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Bits and bolts: The digital transformation and manufacturing

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BITS AND BOLTS: THE DIGITAL TRANSFORMATION AND MANUFACTURING

Matej Bajgar, Sara Calligaris, Flavio Calvino, Chiara Criscuolo, and Jonathan Timmis[1]

Abstract

The digital transformation forces a re-think of government policy as manufacturing business models increasingly transition from "bolts" to "bits". The road to Industry 4.0 implies important and pervasive changes in business dynamics, firm growth and the nature of competition. This report presents a framework for measuring the digital transformation of manufacturing industries, and maps the impact of digital technologies across these several dimensions: firm productivity growth, business dynamism, industry concentration, firm mark-ups and mergers and acquisition activity. It suggests policies that governments can use to facilitate digital adoption and reap the benefits of the digital revolution in manufacturing.

[1] OECD STI/PBD. The authors gratefully acknowledge excellent research assistance from Clara Kögel and very helpful suggestions and feedback from Andrea Garnero, Stéphane Sorbe and Wouter Zwysen.

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1. Introduction

Digital technology is fundamentally changing how companies organise their production, market their products and manage their expansion. They are able to access more markets and do so faster. Intangible assets play a greater role in their success than at any point in the past. Economies of scale mean that the most innovative and efficient companies can capture an increasing share of the market. The digital transformation forces companies to re-think their business models, but it is also accompanied by important changes in business dynamics and the nature of competition at the economy-wide level. Economies appear to be less dynamic, as evidenced by declining entry and reallocation rates across most OECD economies,[2] increased divergence between top and bottom productivity firms,[3] and increasing concentration of output in the hands of several largest firms in each industry.[4] At the same time, production and business dynamics has changed, as indicated by increasing mark-ups of top firms[5] and falling labour share of income.[6] An important role in these trends is also played by an intensifying merger and acquisition (M&A) activity, in many cases targeting IT-service start-ups.[7]

Companies that first come to mind when thinking about the digital transformation are IT-producing services companies. However, the manufacturing sector is no less affected by it. To the contrary, digital technologies underpin the Next Production Revolution which is under way in manufacturing (OECD, 2017) and, thus, paves the road to Industry 4.0. They allow manufacturing companies to automate large parts of their production, achieving higher and more stable quality at lower marginal costs. They also allow them to operate ever-more-complex supply chains, keep closer relationships with their customers and adjust their production in real time to the demands of the market. Furthermore, digital technologies play an increasingly central role in the process of manufacturing products – even outside the typically digital manufacturing industries such as manufacture of computers – and as such determine companies' success or failure. Cars are a good example. Resembling computers on wheels, they rely on digital technologies for anything from fuel injection in the engine to entertainment of the passengers to, more and more, driving themselves. In response, car manufacturers compete not only on the roads but also in the merger and acquisition (M&A) arena, trying to access technology and talent in the form of

[2] The trends were initially documented for the US; see, for example, Decker et al. (2014) and Decker et al. (2016). For cross-country evidence, see Criscuolo et al. (2014).

[3] See Andrews et al. (2016) and Berlingieri et al. (2017).

[4] See, for example, Furman and Orszag (2015), Grullon et al. (2015), Honjo, Doi and Kudo (2014) and Bajgar et al. (2019a).

[5] De Loecker and Eeckhout (2017) for the US and Calligaris, Criscuolo and Marcolin (2018) for 26 mostly OECD economies.

[6] Karabarbounis and Neiman (2014) and OECD (2015) document declining labour shares in a large number of countries. Autor et al. (2017b) and Barkai (2017) show evidence for the US and discuss some potential drivers of the observed trends. De Loecker and Eeckhout (2017) show how the rise in markups implies a decrease in labour share.

[7] See Bajgar et al. (2019b).

digital-intensive start-ups. Indeed, the car company that has perhaps had the most transformative impact on the industry in recent years itself resembles a Silicon Valley start-up more than the industry's incumbents.

Like in the economy at large, the dynamism and competitive environment in the manufacturing sector have been changing in the context of the digital transformation. In some cases, the changes are similar to those observed in services industries, in others they differ. This report maps these changes and additionally identifies policies which governments can use to reap benefits and address challenges that the digital revolution opens in their manufacturing sectors. In doing so, it builds on several recent OECD studies[8] but zooms in on the ways in which the ongoing digitalisation affects manufacturing in particular and on policies that are especially relevant in the manufacturing context.

