evidence on the effect of digitalisation on inflation is scarce and focuses mainly on the e-commerce channel, pointing to a small negative effect. Based on a panel of 207 countries, Yi and Choi (2005) find that a one percentage point increase in the share of people using the internet per annum is associated with an 0.04 to 0.1 percentage point lower annual inflation rate. This figure is broadly in line with Lorenzani and Varga (2014), who estimate the impact of online purchases of goods and services in the EU27 on the basis of the degree of price competition. They estimate that changes in the share of online purchases of goods and services in the retail sector between 2010 and 2015 mechanically lowered inflation in the retail sector by about 0.1 percentage points each year. Along the same lines, Csonto et al. (2019) obtain Phillips curve estimates showing statistically significant negative short-run effects of digitalisation on inflation. They find that the effect of digitalisation on inflation is not large but has increased since 2012 and mainly operates through a cost/competition channel. Finally, for the euro area, Porqueddu and Rubene in Anderton et al. (2020b) find that a one percentage point increase in the share of people shopping online for goods or services reduces annual non-energy industrial goods (NEIG) inflation by 0.06 percentage points, compared to an average annual NEIG inflation rate of 0.6% over the same period. Overall, a considerable level of uncertainty surrounds the aforementioned estimates, owing inter alia to the underlying measure of inflation and digitalisation, as well as difficulties in properly disentangling the effect of digitalisation from that of other structural drivers.

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[110] A survey looking at the effects on inflation alongside other variables is available in Anderton et al. (2020b).

Table 6

Empirical estimates of the effects of digitalisation on consumer price inflation

	Dependent variable	Estimate	Independent variable	Data source	Countries	Sample
Csonto et al. (2019)	Inflation	-0.05 pp (per year over sample period)	Number of IP addresses per country	APNIC	36 advanced and emerging economies	2012-2017
Lorenzani and Varga (2014)	Retail price inflation	around -0.08 pp (-0.53 pp over sample period)	E-commerce integration	European Commission, Civic Consulting	EU27	2010-2015
Porqueddu and Rubene in Anderton et al. (2020b)	NEIG inflation	-0.06 pp (per year over sample period)	Percentage of people looking for information online	Eurostat	EU subset	2003-2018
Yi and Choi (2005)	Inflation	-0.04 to -0.1 pp	1% increase in share of internet users	World Bank	207 countries	1991-2000

The study of the relative behaviour of online and offline prices is still in its infancy but the literature points to differences between the two channels.[111] Lünnemann and Wintr (2006) find that price changes in products traded online are on average smaller than the price changes captured by consumer price index data. Cavallo (2017) compares online and offline retailers in ten advanced economies[112] and finds that price changes appear desynchronised in the two markets but have similar frequencies and average sizes. Gorodnichenko and Talavera (2017) observe that online prices are somewhat more flexible and respond more swiftly to movements in nominal exchange rates.[113] Specifically, they estimate that the pass-through of cost shocks to online prices is between 60% and 75%, compared to between 20% and 40% for bricks-and-mortar shops. Cavallo (2018) shows that the aggregate frequency of price changes in multi-channel retailers has been increasing for the last 10 years. The implied duration for regular price changes, i.e. excluding sales and temporary discounts, has fallen from 6.7 months in 2008-2010 to approximately 3.65 months in 2014-2017, a level similar to what Gorodnichenko and Talavera (2017) found for online-only retailers. Moreover, Cavallo (2018) shows that goods found online (on Amazon) are more likely to have a higher share of identical prices and lower average price dispersion across locations. These results are consistent with Ater and Rigbi (2018), suggesting that the transparency of the web imposes a constraint on bricks-and-mortar retailers' ability to price discriminate across locations. Along these lines, Gorodnichenko et al. (2018) find that prices are adjusted in online shops by about the same amount on average as those in bricks-and-mortar shops. Dumitru and Wieland (2020) exploit information on the weighting scheme of the official German CPI

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[111] The inclusion in the HICP of goods and services traded online has an impact on HICP inflation only if the prices of such products and services change at different rates to the prices of goods and services traded offline. If there are no relative prices changes, the inclusion of online prices in the index does not have any impact on HICP inflation. Online prices are already reflected in the HICP through price collection, though the variation across euro area NSIs is unknown. On this point, see also Work stream on inflation measurement (2021).

[112] Cavallo uses data for Argentina, Australia, Brazil, Canada, China, Germany, Japan, South Africa, the United Kingdom, and the United States, collected in the context of MIT's The Billion Prices Project for offline and online prices.

[113] The evidence on exchange rate pass-through in Gorodnichenko and Talavera (2017) refers to the United States and Canada.

obtained under the umbrella of the Price-setting Microdata Analysis Network (PRISMA) and show that online prices change more frequently than offline prices (see Box 5 for details). Overall, owing to the recent emergence of online and offline microdata for research purposes, this strand of the literature is evolving rapidly, which will enable more in-depth research to better understand the relationship between online and offline prices and their relative dynamics.

Box 5

Online and offline prices: evidence from German CPI microdata

This box analyses and quantifies the degree of price rigidity of online and offline prices using German CPI microdata.[114] In this exercise we use a dataset that includes monthly observations over the period 2015-2019 for about 7.8 million prices per year covering about 81% of the official CPI basket. In defining online and offline prices, we exploit the information of the CPI weighting scheme, which currently includes eight types of outlet, such as discounters, supermarkets and internet trade (see Chart A).[115] In the German CPI the explicit weighting by outlet type is applied to about one-third of the CPI basket (i.e. mostly goods, since there are only a few online services) at the lowest level of the underlying Classification of Individual Consumption According to Purpose (COICOP-10 digit level, e.g. 09.1.2.1.13100 – Digital camera).[116] The aim of our exercise is to study the relative behaviour of online and offline prices and to quantify price rigidity in terms of price changes. Overall, our results show that the frequency of price changes appears to be higher for online than offline products.

Several methodological assumptions were necessary to organise and analyse the data. We identify online products in the German CPI micro database as prices collected for the outlet type “internet trade” (292 COICOP-10 groups), whereas offline products correspond to prices collected for the remaining physical outlet types (667 COICOP-10 groups). Moreover, we define a category “offline traded online” for those offline products for which the same type of online product is available at the COICOP-10 level (also 292 COICOP-10 groups). The latter can be seen as a proper online/offline comparison at the product level.[117] In terms of the frequency of price changes, we follow Dhyne et al. (2006) and compute price changes at the product level in each store. This yields about 504,200 unique products per month, with online products representing one-fifth of observations. Each product has a number of price spells, i.e. sequences of time intervals between two price changes. For any given COICOP-10 group, we compute the share of individual price changes in the total number of price spells across all products in that group. To derive statistics for higher-level aggregates, we apply the official CPI weights as of 2015.

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[114] This box is an update of the findings of Dumitru and Wieland (2020) for Germany. To the best of our knowledge, the availability of CPI microdata by outlet type and internet trade, as found in the German database, is unique in the euro area.

[115] According to the latest CPI base year, 2015, internet trade makes up roughly 11% of the relevant consumer expenditures, although its share varies strongly, from 31% for household appliances to just 1% for food. In contrast to the annually updated HICP weights for goods and services, the outlet-type weights are updated only every five years with the introduction of a new CPI base year.

[116] Outlet-type weights are derived from various sources (e.g. official trade statistics and market research data on turnover distribution in the retail trade). Moreover, the outlet-type weights for a given product can differ across federal states (see Federal Statistical Office of Germany, 2018).

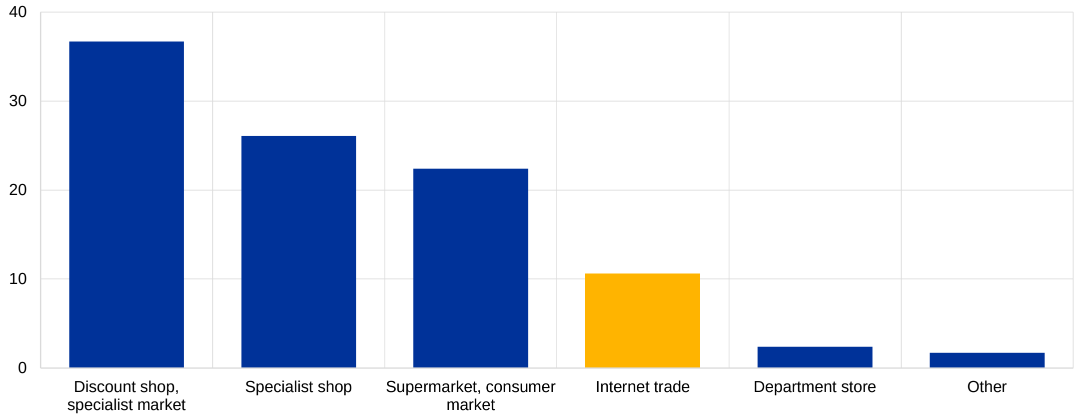
[117] Note that previous studies on online/offline prices compare the same product barcode (e.g. a specific model of women’s sport shoe) for multi-channel retailers who sell both online and offline (Cavallo, 2017 and 2018). Our dataset suffers from the drawback that we cannot identify the same product across different outlet types. Nevertheless, our product definition follows the lowest CPI aggregate possible (e.g. “Women’s sport shoes”). Moreover, the CPI micro database is sampled in a representative way, which underlines the relevance of the products considered here.

Overall, price rigidity – in terms of the frequency of price changes – appears to be lower for online than offline products. As shown in Chart B, online prices change more often than offline prices, especially for non-energy industrial goods (NEIG). This evidence is prominent for semi-durable goods (such as clothing and recreational items) as well as non-durable goods (such as personal care products and stationery). The finding of lower online price rigidity remains true whether we consider all offline products (yellow bars in Chart B) or just those which are also traded online (red bars in Chart B). One exception is the category "processed food", where online products mainly include frozen food and alcoholic beverages. Note that the share of offline discounters in this food category is relatively high, which largely contributes to the higher price flexibility in the offline channel.[118] Finally, differences in price rigidity seem to be positively related to the degree of competition between the online and offline channel: the higher the share of the outlet type "internet trade" in a given COICOP-10 group, the higher the frequency of online price changes in relation to offline prices (correlation coefficient: 0.31). Concerning inflation measurement, this finding suggests that it is reasonable to track online and offline prices across various outlet types, since their dynamics might differ even in the case of a generally high degree of competition.

Chart A

German CPI: aggregated weights of outlet types (2015)

(percentages)



Source: Federal Statistical Office of Germany.

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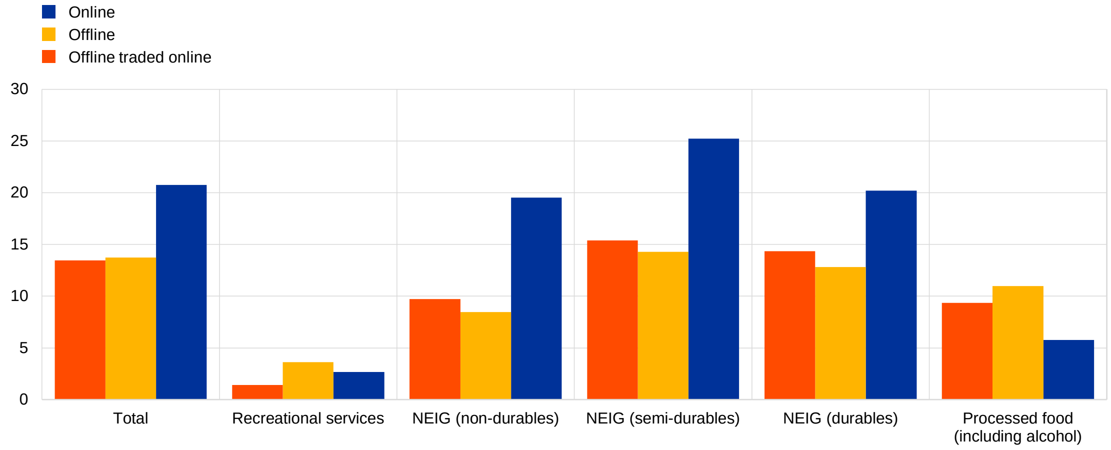
[118] The quality of online products in this food category might also be higher, as reflected in a higher average price level than for offline products.

Chart B

Frequency of price changes in the German HICP

(percentages, 2015-2019)



Sources: Federal Statistical Office of Germany, State Statistical Offices and Deutsche Bundesbank calculations.

5.4.2 Empirical evidence from an augmented “thick-modelling” Phillips curve exercise

The multidimensionality of the concept of digitalisation and the complexity of the interactions make it very challenging to quantify its impact on inflation through the lens of a reduced-form Phillips curve. Additional challenges arise on the data front, as most available proxies span a short sample and are available only at an annual frequency. In this section, we estimate the impact of digitalisation on inflation using a standard Phillips curve framework augmented with ad hoc variables aimed at proxying digitalisation, mostly related to e-commerce use by households or firms. The Phillips curve framework follows Bobeica and Sokol (2019) in which the seasonally adjusted annualised growth rate of the HICPX is regressed on its own lag, a lagged measure of slack, a survey measure of inflation expectations, and a measure of import prices. Starting from this framework, we add a set of variables to proxy digitalisation, distinguishing between measures on the household side and measures on the retailer side.[119] Specifically, on the household side, we consider: the intensity of internet use,[120] the frequency of online purchases, and some variables capturing online purchases by categories of items. On the firm side, the indicators cover three digital activities: providing a description of the items sold on the website, allowing consumers to place orders, and allowing customers to track their orders.

We employ a “thick-modelling” approach to hedge against the uncertainty about measures of economic slack, inflation expectations and digitalisation. This approach consists in running a set of models that differ from each other for the specific variables included, such as the specific measure of slack, the chosen

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[119] All indicators are provided by Eurostat on a yearly basis and have been interpolated using a cubic spline.