The report consists of seven substantive sections.

Section 2. provides a measurement framework for the subsequent analysis by establishing how advanced the digital transformation is in different industries. It documents that in manufacturing the use of digital technologies is less varied than in services, with most industries showing significant but not very high digital intensity. Out of 13 manufacturing industries, only one is classified as having low digital intensity and only three as having a high digital intensity. Importantly, the digital transformation is happening along not one but many different dimensions, and industries may be highly digital-intensive in some of them and much less digital-intensive in others. The intensity of investments in ICT equipment and software and databases and of purchasing ICT goods and services is similar across manufacturing industries, but the "transport equipment" industry stands out in its intensive use of automation and "computer and electronics" by employing many ICT specialists. The "food and beverages" is the least digital-intensive manufacturing industry overall but generates particularly large turnover from online sales.

The following five substantive sections explore how the digital transformation affects various measures of business dynamism and competitive environment in manufacturing: productivity, business dynamics, industry concentration, mark-ups and mergers and acquisitions.

Section 3. discusses the effects that digital technologies have so far had on manufacturing productivity. It points out the apparent paradox in the productivity slowing down at the same time when digital technologies are rapidly spreading across manufacturing industries. It suggests that the paradox can be at least partly reconciled by recent evidence showing that digital adoption is indeed strongly related to productivity gains *on average* but the adoption and the gains from it are not even across firms but rather largely concentrated among highly productive firms that can complement the digital technologies with good management and digital skills. The difference in adoption rates between more and less efficient firms is particularly pronounced in manufacturing. The evidence suggests the importance of policies that encourage firms outside the productivity frontier to acquire skills and intangible capital that are complementary to the digital technologies.

Section 4. investigates the relationship between the digital transformation in manufacturing and business dynamism in the form of firm entry, growth and exit. It documents that manufacturing industries which are more affected by the digital transformation – particularly "Computer and electronics" – show substantially more business dynamism,

[8] See, in particular, Calvino et al. (2018), Gal et al. (2019), Calligaris et al. (2018), Bajgar et al. (2019a,b), Calvino and Criscuolo (2019) and Andrews et al. (2018).

especially in terms of reallocation among incumbent firms. At the same time, the business dynamism in these sectors is declining at a faster rates than in the less digital manufacturing industries. These two findings are in line with the idea that the rise of digital technologies leads to a wave of entry and innovation but as dominant products and services emerge, network effects and winners-take-most dynamics raise barriers for new entry. However, the differences in the levels and trends of business dynamism between industries of different digital intensity appear less pronounced in manufacturing than in services, particularly in terms of entry and exit rates.

Section 5. presents another sign of reduced business dynamism in the form of increasing industry concentration in manufacturing, both in North America and Europe. This trend could imply weaker competition but it can also reflect the growing productivity and innovation advantage of the leading companies. These trends in concentration, however, do not appear to be linked to the digital intensity of the sector.

Section 6. attempts to ascertain the characteristics of the changes which are under way in the manufacturing sector in the context of the digital transformation. Using the mark-up of price over marginal costs as a measure of changes in the production and business environment, it documents a significant increase in mark-ups of manufacturing firms, mainly driven by the highest-mark-up firms. However, unlike in services, manufacturing mark-ups do not appear to be particularly high in digital-intensive sectors. They are instead somewhat lower, likely indicating that leading manufacturing firms face a stronger competition from firms in other countries than leading firms in other sectors.

Section 7. shows that the number and value of mergers and acquisitions by manufacturing firms has increased, although less than in the case of acquirors operating in services industries. Manufacturing firms increasingly buy or invest in target firms operating in digital-intensive industries, particularly in “Data processing” and “Software publishing” and often abroad. This suggests M&As as an important channel for diffusion of digital technologies across industries and countries to the manufacturing sector.

While many policy issues appear in sections 3. -7. , the final section takes a more explicit policy focus and discusses policies that can facilitate digital adoption and productivity growth as manufacturing moves along the path towards Industry 4.0. It emphasises the importance of policies that encourage adoption of digital technologies for promoting productivity growth. It argues that complementary policies should promote roll-out of broadband infrastructure, build capabilities of both individuals and organisations and strengthen incentives through flexible labour markets, competitive product markets, availability of risk capital and lower administrative burden for start-ups.

2. Measuring digital transformation

The digital transformation is radically changing the way in which manufacturing production is organised and managed, significantly affecting economic performance in industry. However, measuring the scope and pace of the digital transformation has been challenging because there is not one but several ways in which a sector can be considered more or less digital. This section presents a new taxonomy of digital sectors that explicitly takes into account the multi-faceted nature of the digital transformation, and is used to analyse different aspects of the digital transformation in the remainder of this paper.

Traditional metrics are only able to partially capture the degree of penetration of (certain) digital technologies and struggle to mirror the fast pace at which the digital transformation unfolds. Furthermore, the usefulness of well-established measures of technology diffusion and adoption can be reduced by the low granularity or inadequate cross-country coverage of the data that are available.

In the context of the Going Digital project,[9] the OECD has led a measurement effort of the digital transformation, proposing a taxonomy of sectors according to the extent to which they have gone digital (Calvino et al., 2018). The approach starts from two considerations.

The first consideration is that digitalisation is a complex phenomenon that is poorly captured by a single indicator. Indeed, digital technologies affect different dimensions of economic activities, such as, the skills and nature of the labour force; the way in which firms compete and markets operate; the characteristics of capital and other inputs used in the production process; and the possibility to automate certain tasks.

The second consideration is that different sectors are affected by digital technologies in heterogeneous ways. In other words, some sectors tend to be characterised by higher digital intensity than others. This heterogeneity across sectors will likely depend on the dimension of digitalisation considered.

In this framework, Calvino et al. (2018) build seven different measures of the digital transformation in sectors representing different facets of digitalisation. These encompass, i) its technological component (using the share of ICT tangible and intangible investments and the share of intermediate purchases of ICT goods and services); ii) the human capital required (focusing on the share of ICT specialists in total employment); iii) the way it changes how markets operate proxied by the share of turnover from online sales); and iv) the extent to which automation is occurring (using the stock of robots per hundreds of employees).

Table 1 presents an overall "global" indicator that summarises the different facets of the digital transformation (also see, Calvino et al., 2018).[10] This summary indicator is available for two time periods: 2001-03 and 2013-15.

[9] See http://www.oecd.org/going-digital/ for an overview of the project and its different outputs.

[10] It is calculated averaging out the position of a given sector in each of the considered dimensions. Further details and robustness are provided in Calvino et al. (2018).

Table 1. Sectoral taxonomy of digital intensity: "global" indicator

Sector denomination	ISIC rev.4	Quartile of digital intensity: 2001-03	Quartile of digital intensity: 2013-15
Agriculture, forestry, fishing	01-03	Low	Low
Mining and quarrying	05-09	Low	Low
Food products, beverages and tobacco	10-12	Low	Low
Textiles, wearing apparel, leather	13-15	Medium-low	Medium-low
Wood and paper products, and printing	16-18	Medium-high	Medium-high
Coke and refined petroleum products	19	Medium-low	Medium-low
Chemicals and chemical products	20	Medium-low	Medium-low
Pharmaceutical products	21	Medium-low	Medium-low
Rubber and plastics products	22-23	Medium-low	Medium-low
Basic metals and fabricated metal products	24-25	Medium-low	Medium-low
Computer, electronic and optical products	26	High	Medium-high
Electrical equipment	27	Medium-high	Medium-high
Machinery and equipment n.e.c.	28	High	Medium-high
Transport equipment	29-30	High	High
Furniture; other manufacturing; repairs of computers	31-33	Medium-high	Medium-high
Electricity, gas, steam and air cond.	35	Low	Low
Water supply; sewerage, waste management	36-39	Low	Low
Construction	41-43	Low	Low
Wholesale and retail trade, repair	45-47	Medium-high	Medium-high
Transportation and storage	49-53	Low	Low
Accommodation and food service activities	55-56	Low	Low
Publishing, audio-visual and broadcasting	58-60	Medium-high	Medium-high
Telecommunications	61	High	High
IT and other information services	62-63	High	High
Finance and insurance	64-66	High	High
Real estate	68	Low	Low
Legal and accounting activities, etc.	69-71	High	High
Scientific research and development	72	Medium-high	High
Advertising and market research; other business services	73-75	High	High
Administrative and support service activities	77-82	High	High
Public administration and defence	84	Medium-high	Medium-high
Education	85	Medium-low	Medium-low
Human health activities	86	Medium-high	Medium-low
Residential care and social work activities	87-88	Medium-low	Medium-low
Arts, entertainment and recreation	90-93	Medium-low	Medium-high
Other service activities	94-96	Medium-high	High

Note: "High" identifies sectors in the top quartile of the distribution of the values underpinning the "global" taxonomy, "medium-high" the second highest quartile, "medium-low" the second lowest, and "low" the bottom quartile. Manufacturing sectors have been highlighted.
Source: Calvino et al. (2018).