[120] This includes data on online banking, on finding information about goods and services, on selling goods and services and on email usage.

measure of inflation expectations or the specific proxy of digitalisation. All models include the import price deflator as a measure of external price pressure. In total, our exercise includes 7,128 models: 972 models add the digitalisation proxies on the household side to the standard Phillips curve variables (slack, inflation expectations, and import prices), while the remaining 6,156 models add the digitalisation proxies on the retailer side.[121] After running each model, we compute the contribution to inflation of each explanatory variable. Finally, we summarise the overall contribution of a variable by averaging across all models.

Based on this analysis, the impact of digitalisation on short-run inflation dynamics appears to be small. Chart 26 presents the estimated contributions to HICPX inflation of the Phillips curve variables. Specifically, in Chart 26 we show the HICPX year-on-year changes (blue line), the estimated contribution from economic slack (yellow bars), the contributions from import prices (orange bars), the contributions from movements in inflation expectations (light green bars), the contributions from the digitalisation proxies (light blue bars), and the unexplained portion (dark green bars). Panel a plots the average contribution of the digitalisation proxies from the models that included the household-side variables, while panel b plots the average contribution of the digitalisation proxies on the firm side. Few indicators of digitalisation yield a statistically significant impact. On the household side, 37% of indicators are significant and refer to the intensity of internet use (online banking and email), as well as to the frequency of online purchases. On the firm side, only 10% of indicators are significant and these refer to the number of purchasing and post-purchasing options available to customers (e.g. whether customers can track their packages or not).[122] Overall, the contribution of the proxies of digitalisation is small (see the light blue bars in Chart 26), although on the household side the contribution is always negative and possibly non-negligible. The same evidence remains true if we only include the proxies of digitalisation that are statistically significant in the Phillips curve.

Our results should be interpreted bearing in mind a number of caveats. First, digitalisation can affect inflation via numerous channels, potentially with long lags. Therefore, capturing its influence within a traditional Phillips curve model can be empirically challenging. Second, the start of the sample period in this exercise is 2005 in the case of digitalisation proxies on the household side and only 2009 for those on the firm side. The sample thus largely spans two puzzling inflation episodes, the

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[121] Digitalisation is here considered with a lag, which also accounts for potential endogeneity issues, but a longer lag structure paints a qualitatively similar picture; the variables are included in growth rates, as in Csonto et al. (2019). In general, the empirical challenges in our exercise arose from the lack of (quarterly) data, the multitude of possible transmission channels, and the lags of the transmission.

[122] Another way to check the explanatory power of digitalisation proxies for inflation is to compare the inflation outcomes with the forecast based on the model conditional on the realised values of all explanatory variables. We performed such an exercise for the low inflation period starting in 2013 and concluded that the digitalisation proxies marginally reduce the associated root mean squared forecast error (RMSFE) of inflation (the average RMSFE for models with proxies on the household side is 0.2684 compared to 0.2812 for their counterparts without such proxies, while the average RMSFE for models with proxies on the firm side is 0.3130 compared to 0.3216 for their counterparts without such proxies). Over the full sample, the average adjusted R^2 for models with proxies on the household side is 0.4263, compared to 0.4130 for their counterparts without such proxies (sample starting in 2005). The average adjusted R^2 for models with proxies on the firm side are slightly higher at 0.1764, compared to 0.1751 (sample starting in 2009).

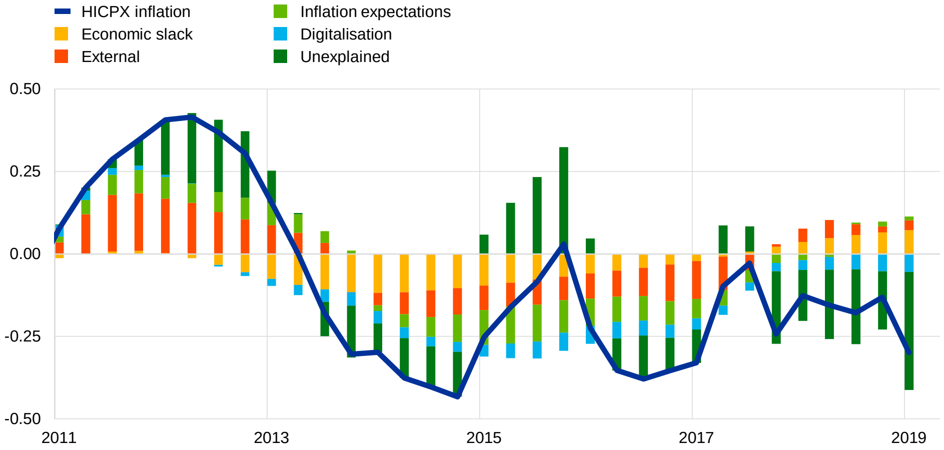
"missing disinflation" and the "missing inflation", the latter being associated with a low inflation regime, yielding a sizeable unexplained component in inflation. Finally, one should bear in mind that the proxies considered for digitalisations are imperfect, and measuring the "true" contribution of this complex phenomenon to the inflation process remains elusive.

Chart 26

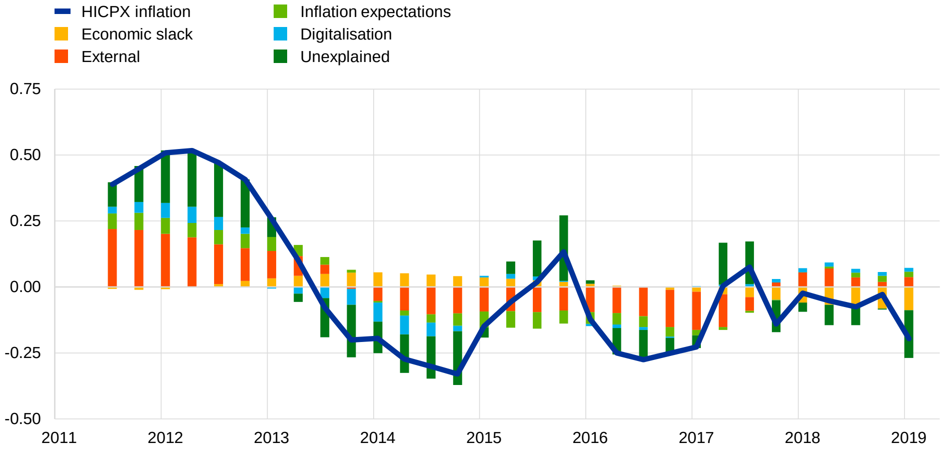
Contributions to HICPX inflation estimated using augmented Phillips curve models

(annual percentage changes and percentage point contributions vis-à-vis historical means)

a) Household side



b) Firm side



Sources: ECB staff calculations based on Eurostat data.
Notes: Panel a: the bars show average contributions across a set of 972 models (differing by the included variables). Panel b: the bars show average contributions across a set of 6,156 models (differing by the included variables). Contributions are derived as in Yellen (2015).

5.5 Summary and recommendations

In this chapter we have presented and discussed theoretical and empirical evidence on the impact of digitalisation on consumer price inflation. From a theoretical point of view, a New Keynesian model helps in disentangling the three main channels through which digitalisation operates (firms' pricing behaviour, market concentration and firms' mark-ups, and firms' productivity). Discussing digitalisation from the perspective of the deep parameters of a New Keynesian model shows that the impact of digitalisation is theoretically uncertain, as several channels can potentially offset each other. On the other hand, the empirical evidence produced so far in the literature is still limited, focuses mainly on the e-commerce channel, and points to a small negative effect. On top of this, the direct effect of digitalisation through relative ICT products inflation in the HICP in the last two decades has been negative. Overall, the literature continues to reinforce the need for further investigation. From a policy perspective, it is important to stress that if digitalisation has heterogenous effects on the slope of the Phillips curve across countries, it might contribute to inflation dispersion and make the transmission of monetary policy less homogeneous across countries. This chapter can also help set the research agenda going forward: it has shown that reduced-form analysis may not be well suited to quantifying the impact of digitalisation on inflation and that a structural approach is needed. At the same time, the discussion based on the New Keynesian framework has shown that the impact of some channels could have different signs in different sectors depending on market structure. It has also pointed to the importance of modelling some aspects of heterogeneity, showing how effects on optimal trend inflation can appear when heterogeneity in firm productivity dynamics is accounted for. This underlines the importance of complementing structural analysis with heterogeneity along some dimensions, which can only be supported by using microdata. For this purpose, the effort made in the context of the European System of Central Banks (ESCB) to acquire microdata on prices both from private data providers and from NSIs (PRISMA) and to improve firm balance sheet data (iBach, ERICA) is a step in the right direction.

6 COVID-19, digitalisation, productivity, labour markets and inflation[123]

Following the onset of COVID-19, there has been an increase in the take-up and use of digital technologies, while teleworking has also markedly increased. However, given the large differences across EU countries in terms of digital adoption before the pandemic, any impacts on productivity, labour markets and inflation may be spread unevenly across EU countries.

Digitalisation is a general purpose technology, where productivity gains may take time to materialise, hence any long-lasting acceleration in digitalisation due to COVID-19 may only deliver higher productivity with a substantial lag. On the other hand, if the COVID-19-related rise in, for example, online retail sales and online banking persists then the significant and rapid productivity gains already experienced by those sectors may extend into the future.

There are early signs that the more digitalised EU economies (and those with higher teleworking potential) weathered the COVID-19 shock better than the less digitalised economies. This has been reinforced by a substantial rise in teleworking, which could have a positive or negative impact on productivity, which may also be heterogeneous across European countries and regions and may exacerbate inequality trends.

The COVID-19 pandemic and the associated acceleration in digitalisation implies potentially far-reaching structural change across product and labour markets which could boost the productivity gains from digitalisation. In addition, there may also be possible temporary labour market disruptions, skills mismatches, and further increases in labour market polarisation and inequality.

An acceleration in digitalisation could also further exacerbate measurement issues relating to prices and output, thereby highlighting the need for digital economy satellite accounts for the euro area economies. Inflation and its dynamics could be further affected by issues related to teleworking and the possible changes in property rental costs and house prices, while significant increases in online retail sales may also affect prices.

The overall impact of an acceleration in digitalisation (if long-lasting) on the economy will also depend on the evolution of institutions, infrastructure, workers’ skills and policy responses: job retention schemes and loan guarantees to firms are essential for now, but may eventually impede job/firm/sectoral reallocation, while the Next Generation EU package is also aimed at boosting the digital transition. The Single Market and the public sector can also play important roles in digital adoption.

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[123] This chapter has been prepared by Robert Anderton, Vincent Labhard and Pedro Neves Rebelo Luís, with input from workstream members. It has benefited from comments from Gaetano Basso, Gilbert Cette, Emanuela Ciappana and Elisabeth Wieland.

6.1 An acceleration in digitalisation due to COVID-19?

Following the onset of the pandemic, there has been an increase in the take-up and use of digital technologies, especially in connection with lockdowns restricting physical mobility within and across regions and countries.[124] The increase in take-up has affected digital services and goods alike, as reflected in the corresponding data, usage/subscription statistics in the case of digital services as available through online platforms[125], and retail sales statistics in the case of digital (or digitally-ordered) goods (as illustrated in Chart 27 below). Also, the stock market performance of selected US digital/tech firms has significantly increased relative to the average equity price since the outbreak of COVID-19, which seems to suggest a more important role and increased demand for digital services now and in the future (see Chart 28).[126,127] Given that these are primarily US tech firms, this may also indicate a further falling behind of Europe in terms of digitalisation. However, the largest technology companies operate globally, so intra-firm productivity, for example, is shared across the global organisation and can also benefit European productivity.[128] As described in further detail in Chapters 3 and 4 on productivity and the labour market, teleworking and remote working have also expanded rapidly during the pandemic. There have also been strong advances in other new technologies that may also deliver productivity gains. For example, the very large investment and effort put into the development of vaccines may have also accelerated the development of new technologies in the health sector.[129]

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[124] In order to fully capture the pick-up, this chapter focuses on short-term, high-frequency data.

[125] See, for, example Kemp (2020) as well as the surveys in Digital 2020 – April Global Snapshot. These surveys of internet users aged 16-64 in selected countries show that the outbreak of COVID-19 is associated with substantial increases in online and digital activities (rising by between 40% and 60% for activities such as streaming films and music, social media, messenger services, etc). Many survey respondents said that they expect their new habits to continue after the COVID-19 outbreak passes (e.g. 15-20% expect their increased use of streaming services and social media to continue).

[126] How much the equity price growth of the digital firms represents a permanent move towards digitalisation is open to debate, particularly given that equity prices of some digital-related firms fell markedly when positive announcements concerning vaccines (e.g. Pfizer-BioNTech) were made in November 2020.

[127] However, a drop in aggregate output may also reduce the incentive to automate (Leduc and Liu, 2020).

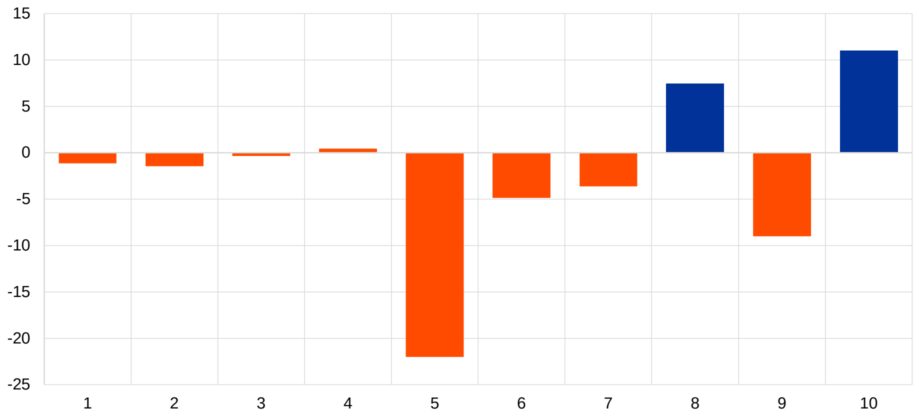
[128] See, for example, McGrattan and Prescott (2010) on the productivity of global firms.