Focusing on this global indicator, there is a persistent variation in digital intensity within manufacturing. About half of the sectors with low or medium-low digital intensity, and the other half with medium-high or high digital intensity. Indeed, most of the sectors are classified either in the medium-low (including sectors such as Textile, wearing apparel, leather or Basic Metals and fabricated metal products) or medium-high digital intensity groups (including sector such as Electrical equipment or Furniture, other manufacturing, repairs of computers). This classification of manufacturing sectors tends to be rather stable in the two periods considered.

However, there is somewhat less variation in digital intensity within manufacturing than within services. Manufacturing sectors tend to less frequently have the highest digital or lowest digital intensity than their market services counterparts. Indeed, only three manufacturing sectors are classified in the top quartile in either of the two periods considered (i.e., Computer, electronic and optical products, Machinery and equipment n.e.c., and Transport Equipment) compared to seven market services sectors; and only one manufacturing sector (Food products, beverage and tobacco) is classified in the bottom quartile compared to three in market services.

Additional insights are evident when focusing separately on each of the different facets that compose the global indicator. Table A.1 in the Appendix reports the classification of digital intensity according to each sub-indicator focusing on the period 2013-15. For each sub-indicator the table reports whether a particular sector scores relatively low (or high) in that particular dimension.[11] A visual representation of the different sub-indicators for manufacturing sectors is also reported in Figure 1 below (and in Figure A.1 in the Appendix). These "spider graphs" show the standardised sub-indicators of the taxonomy, for the different manufacturing sectors in the period 2013-15.[12]

Manufacturing sub-sectors exhibit far more heterogeneity across some digital sub-indicators than others. Panel A (in Figure 1) focuses on investments in ICT equipment and in software and databases in the period 2013-15 and shows that both of these indicators do not seem to exhibit considerable heterogeneity across manufacturing sub-sectors[13]. Similarly, the share of ICT specialists (see Panel B) also shows a more uniform pattern across manufacturing sub-sectors. Except for "Computer and electronics" where the investments in ICT specialists are the highest, the pattern for this indicator is rather homogeneous.

In contrast, the share of turnover from online sales and the robot stock (per hundreds of employees) exhibit a high degree of heterogeneity across sectors (see Panel B). Furthermore, having a high share of turnover from online sales does not necessarily imply having high robots stocks. For instance, "Food and beverage" and "Transport equipment", the sectors with the highest share of turnover from online sales, show both very different robot stocks. While "Transport equipment" is also the sector with the highest robot stock

[11] If a sector is associated with a white cell in an indicator's column, it will have the lowest level of digital intensity (bottom quartile) and the darker the colour, the more digital intensive the sector in that particular dimension (2nd and 3rd quartile) with the "blue" sectors being the most digital intensive (top quartile).

[12] Standardisation is applied before restricting the focus to manufacturing, therefore the scores reflect the relative position of manufacturing sectors in the taxonomy.

[13] "Machinery and equipment" has the highest investment in ICT equipment, whereas "Computer and electronics" is among the sectors with the highest investments in software and databases.

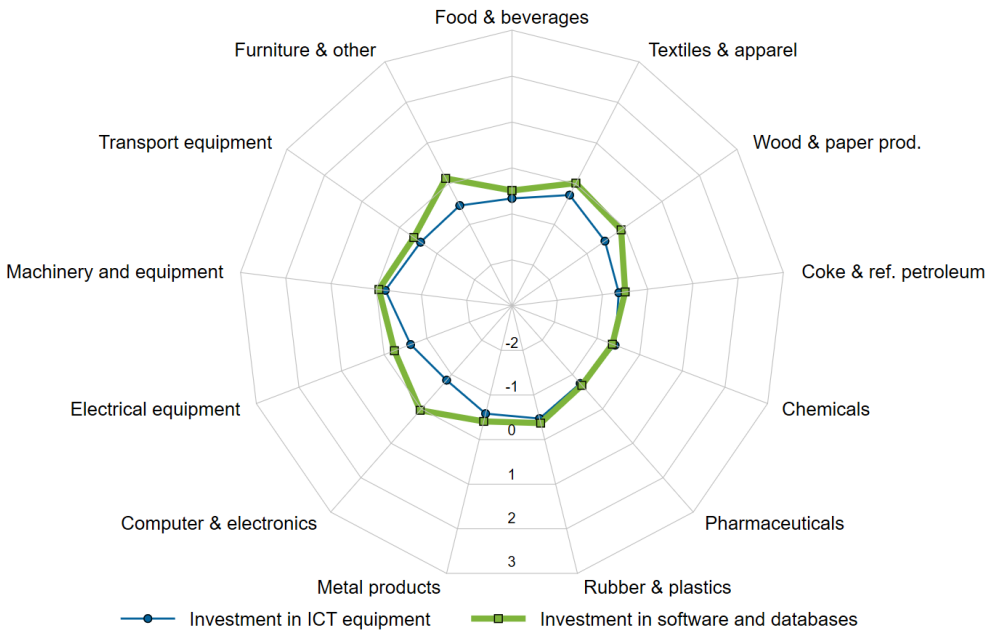
(per hundreds of employees), the "Food and beverages" sector conversely shows an average robot stock.

Finally, Figure A.1 in the Appendix presents the last two standardised sub-indicators: purchases of intermediate ICT goods and services. The purchases of intermediate ICT goods appear more heterogeneous across sectors than the purchases of ICT intermediate services. "Furniture and other" (which includes the repair of computers) is by far the sector with the highest purchases of ICT goods, whereas it shows average purchases of ICT services. On the contrary, for purchases of intermediate ICT services the sectors that are above average are "Computer and electronics", "Transport equipment", and "Wood and paper production".

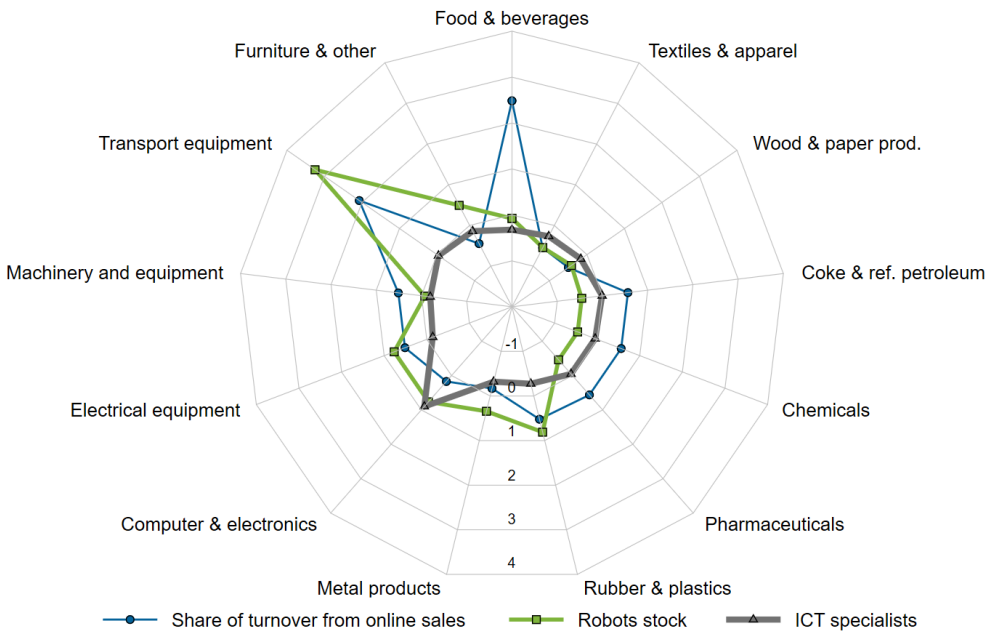
The taxonomy described in this section has been used to analyse different aspects and economic implications of the digital transformation, including its role for mark-ups, productivity, concentration, M&A, and business dynamism. This will be the focus of the remainder of this paper.