[129] Moreover, the outbreak of the coronavirus pandemic has triggered unprecedented demand for digital health technology solutions, a trend that has been gaining momentum in recent years. See, for example, StartUp Health Insights Reports for information on health innovation funding.

Chart 27

Euro area retail trade – change between February 2020 and July 2020

(percentages)

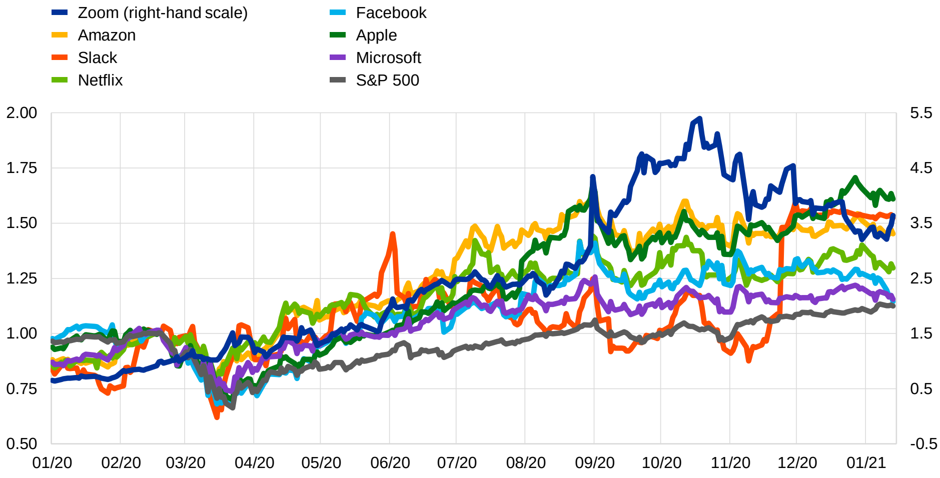


Sources: Eurostat and ECB staff calculations.
Note: 1 – Retail trade, except of motor vehicles and motorcycles; 2 – Retail sale of food, beverages and tobacco; 3 – Retail sale of non-food products (including fuel); ; 4 – Retail sale of non-food products (except fuel); 5 – Retail sale of textiles, clothing, footwear and leather goods in specialised stores; 6 – Dispensing chemist; retail sale of medical and orthopaedic goods, cosmetic and toilet articles in specialised stores; 7 – Retail sale of computers, peripheral units and software; telecommunications equipment, etc. in specialised stores; 8 – Retail sale of audio and video equipment; hardware, paints and glass; electrical household appliances, etc. in specialised stores; 9 – Retail sale of automotive fuel in specialised stores; and 10 – Retail sale via mail order houses or via Internet.

Chart 28

Stock market performance of selected US tech firms and market since the start of the crisis

(index: 20 February 2020 = 1)



Source: Yahoo Finance.

An ad hoc ECB survey of leading euro area companies on the long-term effects of the coronavirus (COVID-19) pandemic on the economy[130] **found that more remote working and an acceleration of digitalisation were the most frequently cited long-term supply-side effects of the pandemic.** Firms were asked to briefly

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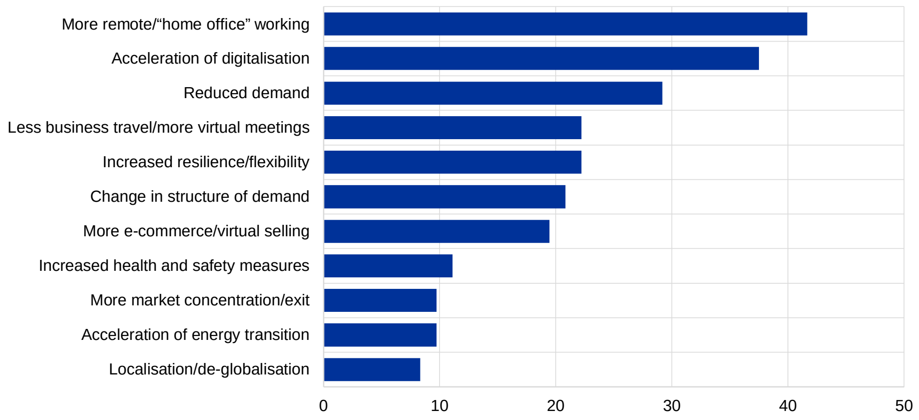
[130] See Maqui and Morris (2020).

explain the most important long-term impacts on their business (see Chart 29). More than 40% of firms surveyed cited increased use of the "home office", while almost as many said that the pandemic had led their company to accelerate the adoption of digital technologies which will change the way they operate in the long term. Around one-fifth of respondents cited a more permanent reduction in business travel and/or increase in virtual meetings, and a similar number pointed to increased e-commerce or – in business-to-business segments – "virtual selling". Around one-fifth highlighted the fact that actions taken in response to the pandemic would make their business more resilient and/or more flexible in the long term.[131]

Chart 29

Main long-term effects of the pandemic reported by leading companies

(percentages of respondents)



Source: Maqui and Morris (2020).
Notes: The survey question was as follows – "What long-term effects, if any, do you expect the COVID-19 pandemic to have on your business (for example, in terms of business organisation or the markets you operate in)? Please list up to three impacts in order of importance." The replies were subsequently grouped by category.

6.2 COVID-19, digitalisation and productivity

As was the case with recent major crises, the COVID-19 pandemic seems to be acting as catalyst for the greater adoption of new technologies, in particular digital technologies.[132,133] Such long-term changes to the organisation of work could open the door to large positive potential impacts in terms of productivity. It remains to be seen to what extent these potential productivity gains will take time to come

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[131] In further questions, nine out of ten firms surveyed confirmed that they had accelerated their take-up of digital technologies and/or automation, while more than three-quarters agreed that a significantly higher share of their workforce would continue to work remotely. Around 60% disagreed when asked if more remote working reduced productivity, compared with just 20% who agreed with the statement. In this regard, while reduced informal, personal interaction was seen as a downside, many advantages were also perceived, including the reduction in time lost through commuting, the possibility to better juggle home and work commitments, and increased connectivity.

[132] However, it is difficult to gauge exactly what the counterfactual situation would have been, as the decline in demand due the initial economic downturn arising from COVID-19 may also have reduced the pace of digital adoption.

[133] See Dieppe (2020) for the impact of large shocks such as epidemics and natural disasters on technological adoption and productivity.

through, as GPTs such as digitalisation are often slow to deliver productivity increases (as explained in Chapter 3). In the shorter term the question is the extent to which the potential productivity gains in some sectors may be offset by disruption and reduced output in other sectors. For example, many activities have seen a marked shift to an online (virtual) environment, affecting ways of working and (e.g. teleworking and videoconferencing) and doing business (e.g. online banking and e-commerce). Some of these changes have the potential to deliver significant and rapid productivity gains. For example, if the shifts during the COVID-19 lockdown towards online shopping and online banking persist, these sectors could potentially experience significant and rapid productivity gains.[134]

Meanwhile, the short-term disruption has been severe, notably in supply chains (industries, firms and jobs) with a strong offline and/or physical component. Manual workers have been hit hard, as has the airline business and supporting industries, especially in the passenger/leisure segment. Other transport and hospitality services, bricks-and-mortar stores and other traditional outlets (high street shopping and outlet centres) have also been affected, particularly in inner-city locations. Digitalisation enables products in these supply chains to be substituted (with less business travel and associated lunches, for example), but for digitalisation to ultimately give a boost to aggregate productivity, there must eventually be positive spillovers in labour-intensive industries and firms (and for the incomes of the corresponding workers). The overall disruption to productivity is likely to be greatest in the supply chains most directly hit by the pandemic, although the industries and firms that survive in these supply chains may also emerge from the pandemic more productive than before.

Teleworking and remote working have increased markedly and are likely to continue at higher levels in the future, but their impact on productivity is not clear and may be heterogeneous across the euro area and EU countries, and their regions. As described in more detail in Chapter 3 on productivity, there are various mechanisms through which teleworking may lead to positive or negative impacts on productivity, including, for example, technological conditions (quality of hardware, software, connectivity), home conditions (childcare, home office environment), support (ICT specialists, teleworking training, management training) and face-to-face interactions with colleagues (e.g. partial teleworking).[135] Calculations of the potential share of teleworkable jobs across European countries in Box 3 (Chapter 4) show that there is a marked digital divide between northern and southern European countries as well as between their regions. Hence, any potential impact on

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[134] For example, assuming that online transactions require fewer employees than offline transactions in retail stores and banks, a permanent increase in these online transactions accompanied by closures of high street shops and banks will probably result in a net reduction in employment and a rise in productivity in these sectors.

[135] A number of measurement issues also arise as teleworking becomes a standard way of working in many sectors. For example, the relevant geographical dimensions of the labour market become less clear as virtual labour flows across regions and borders become more prevalent. Moreover, it could get more difficult to measure actual hours worked. Both dimensions contribute to new challenges in measuring slack, with implications for the conduct of monetary policy.

productivity from teleworking may lead to heterogeneous impacts across both countries and regions.[136]

Moreover, in terms of GDP growth, there are signs that the more digitalised EU economies (and those with higher teleworking potential) weathered the COVID-19 shock better than the less digitalised economies. On average, GDP growth fell by less in the first half of 2020 for the economies that are more digital according to the DESI (see Chart 30)[137], suggesting that they weathered better the unexpected COVID-19 economic shock in the first half of 2020. The same applies when considering the entire course of 2020, as can be seen in the regressions in the first row of Table 7. The positive correlation between GDP growth and digitalisation is even stronger when country-specific teleworking capabilities are taken into account; hence GDP growth during 2020 was seemingly enhanced by digitalisation and potential teleworking capabilities (see second row of Table 7).[138,139] Of course, several other factors are likely to influence GDP growth – such as fiscal support measures and lockdown strictness, which differed across countries. To capture these effects, columns 3 and 4 of Table 7 include a set of controls expected to account for the aforementioned issues, namely a stringency index measuring the severity of lockdown measures taken by countries and an economic support index indicating the level of government provision of income support policies. Results show that the previous conclusions are robust to the inclusion of these controls, strengthening the indications of a positive link between digitalisation and resilience to the COVID-19 shock.[140] These results are consistent with other studies which found that more digitalised sectors acted as a shock absorber to reduce the decline in output, or that higher degrees of technological advancement across regions helped to reduce the unemployment impact during the initial COVID-19 economic downturn.[141]

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[136] According to a recent Eurofound study, most EU workers report a positive experience with teleworking during the pandemic, but very few wish to telework all the time, with the preferred option being a mix of teleworking and presence at the workplace. Also, most workers reported working longer hours compared to before the pandemic. This applies across all euro area countries.

[137] Chart 30 shows that the relationship between the fall in GDP growth and digitalisation may not necessarily be linear (green line), but in the regressions reported in Table 7 we estimate linear specifications in order to simplify the analysis.

[138] The data for teleworking are the proportion of potential teleworkable jobs by country as described in Chapter 4 of this report on “Digitalisation and the labour market”.

[139] Further GDP regressions against the components of the DESI suggest that the sub-components of the DESI for connectivity and human capital are more strongly associated with GDP growth than other components. Preliminary regressions using sectoral data and including fixed effects (which may at least partly capture sector-specific impacts of COVID-19) also indicate that more digitalised countries (supplemented by teleworking potential) did better in terms of growth performance in the first half of 2020.

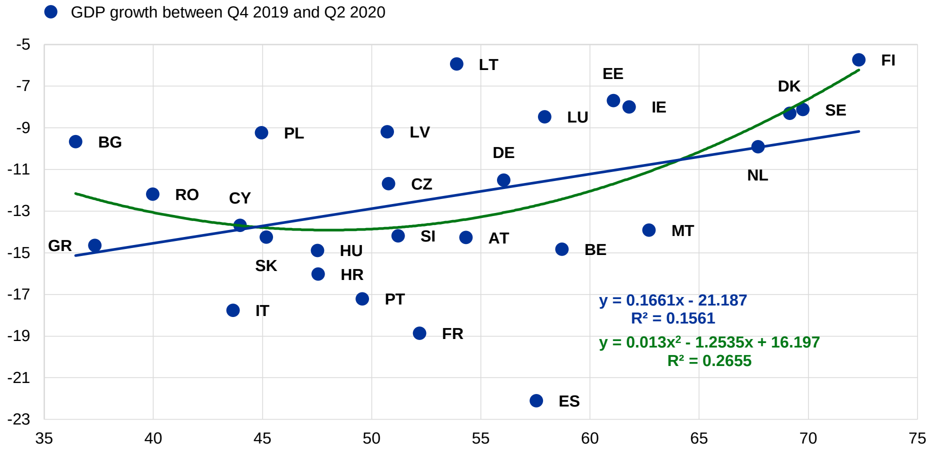
[140] The R^2 increases significantly and coefficients change slightly, highlighting the importance of including these controls.

[141] See, for example, Section 3 of Faquet and Malardé (2020) and Pierri and Timmer (2020a, 2020b).

Chart 30

Decline in GDP growth (Q4 2019 to Q2 2020) and degree of digitalisation across EU countries

(y-axis: GDP growth between Q4 2019 and Q2 2020, percentages; x-axis: DESI)



Sources: Eurostat and ECB staff calculations.
Notes: EU27 countries. DESI = Digital Economy and Society Index (higher value denotes higher degree of digitalisation).