Figure 1. Standardised digital intensity indicators – Manufacturing – 2013-15

Panel A – ICT investments



Panel B – Markets, Automation and Human Capital



Note: the graph illustrates the standardised components of the taxonomy of digital intensity for the different manufacturing sectors. See Calvino et al. (2018) for details.
Source: authors' elaboration based on Calvino et al. (2018).

3. Productivity

Aggregate productivity growth slowed in many OECD economies over the past decade, which highlights a seeming contradiction with the existence of potentially transformative new technologies that could greatly increase productivity and economic welfare (see Brynjolfsson and McAfee, 2014). In other words, we see transformative new technologies everywhere but in the productivity statistics. This section looks beyond the aggregate, presenting new evidence of technology adoption in manufacturing and examining how this relates to firm productivity growth in the sector.

The apparent paradox and the nature of the decline of productivity growth has divided economists. Some argue that the speed of innovation, one of the main engines of productivity growth, is slowing down, or that new technologies do not have the potential to raise productivity as past innovations did (Gordon, 2012). Others draw a more optimistic picture, suggesting that some new technologies have the potential to bring disruptive innovations and productivity growth, but time is needed for productivity gains to be realised. This may be because of adoption lags, adjustment costs, and the need for costly complementary investments in intangible assets (Brynjolfsson and McAfee, 2012; Brynjolfsson et al., 2017).

A first step to overcoming these conflicting views is to look beyond aggregates, as this section does. The apparent paradox is not new, but echoes earlier debates relating to computers and earlier Information Communication Technologies – that were largely only resolved with greater availability of micro-level evidence (Draca et al., 2009). This earlier debate highlighted that productivity gains are heterogeneous across firms and rely on complementary investments in skills, management and organisation.

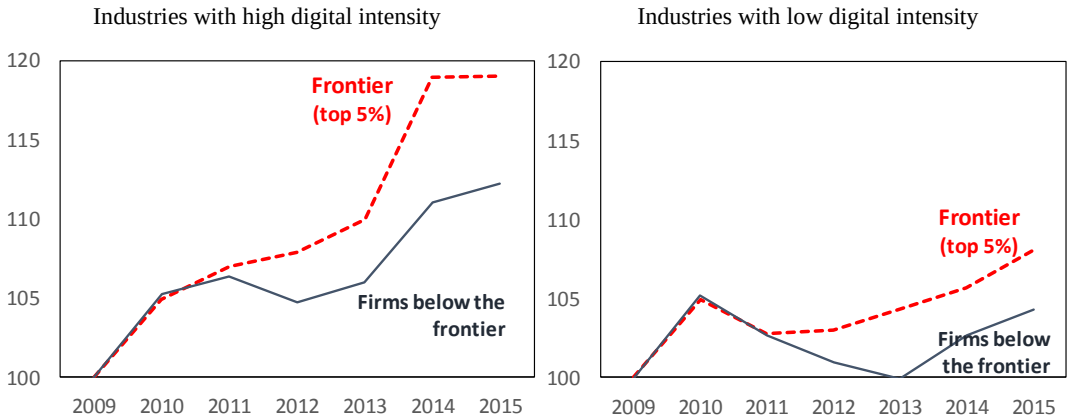
Recent micro-level evidence has raised concerns that new digital technologies may be linked to increasing productivity gap between frontier and other firms. The productivity slowdown has accompanied an increasing productivity divergence between highly-productive "superstar" firms and a mass of laggard firms where productivity growth has been sluggish (Andrews et al., 2016; Berlingieri et al., 2017). At the same time, new digital technologies can yield positive effects on productivity at the firm and industry level (Draca et al., 2009; Syverson, 2011; Gal et al., 2019). Figure 2 shows indeed that the productivity divergence is more pronounced in digital intensive industries.

One possible explanation for it is that technologies and knowledge developed at the frontier do not diffuse to all firms as they did in the past, and that digitalisation is contributing to exacerbate this phenomenon. Indeed, benefitting from digitalisation requires firms to reorganise production processes, which in turn requires good management and digital skills that are more likely to be found in highly productive firms.

Combining cross-country firm-level data on productivity and industry-level data on adoption across 21 EU countries and Turkey and 25 industries over 2009-2015, Gal et al. (2019) assess how the adoption of a range of digital technologies affects firm productivity. The digital technologies considered include enablers such as access to high-speed broadband internet, simple and complex cloud computing (i.e. e-mail services vs. online renting of data or computing capacities), as well as back and front office integration systems such as customer relationship management (CRM), and enterprise resource planning (ERP) software.

Figure 2. Productivity dispersion has widened, especially in digital intensive industries

Multifactor productivity (MFP) at the productivity frontier and for the average non-frontier firm (2009=100)



Note: The "frontier" is measured by the average of log multi-factor productivity, based on the Wooldridge (2009) methodology, for the top 5% of companies with the highest productivity levels in each 2-digit industry and year, across 24 countries. The "firms below the frontier" corresponds to the average of the log-productivity distribution of non-frontier firms in each industry and year. The values obtained for the detailed 2-digit industries are averaged to industry groups that are classified either as having "high" or "low" digital intensities according to the methodology in Calvino et al. (2018), discussed in section 2. The series are normalised to 100 in the starting year (2009=100).
Source: Gal et al. (2019) following the methodology in Andrews et al. (2016[1]).

Gal et al. (2019) find that overall digital adoption in an industry is associated with productivity growth of firms in those industries. For example, a 10-percentage point increase in the use of high-speed broadband internet (resp. cloud computing) at the industry level is associated with a 1.4% (resp. 0.9%) increase in multi-factor productivity for the average firm in the industry after 1 year, and 3.9% (resp. 2.3%) after 3 years.

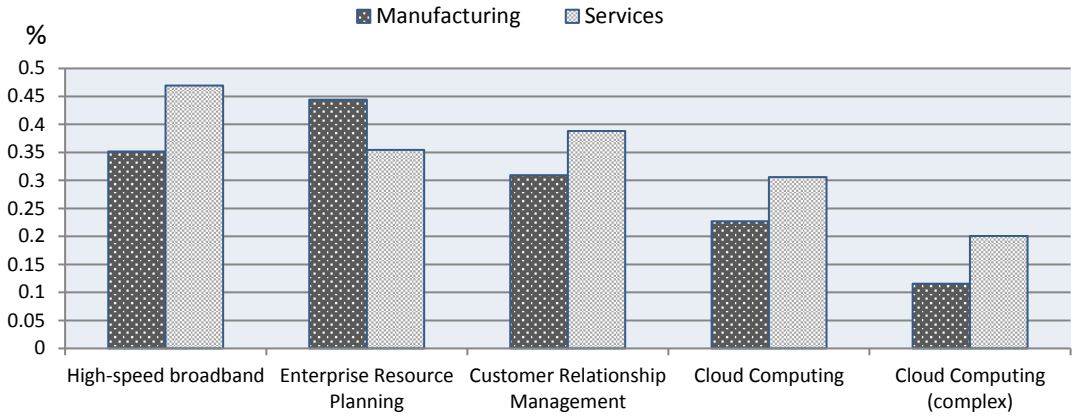
However, there are differences in the productivity benefits from digital adoption among firms belonging to different sectors and with different levels of productivity. First, the take up of digital technologies is generally higher in services than in manufacturing (Figure 3). However, Gal et al. (2019) find that the association of digital adoption with higher firm-level productivity is much stronger in manufacturing than services for most technologies, with the notable exception of high-speed broadband[14] (Table 2). This could reflect not only higher marginal effects due the lower level of take up in manufacturing, but also other characteristics potentially cutting across the two macro-sectors.

Finally, Gal et al. (2019) show that more productive firms tend to benefit from the diffusion of digital technologies more than less productive firms. This may be because (i) they are more likely to invest themselves in these technologies, (ii) they tend to enjoy higher productivity benefits when they adopt, and (iii) they benefit more from interactions with digitalised peers in the same industry. These factors likely reflect that more productive firms benefit from a higher endowment of (or better access to) human and organisational capital that are essential complements to digital technologies.

[14] However, note that the productivity effects of broadband have been shown to often only materialise when the necessary complementary inputs are also in place such as such as software and skills, De Stefano et al. (2018).

Figure 3. The diffusion of digital technologies across sectors

Selected technologies, 2016 (or latest available)



Note: This graph shows the average adoption rate of selected digital technologies in the manufacturing sector (NACE Rev.2 10-33) and the services sector (NACE Rev.2 10-33) of the 21 countries included in this analysis.
Source: Gal et al. (2019).