Table 7

Regressions: GDP growth, digitalisation (DESI) and teleworkable jobs

Dependent variable	Constant	DESI	DESI*TW	R2	Controls
GDP growth (y-o-y)	-9.83***	0.091**		0.03	NO
GDP growth (y-o-y)	-8.92***		0.22***	0.06	NO
GDP growth (y-o-y)	-1.28	0.072**		0.41	YES
GDP growth (y-o-y)	-0.96		0.18***	0.42	YES

Sources: Eurostat and ECB staff calculations.
Notes: Each regression is computed based on a panel data section comprising the EU27 countries and year-on-year (y-o-y) GDP growth for the period from Q1 2020 to Q4 2020; DESI*TW is an interaction term between the DESI and the percentage of potentially teleworkable jobs; ** and *** denote statistical significance at 5% and 1%, respectively. Controls include the Oxford COVID-19 Government Response Tracker indices of stringency of lockdown measures and policy support during the pandemic.

6.3 COVID-19, digitalisation and the labour market

The short and longer-term transformational effects of the pandemic on the labour market in connection with the more digital economy are uncertain but could be far-reaching. Compounded by the digitalisation shock, the lockdown-induced falls in consumption in interaction-intensive sectors (bricks-and-mortar retailers, travel and tourism, arts and entertainment) will have, at least in the short run, distributional effects favouring digital-intensive sectors. In the medium run, in order to reduce interaction among workers and keep production going, and thanks to the diffusion of new communication technologies (ultra-fast broadband and 5G mobile networks), both manufacturing and service employers may speed up their adoption of automating technology whose productivity is not affected by COVID-related uncertainty. However, a drop in aggregate output will also reduce the incentive to automate (Leduc and Liu, 2020). Some quantitative estimates of the impacts see short-term labour market displacement with more benign effects in the medium-term: for example, The Future of Jobs Report 2020 (World Economic Forum, 2020) suggests that the displacement effects from automation are going to speed up as a result of the pandemic, with 85 million jobs to be lost (but also 97 million to be created) by 2025 across 26 countries.[142]

In the short run, inequality may also increase. This is consistent with the idea that technology increases the productivity of high-skilled workers relative to low-skilled workers, thus raising the relative demand for and wages of skilled labour (Katz and Murphy, 1992). Similarly, Abbritti and Consolo (2019) show that an automation shock may lead to higher wage inequality over time, as skilled labour is complementary to automated capital.[143] In addition, a number of channels may contribute to magnifying inequality. Increased teleworking is associated with higher-paid jobs, which may also exacerbate inequality trends.[144] According to The Future of Jobs Report 2020, workers displaced during the COVID-19 pandemic have been mostly female, young and low-wage workers. In addition, low-wage jobs tend to be less suitable for remote working, making low-paid workers disproportionately more likely to stop working during a pandemic. Finally, employment among women may decrease when complementary services, such as childcare, are locked down. Lack of digital literacy is also associated with greater income inequality in times of crisis, although the increase in digitalisation due to COVID-19 may also trigger an increase in digital literacy and skills through "learning by doing".

During the COVID-19 crisis in the euro area, the decline in employment led to an increase in inequality which was strongest for temporary employees, the young and workers with lower levels of education. Chart 31 shows that employment of workers with high levels of education was virtually unaffected by the pandemic, whereas workers with lower levels of education saw a sharp decline in their employment. The better employment outcomes for the higher-skilled compared to those with fewer skills may be associated with the increased use of teleworking and may be consistent with the ongoing, or even accelerating, adoption of automation processes and the labour market polarisation associated with digitalisation. The pandemic has also been associated with a rise in inequality for employees with temporary contracts; while there are many reasons for the differences in the evolution of employment across different categories of workers during the pandemic, employment decreased most for employees with temporary contracts. Among these workers, young workers were more affected than older workers. Similarly, but to a lesser extent, employment also declined more for women than for men.

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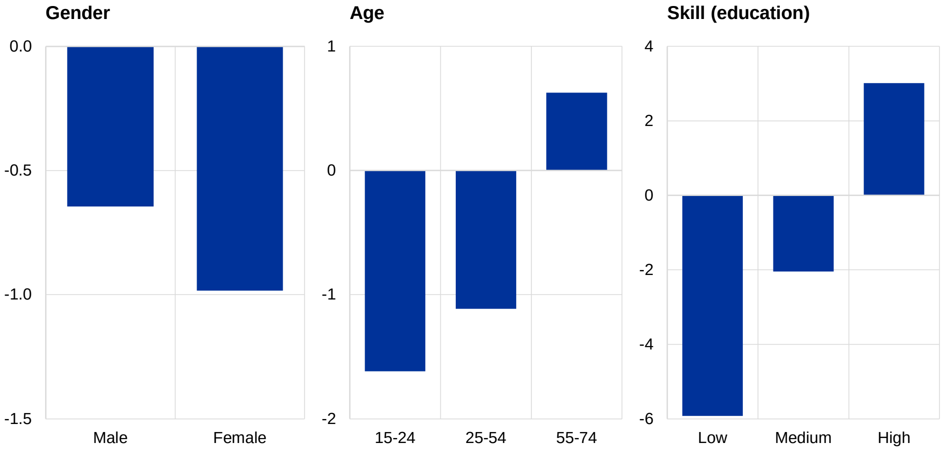
[142] Two ECB podcasts also discuss the implications of digitalisation for European labour markets, including trends in automation and the associated labour market polarisation, including with respect to how higher-skilled jobs may also be automated by AI (see ECB, 2020a and 2020b). See also Dias da Silva et al. (2019).

[143] The main results of Abbritti and Consolo (2019) on an automation shock and inequality are also reported in Section 5.3 "A general equilibrium perspective of how automation affects the labour market" by Consolo, A. in Anderton et al. (2020b).

[144] The initial impact of the pandemic was much less severe for high-skilled workers, even in non-teleworkable jobs. However, teleworkability was an important factor for manual occupations (Petroulakis, 2020).

Chart 31
Impact on employment during the pandemic (Q4 2019 to Q3 2020)

(percentage changes)



Sources: Eurostat, Labour Force Survey database and ECB staff calculations.
Notes: The chart shows the cumulative impact on the labour force across groups between Q4 2019 and Q3 2020. Skill is measured by level of education, with low-skilled having lower secondary education, medium-skilled having upper secondary education and high-skilled having a university degree or higher.

At the same time, not all jobs can be digitalised (e.g. large numbers of jobs in tourism and health care, etc.), at least not in the short term. Indeed, an acceleration in digitalisation and automation could further exacerbate job polarisation trends, as jobs characterised by routine tasks can be easily automated, which has resulted in a fall in the employment share of medium-skilled jobs (such as bank tellers, machine operators and office clerks) compared to the share of high and low-skilled jobs. High-skilled jobs have limited automation potential, and are complementary to digital technologies, while automation has not yet affected many non-routine low-skilled jobs (such as cleaners, security staff, care workers, etc., whose jobs are difficult to automate).[145,146]

An acceleration in digitalisation in the aftermath of the COVID-19 pandemic could also speed up the process of structural change with differential effects across sectors. For instance, job losses in retail bank branches that have occurred over the past few years are likely to have accelerated as a result of the pandemic and the sudden increase in online banking. Such structural change, particularly if it occurs rapidly, may lead to some temporary disruption in the labour market as well as a skills mismatch, while geographical labour market mismatches within and across countries could decline as virtual labour flows increase.

Based on the ECB survey of large companies, most firms expected the pandemic to have a positive long-term impact on productivity but a negative

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[145] Nevertheless, recent developments in digitalisation are also opening up new possibilities for the automation of high-skill jobs. For instance, Autor and Reynolds (2020), among others, claim that unemployment will also increase for high-skilled and self-employed workers (not only for medium and low-skilled workers) as AI advances and firms realise that they can cut labour costs and experience future productivity gains through digitalisation.

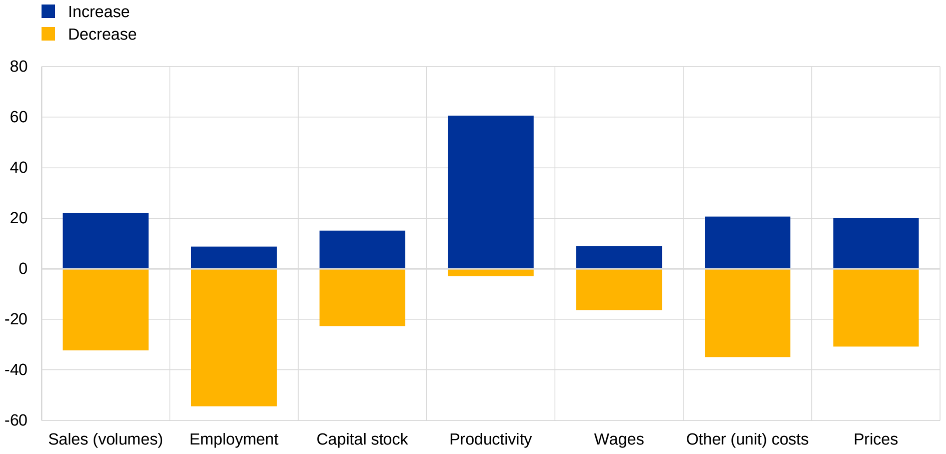
[146] For descriptions of labour market polarisation trends in Europe, see Goos et al. (2009); Section 5 “Labour Markets” by Petroulakis, F. in Anderton et al. (2020b); Dias da Silva et al. (2019); and Michaels et al. (2014).

impact on employment (see Chart 32). When asked to assess the overall long-term effect on selected aggregates, 60% of firms said that productivity in their business or sector would increase, while hardly any saw productivity decreasing as a long-term consequence of the pandemic. Conversely, 55% anticipated a negative long-term impact on employment, compared with around 10% who saw a positive effect. Meanwhile, relatively few saw the pandemic having any long-term effect on their company's capital stock. The anticipated long-term effect of the pandemic on sales (volumes), prices and costs were slightly negative on balance, but most respondents indicated that they did not anticipate – or were unsure about – any long-term effect.

Chart 32

How firms see the long-term effect of the pandemic on business aggregates

(percentage of respondents)



Source: Maqui and Morris (2020).
Notes: The survey question was as follows – "Focusing on your own business/sector, how would you assess the overall long-term effects of the COVID-19 pandemic on the following?" Respondents could answer (i) increase, (ii) decrease, (iii) no change or (iv) don't know. In the chart, "increase" is assigned a score of 1 and "decrease" a score of -1.

6.4 COVID-19, digitalisation, price measurement and inflation

6.4.1 COVID-19, digitalisation and price measurement

An immediate implication of the pandemic for price measurement is that spending patterns and price setting may be evolving as digitalisation intensifies due to COVID-19.[147] The switch to increased online shopping implies that spending on online platforms accounts for a greater proportion of expenditure, and so the (possibly different) prices charged and frequency of price changes online may be more relevant than before the pandemic (see also Section 6.4.2). It is not clear whether all changes in spending or pricing patterns during the year will have to be

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[147] In the HICP, annual spending weights for a given year t should reflect the spending patterns of year t-1. For practical reasons, national accounts data for t-2 are generally used for this purpose in normal times. For a more detailed discussion of COVID-19-related changes in spending patterns and their implication for the HICP, see Work stream on inflation measurement (2021) and Kouvavas et al. (2020).

taken into account for the production of price statistics, but it is clear that if the production process of price statistics remains unchanged, the resulting data may affect the biases in those statistics. This in turn may mean that inflation measures for the period during and after the pandemic may not be fully comparable with inflation measures from the pre-pandemic period.

At the same time, the traditional collection and compilation of statistical data has been made more difficult by the pandemic. In the early phase of the pandemic, for example, widespread lockdowns made it challenging for NSIs to collect price data from all outlets, or for all products, or to deploy all the staff needed for this task. Instead, NSIs had to resort to estimates ("imputed" prices).[148] Although disruptions to data collection and production may also have occurred in the past, few of them had the scope and scale of the disruption brought about by the COVID-19 pandemic, notably owing to the lockdowns and associated restrictions. Now, more than a year since the start of the pandemic, statistical data production is returning to normal thanks to measures taken to cope with the distortional impact of the pandemic. However, it is clear that there was increased uncertainty surrounding data collection and compilation, particularly in the earlier months of the pandemic.[149]

In the longer term, and more broadly, the pandemic may also accelerate a concomitant change in the way that price statistics and other statistics are compiled. This relates to the increased use of online data or data from other non-traditional sources (e.g. from scanners or websites) to assess price developments. The pandemic may also strengthen efforts to adapt the entire framework for the collection and production of statistical data (i.e. beyond price statistics) in order to pave the way for non-standard data sources or other methodological changes that may facilitate the process of data collection and production going forward. In this way, the pandemic may act as a catalyst for a major change in and modernisation of data collection and production.

6.4.2 COVID-19, digitalisation and inflation

Besides challenges in price measurement, the impact of COVID-19 on inflation is highly uncertain looking ahead. At least two responses to the COVID-19 shock seem relevant and sufficiently persistent to have a visible effect on inflation going forward. The ongoing COVID-19 pandemic has triggered large responses in several sectors of the economy. Overall, the impact of the current crisis on inflation remains very uncertain, given the nature of the shocks and their persistence. However, it is possible to argue that in at least two respects (increased teleworking and online purchases), the COVID-19 shock might have effects on inflation beyond the very short run. We briefly discuss both aspects below.

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[148] To date, for the euro area, the highest share of imputed prices in the official HICP was 32% in April 2020. For more on COVID-19 and HICP, see Eurostat's website.

[149] As a case study, Box 10 in the Appendix looks at how non-market services have been affected by COVID-19.

The pandemic has drastically increased the number of people working from home.[150] **This can potentially have an impact on house prices and rents.** According to the Eurofound[151] e-survey on "Living, working and COVID-19", over three-quarters of EU employees want to continue working from home at least occasionally, even after COVID-19 restrictions are lifted.[152] The above evidence applies across all euro area countries. While it is hard to make any prediction on the long-term dynamics, the increased demand for housing owing to the increase in teleworking could potentially drive up house prices and rents. On the other hand, there could be reduced demand for city dwellings, which would remove a driving force of aggregate house price and rent increases. As a result, the impact on inflation could be long-lasting, but the overall impact on inflation is uncertain.

The pandemic has also raised the share of people shopping online. In August 2020, the Deutsche Bundesbank Survey on Consumer Expectations (which covers about 2,000 respondents) featured a special question on online buying behaviour.[153] Chart 33 shows the results of the survey: for most categories, respondents indicated that they bought more via the internet than in the pre-COVID-19 period, notably for categories which previously had a relatively low share of online buyers (food and beverages, body care, courses). Looking forward, it is hard to predict whether this trend will continue or not. Nevertheless, it seems plausible that the share of people buying online will be permanently higher than before the pandemic and also expand to more aspects of consumption, thereby potentially increasing the indirect effect of digitalisation on inflation via e-commerce and mark-ups (see Chapter 5).[154]

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[150] See Chapter 4.

[151] Eurofound is the European Foundation for the Improvement of Living and Working Conditions.

[152] See "Working during COVID-19" on the Eurofound website.

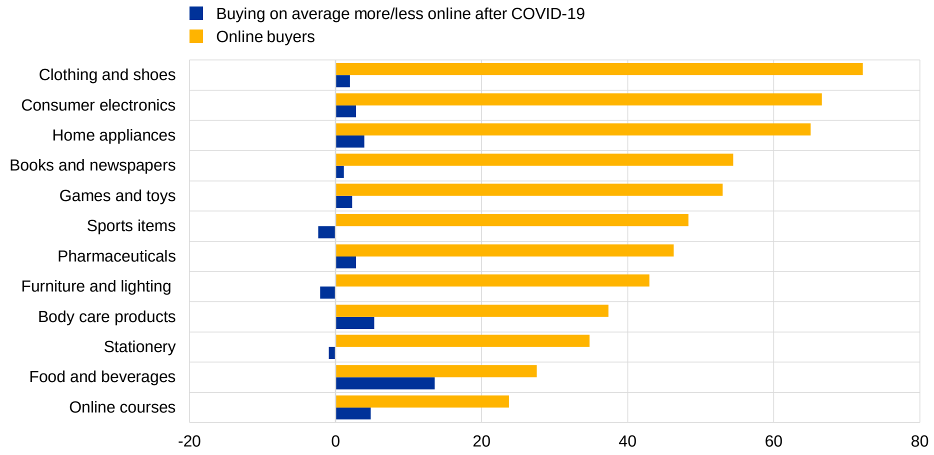
[153] The exact question was as follows: "In comparison to the period before the outbreak of the COVID-19 pandemic: How often did you buy the following categories online in the course of the pandemic restrictions?" (1: more often; 0 = same as before; -1 = less often; neither bought online before nor after).

[154] The extent of further growth in online sales may depend on a number of country-specific and other factors, such as the market structure (small or large firms); firms' ability to adapt to digital technologies and to sell online; and the extent to which online sales already exist.

Chart 33

Online buying behaviour before and after COVID-19

(percentages)



Source: Deutsche Bundesbank Survey on Consumer Expectations – August 2020.
Note: Weighted results.

6.5 Policy response

The overall impact of COVID-19 on the broader economy is also going to depend on the policy response to the pandemic, as governments seek to protect employment and industries from the fall-out. Policy support in the form of job retention schemes and loan guarantees to firms have been put in place in many countries, and while they are essential in the short term to prevent a widespread collapse, they may eventually impede job/firm/sectoral reallocation that could otherwise take place. For example, business churn – the entry of new, more competitive firms and the exit of less productive ones – also boosts productivity (see Table 8),[155] and policies need to ensure that such restructuring is able to take place efficiently at the earliest opportunity. However, although a higher rate of churn would normally raise productivity, withdrawing policy support too soon during the COVID-19 shock may cause viable, higher-productivity firms to exit and thus have a negative impact on productivity. Product, labour and financial market regulations may also need to be changed in order to fully reap the potential gains from digital technologies, while maintaining inclusiveness and safeguarding vulnerable groups who may experience job insecurity and lower earnings. Digitalisation may entail greater market concentration among firms, which may lead to a more uneven distribution of income and wealth. It may be necessary to put in place further policies to maintain equal opportunities, while supporting those in the labour market particularly affected by the transition to a digital economy. Access to relevant education and training, along with business models supporting digital skills, tasks and jobs, would seem especially

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[155] See Anderton, Di Lupidio and Jarmulska (2020), who show that across EU countries: (i) competition-enhancing regulation is associated with a higher degree of business churn; (ii) business churn is positively related to higher productivity by facilitating the entry of new competitive firms and the exit of less productive ones; and (iii) productivity catch-up towards the productivity leaders is a slow and weak process.

important. Financing of intangible investment, which is hard to collateralise, may be more suited to equity financing than traditional bank financing. These issues may require policies at the EU level as well as at the national level.

Table 8

Impact of business churn on productivity: evidence for EU countries

	Companies < 10 employees			Companies >= 10 employees		
	1	2	3	4	5	6
2nd step	TFP growth					
Cyclical downstream indicator	0.0023*** (0.0005)	0.0024*** (0.0006)	0.0024**** (0.0005)	0.0026*** (0.0006)	0.0025*** (0.0005)	0.0026*** (0.0006)
Churn rate (t-1)	0.0656** (0.0297)			0.1685** (0.0644)		
Birth rate (t-1)		0.0877** (0.0442)			0.1963** (0.0848)	
Death rate (t-1)			0.1468** (0.0481)			0.3163** (0.1497)
TFP catch-up	-0.0615*** (0.012)	-0.0639*** (0.0129)	-0.0579*** (0.0113)	-0.0553*** (0.0088)	-0.0599*** (0.0102)	-0.0556*** (0.0078)
TFP leader	0.0848 (0.0686)	0.0953 (0.0744)	0.086 (0.0648)	0.088 (0.0088)	0.0883 (0.0617)	0.0952 (0.0607)
N	1,310	1,350	1,320	1,644	1,713	1,663
R-squared	0.5329	0.5255	0.5387	0.5008	0.4919	0.4975

Source: Anderton, Di Lupidio and Jarmulska (2020).
Notes: Fixed-effects model. Fixed effects for country-time and sector have been included. Dataset trimmed for outliers. Robust Driscoll and Kraay's standard errors in parentheses: * p<0.1, ** p<0.05, *** p<0.01. Results show that increased rates of churn (the entry and exit of firms), as well as increased rates of firm entry or firm exit, increase total factor productivity (both for firms with less than 10 employees and for firms with more than 10 employees).

Meanwhile, many EU government initiatives and the Next Generation EU package will enhance and facilitate the transition to the digital economy in Europe. In this context, it is worth recalling that the public sector plays an important role in overall digital adoption in an economy. The transformation of public administration, the promotion of digital options in public education and the use of digital technologies in the public health sector may serve as triggers for the broader spread, and broader acceptance, of digital technologies across the entire economy. Some of the most digital economies in the euro area score highly in this respect (see the comparison of the corresponding DESI category in Chart 4 in Chapter 2).

The productivity response to an acceleration in digitalisation may need time, however, and may depend heavily on the evolution of institutions, infrastructure, workers' skills and methods of production and management. The initial position is also one of considerable cross-country heterogeneity in digital adoption, which implies that potential productivity gains may be spread unevenly across countries. By the same token, it is possible that the gaps in digital adoption and productivity between European countries and the United States may not be closed and the acceleration in digitalisation as an opportunity for Europe to catch-up may be lost.[156,157]

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[156] According to Hallward-Driemeier et al. (2020), the EU is on a par with the United States in operational technologies, but it lags behind in information and transaction technologies, which would allow productivity gains for small firms as well as large ones. SMEs in Europe would therefore benefit from investment in these specific technologies.

[157] Another important dimension that is being looked into is the welfare effects of digitalisation. Such effects could stem from three broad sources: market products (with better quality, new varieties or free services), non-market production (supported by digital products or information) and online shopping and the sharing economy (with lower prices and more variety). Such aspects are being looked at in the context of a more people-focused approach to statistics on economic performance, as discussed for example in IMF (2020). See also Box 10 in the Appendix of this report: "Digitalisation, COVID-19 and the non-market services in national accounts".

7 Implications of digitalisation for monetary policy[158]

Digitalisation has affected and is going to continue to affect the environment in which monetary policy operates. This report has covered the key macroeconomic areas where the impact of digitalisation may play an important role, namely: productivity, labour markets and inflation. The material presented so far, and the implications it has for monetary policy are summarised in this chapter. In this context, it should perhaps be recalled that other implications of digitalisation, for example regarding financial technology (fintech), payments and digital currencies, are beyond the scope of this report.

According to the literature, digitalisation may give rise to measurement bias: inflation may be overestimated, and real GDP underestimated.

Many variables relevant for monetary policy may be influenced by digitalisation. Through productivity, digitalisation may have an impact on potential output, the associated slack and gaps, and the natural interest rate. In a technologically optimistic scenario, productivity growth will increase, raising the natural rate of interest and giving monetary policy more room for manoeuvre. The credit channel of monetary policy may be weakened if bank lending is directed away from difficult-to-finance intangible investment. If it is then redirected to property finance, the effects of monetary policy on household consumption and house prices may be strengthened.

If it persists, the direct downward impact on inflation of digital products themselves may lower observed inflation. The possibly of greater dispersion of productivity may affect optimal trend inflation, which is a yardstick for calibrating a possible inflation target. Through labour market variables, digitalisation has an impact on the Phillips curve trade-off between wage inflation and unemployment, which could increase or decrease. That trade-off is also affected by the impact of digitalisation on product markets – for example, via higher market concentration of "superstar" firms and greater competition from increased online sales.

As a result, the process of digitalisation and its possible impact need to be closely monitored, including, for example, the rate/speed of its adoption/diffusion, whether digitalisation will reach a saturation level in the medium/longer term or will be a permanent ongoing process, how digital adoption differs across different technologies and different countries, regions, sectors and industries, and how all this affects the incidence of shocks and their transmission. The data generated by digital technologies themselves may be very useful in such monitoring and may, along with the corresponding modelling and forecasting techniques, become a more regular part of the monetary policy toolkit.

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[158] This chapter has been prepared by Robert Anderton and Vincent Labhard, with input from workstream members. It has benefited from comments from Gilbert Cette, Luca Dedola, Hanna Freystatter, Chiara Osbat and Filippos Petroulakis. Aspects of this chapter also build on Anderton et al. (2020b).

All of the above may also become more pertinent if the acceleration of digitalisation experienced during the COVID-19 shock turns out to be largely permanent rather than temporary.

7.1 General points

Digitalisation has been affecting, and will continue to affect, the environment in which monetary policy operates. Digitalisation has been ongoing for several decades, and it is likely to continue for several more: digital technologies that emerged in the early phases of digitalisation in the 1940s to the 1980s have long since matured; others from the 1980s to the 2020s, such as digital communication and production technologies supported by artificial intelligence and machine learning, are still maturing; while some are still in their infancy in the 2020s, such as edge and quantum computing, which are expected to deliver a great leap forward in processing power and efficiency.

Digital adoption and diffusion are heterogeneous across euro area and EU countries, with possible implications for monetary policy. Digital adoption and diffusion are advanced in a number of countries, including the most digital countries in the EU and some of the EU's competitors, like the United States, but other EU countries, and the EU as a whole relative to the United States, have some catching up to do. The heterogeneity across the euro area can create more divergent economic and monetary conditions and impede the efficient transmission of monetary policy, while the lag compared to the United States and Japan can affect the external position of the euro area, with implications for incomes, exchange rates, and inflation.

Digitalisation can be both a source of shocks and a factor in the adjustment/response to shocks. As a supply and technology shock, digitalisation has been and is transforming supply and demand in product and labour markets, the functioning of those markets, the market structure and the degree of competition. Like other supply/technology shocks, digitalisation is expected to raise productivity and lower prices. But digitalisation may also be a source of new types of shocks, such as information shocks, with news and noise being transmitted rapidly through digital media, influencing economic agents, businesses and households to reoptimise and adjust their behaviours. Digitalisation may also affect the nature of shocks (in terms of symmetry and/or asymmetry, for example), and of course the transmission of and/or response to other shocks, including monetary policy shocks.

Against this background, the way monetary policy is conducted and the monetary policy framework may have to be adapted. The following sections discuss the relevance of digitalisation for monetary policy from the perspectives of price measurement issues, productivity, labour markets and inflation. Although the focus of this report is on the implications for monetary policy, it is important to note that other policy areas may have to be adapted too. This applies both to policies for which responsibility lies with central banks and associated entities (supervisors, etc.), and policies for which responsibility lies with other institutions.

7.2 Role of measurement

The uncertainty surrounding price measurement and other measurement issues may increase in the digital era and make monetary policy even more challenging. Not enough is known yet, for example, about how digitalisation affects the measurement of inflation, particularly regarding the prices of digital services and products. This may also have repercussions for the measurement of the real values of investment, output and productivity (which are derived from their nominal values using appropriate deflators). Some findings suggest that the slowdown in GDP growth and productivity, which started before the global financial crisis, may be less pronounced if deflators are computed under different methodologies. At the same time, it should be noted that even if one allows for such changes (correcting for possible mismeasurement), the main conclusion that productivity growth has substantially slowed down is not overturned. In addition, ostensibly “free” services (such as social media where consumers “pay” with their data or by accepting advertising) may pose challenges as to how these benefits are measured. From a monetary policy perspective, it is important therefore to maintain close monitoring of the evolution of the digital economy and the inflation measurement challenges it implies going forward.

If there are measurement issues or mechanisms related to digitalisation that lead to lower readings of inflation in the short run, and these are not internalised by the central bank, then reaching an inflation objective may become more challenging. However, the impact of digitalisation on inflation is not clear-cut, and may differ at short and long horizons. Apart from the possible impact of more flexible (dynamic) pricing, which is likely to occur across all horizons, as well as the estimated direct and indirect downward impacts of digitalisation on inflation in the shorter term, there may be upward pressure on mark-ups and inflation from digitalisation in the medium to long term via increasing concentration. Possible measurement issues related to digitalisation and productivity may also affect judgements about the natural rate of interest.

7.3 Role of main macroeconomic variables

Digitalisation has an impact on potential growth and slack, and inflationary pressures.[159] As productivity is an important driver of the output gap which, in turn, influences assessments of inflationary pressures, ignoring or underestimating the possible boost to potential growth linked to digitalisation, if and when it occurs, could lead to misreadings of inflationary pressures. However, as shown in the productivity chapter of this report, productivity dynamics arising from digitalisation at the aggregate level so far seem subdued compared to what one might have expected, even when the various sources of bias in statistical measurement are taken into account. Furthermore, productivity affects the natural rate of interest – the rate of interest that is consistent with the full use of available factors of production. Stable inflation with lower

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[159] The implications of digitalisation for monetary policy are also discussed in G7 Digitalisation Working Group (2020).

productivity growth would imply a lower natural rate and hence a higher probability of hitting the lower bound. If digitalisation supported productivity in ways that cannot yet be measured accurately, the central bank could risk incorrectly estimating the natural rate and thus miscalibrating monetary policy. Also, digitalisation may make the economy less responsive to the credit channel of monetary policy, if the challenges associated with the financing of intangible investment, which is hard to collateralise, lead to bank lending being redirected to other areas.[160,161] If bank lending is directed more towards property finance, for example, monetary policy may have greater effects on households and house prices.

Digital and automation technologies have important implications for the Phillips curve trade-off between price and wage inflation and unemployment. Digital and automation technologies lead to non-neutral effects across capital and types of skilled labour. The skill-biased impact on the labour market affects the relationship between unemployment and wage inflation – flattening the Phillips curve.[162] In addition, digitalisation and automation lead to income inequality via higher wage premia for high-skilled workers and favouring certain types of occupations. This can affect the income and wealth channels of monetary policy, as heterogeneous effects from digitalisation on labour income and wealth could have implications for households’ marginal propensity to consume. In turn, heterogeneous consumption behaviour may affect how both standard and non-standard monetary policy measures could ultimately affect household consumption and investment decisions. Rapid increases in teleworking may also give rise to various measurement issues relating to labour market slack.[163]

Digitalisation also has implications for the price Phillips curve trade-off via some of the structural parameters. In some cases, this may lead to a steeper curve. Digitalisation can increase the frequency of price changes, for example, making prices more flexible and leading to a steeper Phillips curve. This is likely to have a first-order effect on monetary policy transmission, i.e. the transmission of monetary policy to inflation is likely to be faster. Another channel involves the number of goods available on the market, which is connected to the elasticity of the mark-up function. If digitalisation increases the number of products, this channel in isolation would also tend to steepen the curve. In other cases, digitalisation may imply a flatter curve. This would be the case, for example, if it reduced the level of mark-up that firms wanted to charge over their marginal cost. The other channel flattening the Phillips curve is through firms’ marginal cost. Digitalisation may reduce the “labour share”, leading to a

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[160] See Döttling and Ratnovski (2020).

[161] For a description of policy proposals regarding the financing of intangible investment, see Nicoletti et al. (2021).

[162] The marginal costs of producing some digital products may be very small or close to zero, such as supplying an additional computer game to a customer online, which reduces the output elasticity to factors such as labour.

[163] A number of measurement issues may arise as teleworking becomes a standard way of working in many sectors. For example, the relevant geographical dimensions of the labour market become less clear as virtual labour flows across regions and borders become more prevalent. Moreover, it could become more difficult to measure hours worked. Both dimensions contribute to new challenges in measuring slack, with implications for the conduct of monetary policy.

lower elasticity of marginal costs to sales and hence a flatter NKPC, all other things being equal.

The theoretical framework sketched above is relatively simple, but even within this highly stylised model there remains ambiguity regarding the impact of digitalisation via the various channels. This simple overview shows that a quantification of the indirect impact of digitalisation on inflation and monetary policy transmission is very complicated, but it also indicates important directions of research that can lead to this quantification: understanding what the dominant market structure in each economy is and if it has changed, understanding the pricing behaviour of firms within that market structure, and understanding the impact of digitalisation on productivity. These "ingredients", whose quantification largely hinges on the availability of micro and more granular data, can then inform the specification and estimation of structural models.

Digitalisation may also feed into optimal trend inflation, and thereby influence the specification of a possible inflation target, by increasing productivity dispersion across firms. Firms' productivity dispersion can affect both the slope of the NKPC and optimal trend inflation. Starting with the slope of the NKPC, the effect of productivity dispersion is theoretically ambiguous depending on which firms improve in terms of productivity growth: the new or the old ones. For instance, if productivity dispersion increases because the entry productivity level of new firms grows faster, incumbent firms would see their market share decline going forward. Therefore, incumbents emphasise current cost conditions more than future cost conditions, which raises the slope of the NKPC. The slope of the NKPC would decrease in the opposite case.

In addition to affecting the slope of the NKPC, productivity dispersion may also feed into optimal trend inflation. When digital technologies and automation lead to only temporarily higher productivity dispersion, this can have temporary effects on inflation dynamics, but it is unlikely to modify monetary policy transmission. However, when digital technologies and automation lead to permanently higher structural productivity dispersion, this can affect monetary policy transmission and, depending on the monetary policy rule, also the average level of inflation.

Finally, long-lasting changes in productivity dispersion can affect inflation via monetary policy itself. Suppose that optimal trend inflation experiences a long-lasting decline, leading to a permanent shift in the augmented NKPC that exerts downward pressure on inflation. In this scenario, a central bank responding to both inflation and output, and unconstrained by the zero lower bound, may offset the downward pressure on inflation only partly, in order to prevent the output gap from opening up too much. To avoid this predicament, the central bank should adjust its inflation target to optimal trend inflation.

Appendix

Box 6

Estimates of “free” services (free digital content)

Some estimates of the value of “free” services are available. Ahmad et al. (2017) found that, if free media funded by advertising were added to household consumption expenditure, the average growth rate of GDP in the United States in 2011-13 would increase by 0.07 pp, the largest impact across the countries considered, driven mainly by web portals. The assumption made by the authors is that the value of the free products provided to the households is equal to the revenue that the producers of these products receive from advertisers. However, most providers of these “free” internet services charge advertisers and are indirectly accounted for in GDP via the value of the goods or services that are sold through advertising (see Groshen et al., 2017). The value of the free services provided by Wikipedia, which has no revenue from advertisements and is not captured in the national accounts, was found to be insignificant relative to GDP.

It is unclear, however, to what extent those estimates are consistent with indirect financing through advertising or data collection. Table A shows the classification from the literature survey in Bourgeois (2020), which also covers free services provided by Facebook (indirectly funded by advertising and data collection) and YouTube (funded through advertising and data collection, but also offers users the option of a paid-for, ad-free service and makes occasional payments to some content providers). This suggests that there is no single solution for measuring free services, and specific solutions may depend on the objectives, but also that the “changes in the organisation of these pseudo-markets may, one day, come to the aid of the national accountants, whether in the form of spontaneous changes or changes resulting from regulatory policies to which these markets may be subject”. This could be interpreted as meaning that economies have not yet completed the transition to a stable digital economy type, which obviously creates difficulties for statistical measurement.

Table A

Symmetry between financing through advertising and financing through data collection

Two-sided market	Accounting classification	Indirect financing through advertising	Indirect financing through data and personal data collection
Household side	Potential classification as final consumption expenditure (FC)	Immediate consumption of free service + potential deferred effect of consumption of sponsored products and brand influence	Immediate consumption of free service
Company side	Potential classification of part of the costs as intermediate consumption (IC)	Short-term purchase of sponsored products	Better targeted advertising in the short-term, resale of personal data collected
	Potential classification of part of the costs as investment expenditure (gross fixed capital formation, GFCF)	Medium and long-term effects linked to the brand, logic of influence	Later indirect value measurements, for example through artificial intelligence and algorithms and valuation of intangible assets (organisational, brands, etc.) linked to data

Source: Bourgeois (2020).
Note: The companies may be advertisers (in the case of an advertising model) or data collectors.

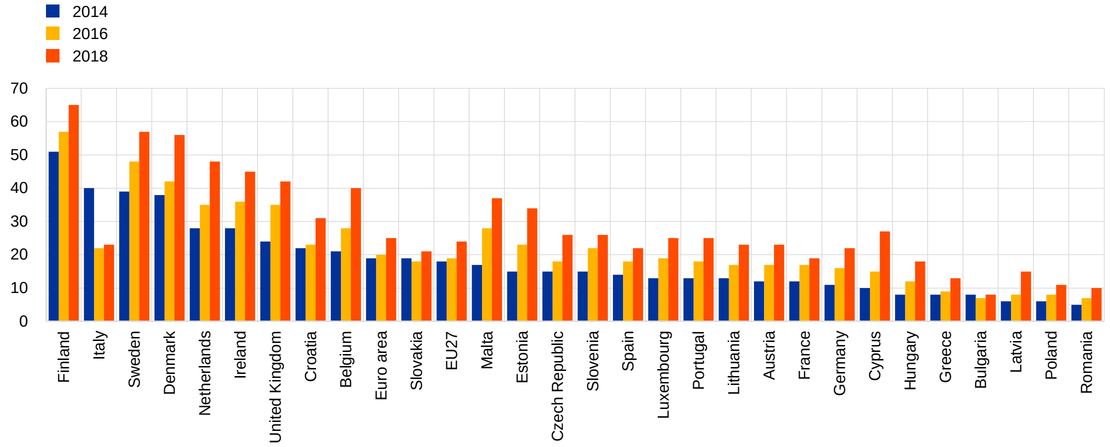
Box 7
Cloud computing services as a growing digital phenomenon

The challenges of measuring the supply of and demand for cloud computing services are becoming more important. Cloud services are a relatively recent phenomenon.[164] But they are growing rapidly and have increased notably over the last five years in many EU countries. Moreover, the increase has been uneven across countries, not unsimilar to the observed heterogeneity of adoption of ICT services referred to in Chapter 2. It should be noted that, to some extent, households are also benefiting from cloud services, for example via online access to software packages like Microsoft Office (software as a service) or cloud storage provided by computer companies like ASUS.

The increase in the use of cloud services has been most prominent in the business sector, as shown in Charts A and B. Cloud services imply a product transformation – the shift from "physical" asset software (or disk storage) as a product to a cloud-based software service which can be further customised to meet the needs or wishes of the individual user. UNSD (2020) points out that cloud services can be thought of as a substitute for investment in computer and communications hardware by firms, as well as the development of own-account software; i.e. fixed capital investment gets replaced by the purchase of an intermediate input (cloud computing services). As a result, traditional measurement of the price changes becomes difficult for reasons explained in Chapter 3.

Chart A
Cloud computing usage by the business sector

(percentage of enterprises)



Source: Eurostat survey on ICT usage in enterprises.
Notes: Purchases of cloud computing services by businesses (percentage of enterprises with ten or more employees, excluding the financial sector). Countries sorted by 2014 data. Break in time series in 2016 for Italy.

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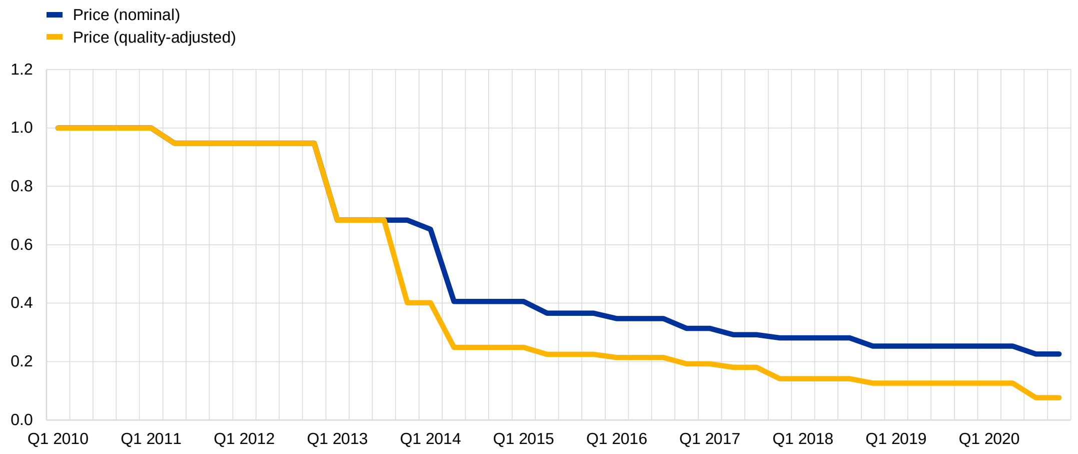
[164] Three types of cloud computing are distinguished in the literature: (1) SaaS: software as a service (email, applications for end users), e.g. Office 365, gaming, cloud storage, etc.; (2) PaaS: platform as a service (operating systems, application development, web servers), e.g. Google App Engine, which allows users to build web and mobile applications; and (3) IaaS: infrastructure as a service (servers, networking, system management).

Chart B

Price indices for cloud computing services: unadjusted and quality-adjusted

(price index: Q1 2010 = 1)



Source: Coyle and Nguyen (2020).
Notes: Prices are computed for the grouped product classes ("large") of Amazon Web Services relating to the operating system Linux. Price index has a value of 1 in base period (Q1 2010).

As much of cloud computing is an intermediate input to production, cloud computing is hard to track in the statistical system. Specifically, the data do not typically distinguish between cloud services and traditional services or whether services are produced internally or purchased or generated at the "edge" (UNSD, 2020; and Byrne, Corrado and Sichel, 2018).[165]

Contracts for cloud services can vary greatly in terms of duration and level of responsibility offered as part of the service, and thus also in terms of price. The price measurement is further complicated by the fact that the supplier and user of the cloud service may be located in different countries; it may not even be clear to the user which entity is actually providing the service or where the entity is located (it is "in the cloud"). In addition, for private households there is also an overlap with online streaming services, which poses another challenge for price and volume measurement.

Cloud services for consumers mainly consist of SaaS, as well as data storage and hosting services which are probably IaaS. Although it is possible to classify these services in the statistical classifications[166], it is difficult to have separate CPIs for IaaS-type cloud computing services consumed by households, while it is less problematic to obtain prices for cloud-provided software when their expenditures in the consumer basket become statistically significant. Eurostat (2018a) recommends that existing price indices for packaged software in CPIs can be used to deflate SaaS services. However, for PaaS and IaaS, as long as specific indices for these types of services are not available, PPIs for computer programming services and information services could be used as proxy.

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[165] A large increase in the volume of data means that it is not feasible to transmit all of it to the cloud for processing in real time. Hence, businesses and governments locate the processing and storage of data collections close to internet providers' networks, giving rise to the term "edge computing", reflecting this proximity. This data streamlining solution allows the transmission of only higher-value data to a cloud centre for further use.

[166] According to Eurostat (2018a), in ECOICOP, SaaS will be classified under 09.1.3.3 "Software", whereas IaaS is currently recorded (in accordance with case law) under 12.7.0.4 "Other fees and services". The revised COICOP classification agreed at the United Nations in March 2018 provides for a new category 08.3.3.0 "Internet access provision services and net storage services" to capture IaaS used by consumers.

For the use of IaaS-type cloud services by households, the closest possible CPI should be used for deflation.

Having a set of recommendations is extremely useful for statisticians. However, a typical obstacle faced when collecting data for price (or volume) measurement of cloud computing services and incorporating them in the macroeconomic statistics is that the companies providing these services, although willing to cooperate, often do not provide the required information (discussed in OECD, 2019). As a result, sometimes statistical judgement might not be excluded, which makes the measurement of cloud computing services challenging.

Box 8

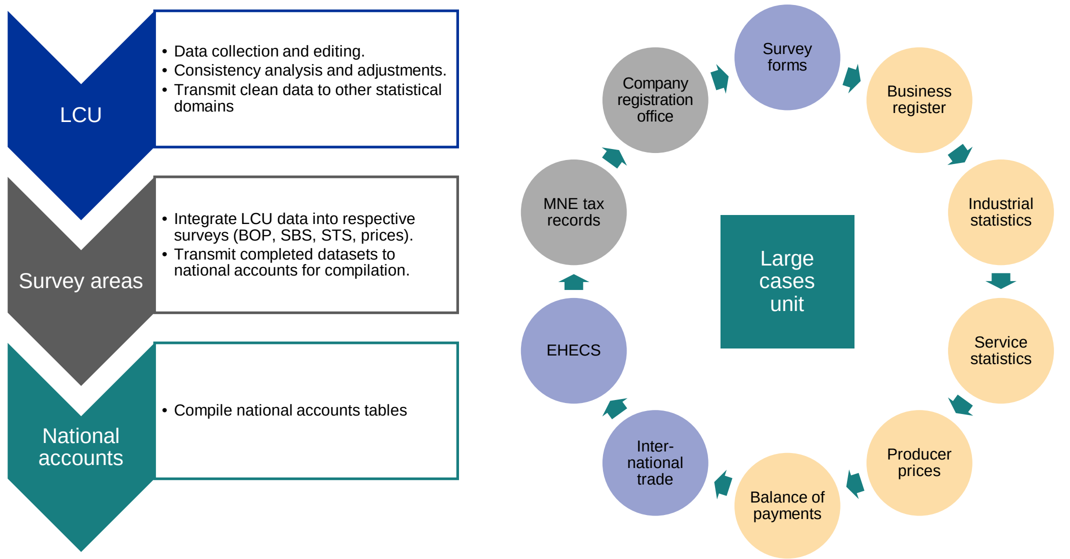
Cross-border transactions: the case of intellectual property products (IPP)

Increased globalisation and multinational enterprises (MNEs) create challenges for national accounts and balance of payments statistics. This is because MNEs, whether or not they are high-tech and digitally oriented, allocate parts of their business across countries to take advantage of favourable fiscal or regulatory frameworks (and not only to exploit economic competitive advantages). These include the relocation of IPP, which in the well-known case of Ireland led to 26% increase in Irish GDP in 2015 and a subsequent upward revision of euro area GDP by 0.4 pp, and other transfers of IPP (usually R&D) that lead to changes in investment and import/export variables, without necessarily having to a significant impact on GDP.

In practice, GDP measures more than just the economic output generated by domestic labour and installed capital. As noted by Deutsche Bundesbank (2018), an example of this is the “income from licenses, which serve to produce output abroad through the combination of labour and real installed capital there, counts towards domestic product. In consequence, the organisational decisions taken by multinational enterprise groups for, say, tax optimisation purposes can lead to abrupt shifts in the allocation of value added between national economies, thereby triggering jumps in domestic product levels. This can make interpreting key macroeconomic indicators such as economic growth, investment activity and productivity trends considerably more difficult”. The problem of cross-border transactions thus has an impact not only the GDP measure of some countries but even makes cross-country comparisons globally more difficult.

Action has been taken to tackle those challenges. Initiatives were set up by statistical agencies in recent years with the aim of building up more knowledge of how MNEs operate and collecting and sharing information across statistical domains and affected countries to improve data measurement. Some EU countries are creating special “large cases units” for consistent measurement of MNE activities across all statistical domains, following the Irish approach. As a result, better measurement, better statistics and better cross-country comparability are expected. An important addition here is the successful relevant communication and data presentation, as well as the collaboration with the main policy users.

Figure A
Example of Irish approach to MNE measurement



Source: Presentation at the ECB's Directorate General Statistics WG-FA/WG-ES Expert Group on Foreign Controlled Corporations, September 2020.
Note: "BOP" stands for "balance of payments", "SBS" stands for "structural business statistics", "STS" stands for "short-term business statistics" and "EHECS" stands for "Earnings, Hours and Employment Costs Survey".

Box 9
Going further: digital economy satellite accounts[167]

Digital economy satellite accounts aim to capture transactions that are of a "digital nature". This means items are digitally ordered (via methods designed for receiving and placing orders), delivered (via downloadable services and data flows) and/or enabled (via intermediary platforms), as shown in Figure A below.[168] Data for these transactions are taken from supply and use tables, a core part of current national statistical information systems which categorise transactions depending on the production process, the origin of various goods and services (supply) and the destination of those goods and services (use) (see, for example, Ahmad et al., 2018; and Mitchell, 2018). However, data on transactions of a digital nature are not always available at the required granularity, and sometimes not at all.

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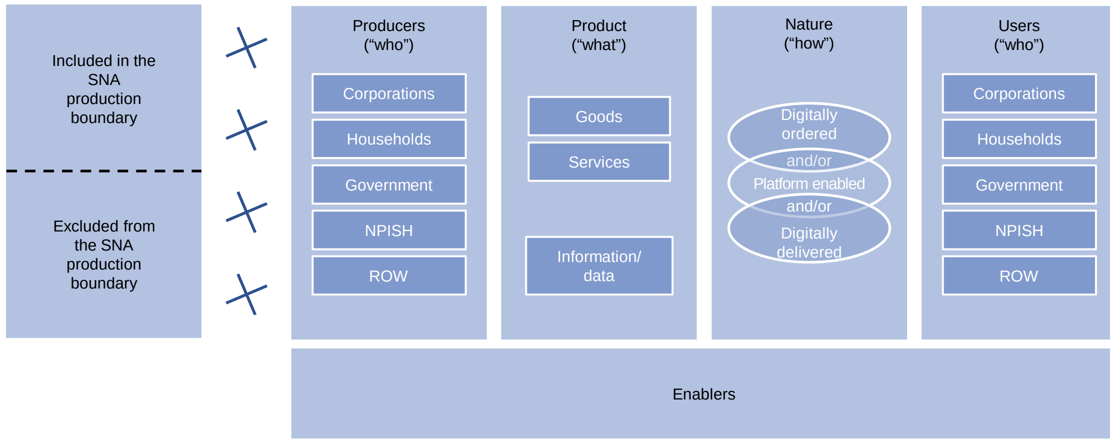
[167] See OECD (2018).

[168] More generally, satellite accounts provide a framework for capturing specific aspects of economic activity in the context of national and regional accounts. They exist for example for the environment, health, transport, tourism and unpaid household work, and are being envisaged (or contemplated) inter alia for education and human capital, the third sector and the social economy, and the space economy.

Figure A

Dimensions of the digital economy



Source: Ahmad et al. (2018).
Note: “NPISH” stands for “non-profit institutions serving households”; “ROW” stands for “rest of the world”.

Digital economy satellite accounts require more refined breakdowns of products than existing national and regional accounts. The more granular breakdowns are based, for example, on the mode of ordering and delivery, thereby providing more information on electronic ordering (e-commerce), electronic delivery and platform-enabled transactions. They also involve revised breakdowns and new groupings of producers depending on their relevance for the digital economy, e.g. digital intermediary platforms, e-sellers, and firms dependent on intermediary platforms. Finally, the framework also accounts separately for digital enablers, in both the producer and the product dimensions.

They also employ new categories of goods and services that are outside the scope of the current national and regional accounts.[169] In particular, the list of products also includes services outside the production boundary of the central framework, representing the production and consumption of “free” digital services that are not currently in scope. For example, such new product categories include digital data services, free search services and social media. It is expected that, although being currently outside the SNA production boundary, the estimates for these services would provide a better picture of the size of their production in the digital economy as illustrated in the satellite accounts.

A number of challenges in relation to digital economy satellite accounts have yet to be resolved. This applies mostly in relation to digital services. These challenges are related to the statistical measurement of e-tailors (online retailing platforms), the implicit payments for intermediation services of the online platforms, their classification in the activity classification (NACE), as well as the measurement of free services and data, as described in UNSD (2021). However, there are also some challenges in relation to goods. One such challenge relates to the treatment of 3D-printed products, as they may not contain any digital parts but are digitally enabled (made by means of a digital technology).

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[169] The separately identified products, including both newly defined products and traditional products for which additional breakdowns are requested, are explained in Ahmad, N. and Ribarsky, J. (2018) and UNSD (2021).

Eventually, digital economy satellite accounts are going to be an important step towards a better measurement of prices and inflation in the digital era. Primarily, they will do so by capturing (additional) activities not currently within the scope of the national and regional accounts, thereby allowing possible corrections to the estimates of economic activity and the implicit deflators for the corresponding national and regional aggregates and deflators. While covering additional activities is likely to increase measures of activity, the impact on prices (and hence inflation) is less clear. The price index may rise as a result of including the prices of “free” products.

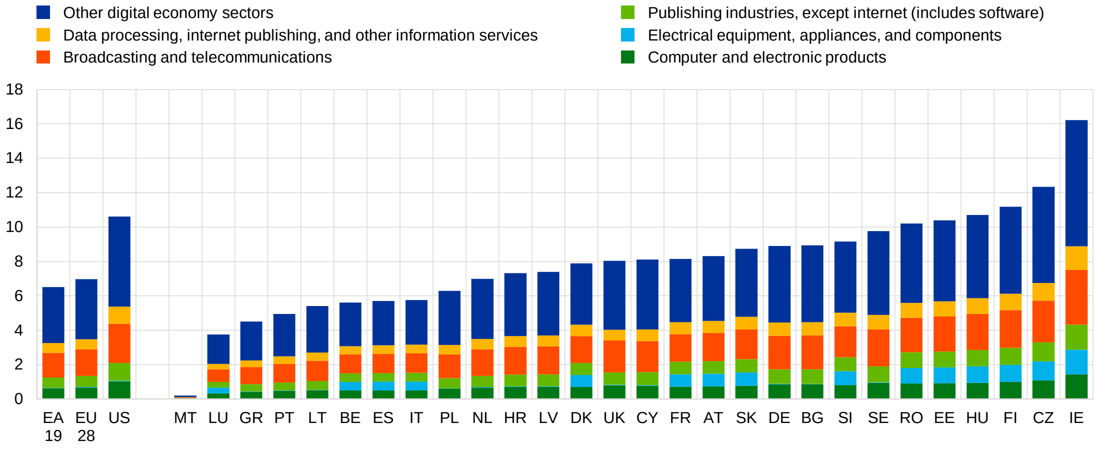
For the time being, digital economy satellite accounts are available only in a few countries. The accounts for the United States were first released in 2018, going back to 1997. Accounts for Canada were released in 2019[170] for the period from 2010. In current prices/nominal terms, they put the share of the digital economy in the total economy at 9.0% of GDP for the United States (2018) and 5.5% for Canada (2017), with annual growth rates of 6.8% (2006-2018) and 4.9% (2010-2017), respectively, compared to growth rates of 1.7% and 3.6%, respectively, for the total economy.[171] The US accounts, to which the ones for Canada are closely aligned, include (i) the infrastructure supporting computer networks, (ii) the e-commerce transactions enabled by those networks and (iii) the digital media content created and used.[172] Chart A below shows what the satellite accounts for the euro area would look like if the ratio of the activities selected in Section 2.2.1.3 and the satellite accounts were the same as for the United States.

Chart A

Size and growth of the digital economy according to the digital satellite accounts (constant prices)

(percentages)

Composition, by NACE sector, 2018*



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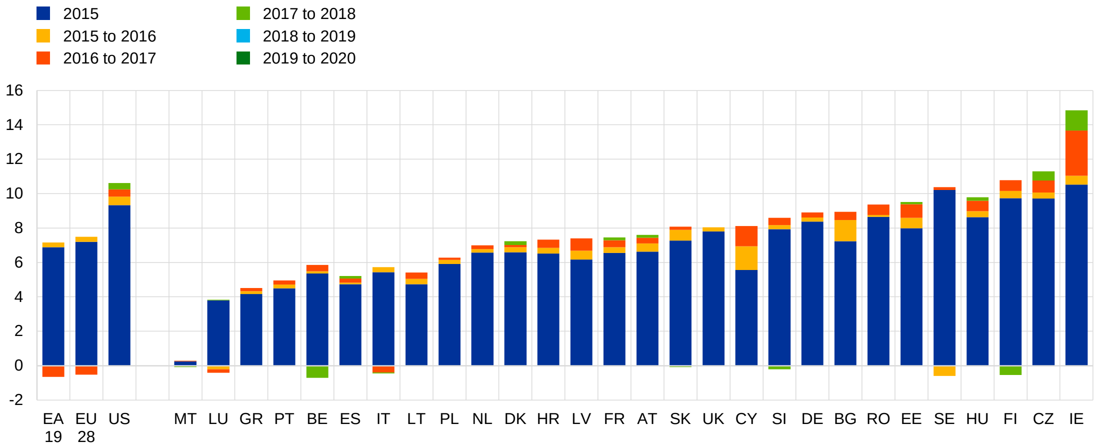
[170] See Statistics Canada (2019).

[171] The previous release for the United States (April 2019) had put the share of the digital economy in GDP at 6.9% and annual growth at 9.9% for the period 1997-2018. It may be worth pointing out that the digital satellite accounts only constitute estimates of true outcomes and are surrounded by uncertainty. This is a feature they have in common with the system of national and regional accounts.

[172] The US digital satellite accounts include products that are “primarily” digital. This implies that transactions involving an important non-digital/physical component are excluded, such as, for example, the sharing economy.



2015 share and change in share by year, 2016-20**

Sources: BEA and ECB/NCB staff calculations.
Notes: *2017 for EA19, EU28, GR, PT, LT, PL, NL, HR, LV, CY, DE, BG and SE; 2016 for UK. The data for the United States are from the digital satellite accounts for that country, the data for the euro area and EU and their members are obtained by multiplying the value added from Section 2.2.1.3 with the ratio (for the United States in 2018) of value added according to the satellite accounts to the value added from Section 2.2.1.3. In other words, the chart shows how the satellite accounts would look for the countries if the relative size of the digital economy according to satellite accounts and digital economy sectors is assumed to be the same as for the United States. **As/where available.

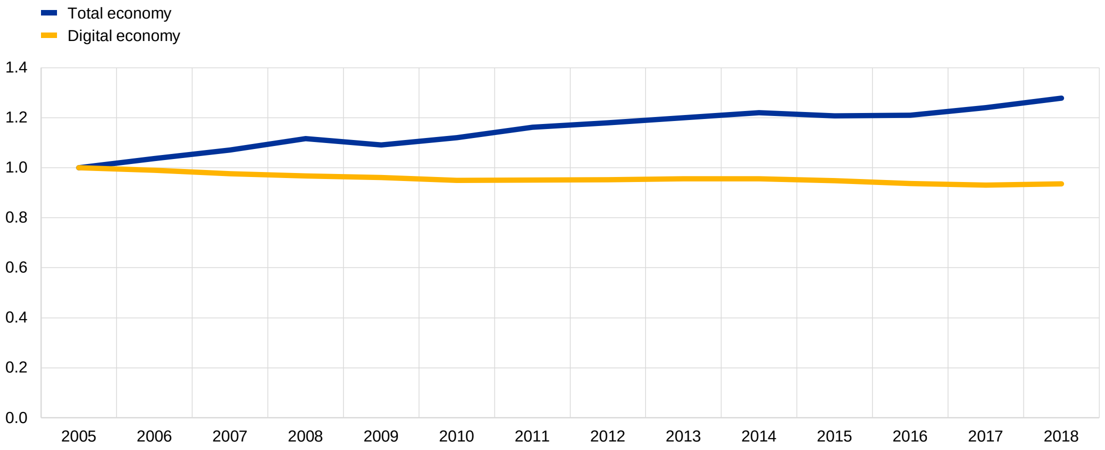
The digital satellite accounts available so far illustrate well their importance for measuring the size of the digital economy. They may also provide information on price developments. Chart B below shows that in many instances the deflators for digital products are trending down. In particular, declining prices for hardware have been the main driver of the overall price decrease measured for the digital economy. However, Chart B also shows that the dynamics of the different deflators are very different, with a few deflators also moving sideways or even trending up.

Chart B

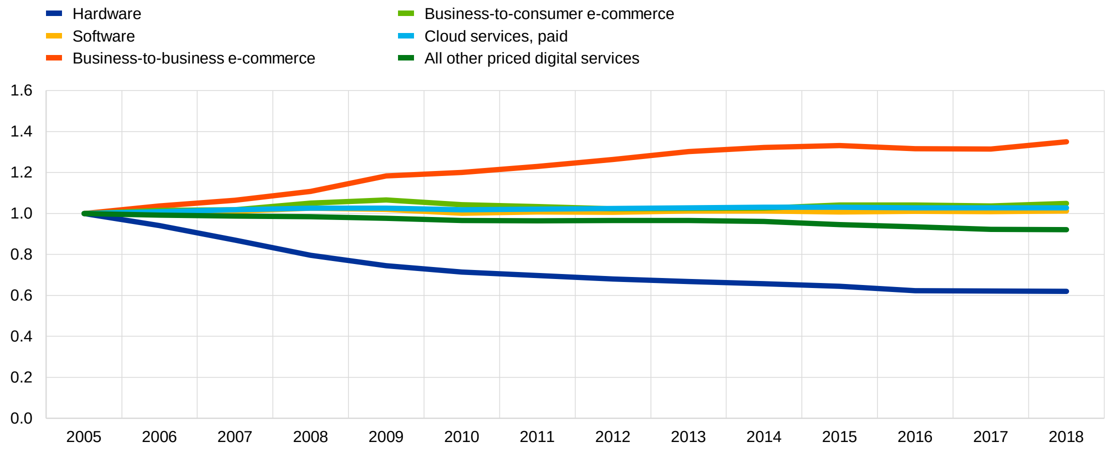
US deflators according to the digital satellite accounts

(index: 2005=1)

Gross output price index



Gross output price indices for digital economy components



Source: BEA.

Going forward, digital satellite accounts may become available for further countries. The OECD has finalised the conceptual framework and is asking its member countries to start providing national digital satellite accounts starting in 2020.[173] In the EU, in 2020 Eurostat initiated a financial support procedure for member countries developing digital economy satellite accounts.[174] As several steps are involved in the development and production of such satellite accounts, and against the background of the disruption caused to statistical production by the COVID-19 pandemic, it remains to be seen when such satellite accounts are going to be available and for how many countries.[175]

Box 10

Digitalisation, COVID-19 and non-market services in national accounts

Digital education boomed during the COVID-19 pandemic owing to closures of educational facilities. Statisticians had to adapt their measurement practices in order to correctly reflect this in the government consumption expenditure statistics. Owing to the different results for the EU countries published by Eurostat, with the first estimates for the first quarter of 2020, and later for the second quarter of 2020, the attention of economists and the media[176] was drawn to an already known, but this time more visible, issue in the volume measurement of non-market services.

The measurement of education services during the COVID-19 pandemic was shown to be even more challenging than in normal circumstances. While education services are not typical digital services,

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[173] The process started with initial work by the OECD and the IMF in 2016 that fed into an "Advisory Group on Measuring GDP in a Digitalised Economy", with the conceptual framework presented (and key ideas discussed) for the first time in 2018, and promoted by the G20 in the same year. The key issues included the items outside SNA boundaries, information/data as a product, and the distinction between "digitally ordered", "platform-enabled" and "digitally delivered".

[174] The timing of the release has become more uncertain due to the COVID-19 pandemic and its adverse impact on production processes and schedules.

[175] The key steps for digital (and other) satellite accounts were laid down in van de Ven (2019). They include (1) defining and compiling data for the desired breakdown of activities, (ii) defining and compiling data for the desired breakdown of products, (iii) breaking out taxes less subsidies, (iv) defining and compiling data for the breakdown of value added, (v) incorporating services produced within the enterprise, (vi) incorporating services produced by households for own use, (vii) more detailed data on employment, (viii) more detailed data on investment and capital stocks, (ix) complementing supply and use tables (SUTs) with physical performance or outcome indicators, and (x) complementing SUTs with other physical indicators.

[176] See Arnold (2020).

the use of technology has been growing and this was very apparent during the crisis. The main price measurement difficulties arise mainly from the lack of a market price for these services (sum of cost is used) but also from the fact that explicit quality adjustment is not carried out (and not required by Eurostat). A notable recent initiative in this field is the "Atkinson Review", a year-long review of the measurement of UK government output and productivity which recommended methods and approaches that can be used to measure changes in government output and productivity directly (see Atkinson, 2005). These recommendations to apply direct output measures are in line with Eurostat's recommendations, but some countries face difficulties in applying them strictly owing to changing realities (new health or education systems), data source availability and, occasionally, staff constraints.

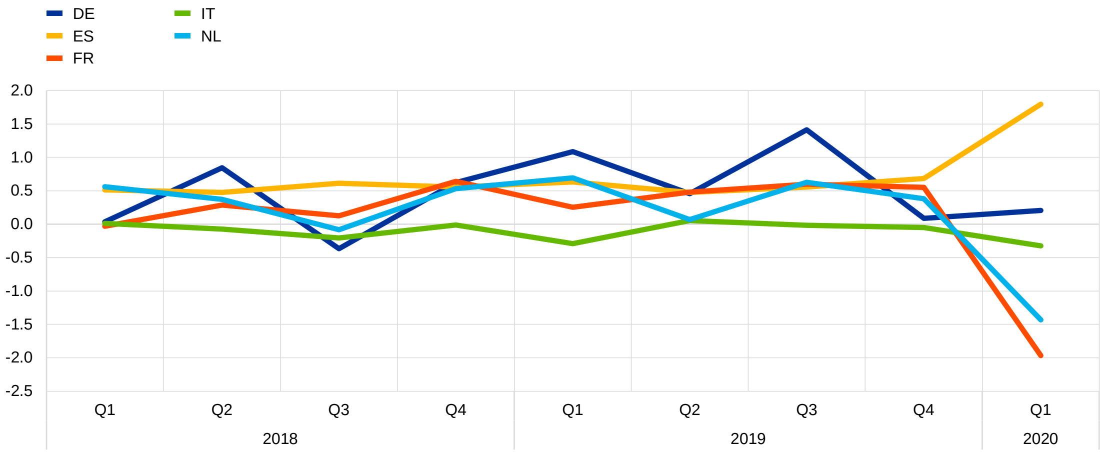
The differences in non-market services observed across countries suggest that data gaps and measurement issues could have been relevant and that different methodologies applied. In particular, the strong decline in government consumption in France stands out as one of the factors explaining the different magnitude of the declines in the GDP flash estimates. In addition, data for Spain clearly showed divergence in government consumption growth compared to the other countries in Chart A. Eurostat and the OECD collected information on the national practices (during the summer of 2020) with a view to identifying cases where improvements and better harmonisation are needed and to provide further recommendations in this field during the COVID-19 period.

Chart A

Government final consumption expenditure

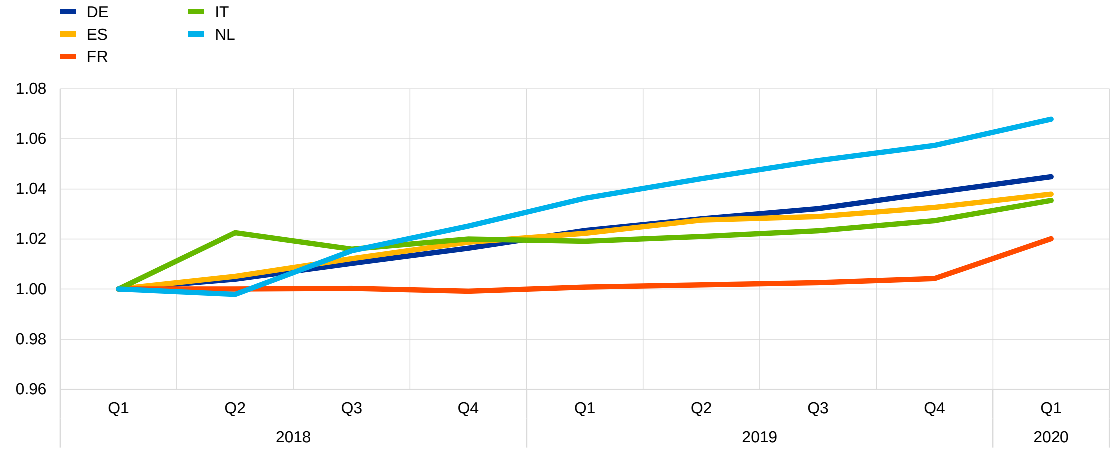
Quarter-on-quarter volume growth, seasonally adjusted

(percentages)



Implicit deflator, seasonally adjusted

(index: Q1 2018 = 1)



Sources: Eurostat and ECB calculations.
Note: Data as at 28 May 2020.

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