These results are consistent with the idea that digitalisation, while supporting productivity for the average firm, has also played a role in the widening productivity divergence between firms (documented in Andrews, Criscuolo and Gal, 2016; Berlingieri et al., 2017). It is also in line with recent findings on the speed of catch-up of laggard firms (i.e., 40% least productive firms) by Berlingieri et al. (2018). Berlingieri et al. (2018). These papers show that whilst laggard firms tend to grow faster than the rest (i.e., they "catch-up" faster) [15], laggards converge at a lower speed in industries characterised by a higher level of skills and a larger share of ICT specialists. On the contrary, policies related to training and public R&D expenditures seem to foster catch up of laggards. This will be further discussed in Section 8. .

Overall, the evidence suggests new frontier technologies do not immediately diffuse to all firms, but highlight the importance of skills for diffusion. Laggards that often do not have the necessary absorptive capacity, may have more difficulties in catching-up in sectors where technology and knowledge matter the most.

[15] These papers do not find a significant difference in the speed of catch-up between manufacturing and market-services firms.

Table 2. Differentiating between manufacturing and services

Dependent variable: MFP growth

	High-speed broadband	Enterprise Resource Planning	Customer Relationship Management	Cloud Computing	Cloud Computing (complex)	1st principal component
Frontier growth	0.184***	0.170***	0.178***	0.179***	0.182***	0.189***
	(0.0413)	(0.0400)	(0.0410)	(0.0409)	(0.0421)	(0.0443)
Gap to frontier (lagged)	0.127***	0.125***	0.126***	0.126***	0.128***	0.129***
	(0.00540)	(0.00508)	(0.00512)	(0.00522)	(0.00523)	(0.00561)
Age	-0.000204***	-0.000215***	-0.000203***	-0.000219***	-0.000282***	-0.000270***
	(5.38e-05)	(5.04e-05)	(5.31e-05)	(5.17e-05)	(4.97e-05)	(5.30e-05)
Employees (log)	0.0256***	0.0254***	0.0257***	0.0258***	0.0271***	0.0273***
	(0.00201)	(0.00194)	(0.00195)	(0.00199)	(0.00207)	(0.00217)
Digital technology (Manufacturing)	0.119**	0.113***	0.211***	0.189***	0.359***	0.0264***
	(0.0535)	(0.0419)	(0.0481)	(0.0524)	(0.115)	(0.00517)
Digital technology (Services)	0.173***	0.0526	0.158***	0.0589	0.0644	0.0140***
	(0.0329)	(0.0578)	(0.0384)	(0.0509)	(0.0574)	(0.00395)
Observations	1,223,625	1,273,088	1,256,137	1,275,982	1,221,521	1,135,046
R-squared	0.073	0.073	0.073	0.073	0.074	0.074

Note: Colum 1-6 of this table show the results of the equation where firm-level multifactor productivity growth is regressed on growth of the top 5 percent frontier firms in each sector-year cell, the firm's gap to this frontier, age and size (measured by the number of employees), and the interaction between digital technology adoption rates and a dummy for the sector. All regressions include sector and country-year fixed effects and are clustered at the country-sector level. The last column shows results for the 1st principal component of the five technologies. Firms at the sector-year frontier are excluded from the regressions. Regressions are based on firm-level data from 21 countries and 25 sectors (NACE Rev 2, 10-83) over the period 2010-15 for firms with more than 10 employees. To maximise coverage, unweighted averages of each digital technology variable are used over the period. ***, ** and * represent p<0.01, p<0.05 and p<0.1 respectively.
Source: Gal et al. (2019).

4. Business dynamics

Business dynamics – the process of firm entry, growth and exit – has also been significantly affected by the digital transformation. Over the 1990s and the early 2000s digital technologies diffused very fast, influencing different domains of economic activity and becoming the general-purpose technology of the 21st century. Many new companies were set up – often starting with little means – and some of them succeeded, gaining significant market shares and becoming nowadays leaders in their domain. However, as these leaders consolidated their positions, this has reduced incentives for further entry and seems to have led to a reduced business dynamism in the more recent years. This section discusses the often-conflicting role that digital technologies play in business dynamics.

Recent OECD work (Calvino and Criscuolo, 2019) has focused on the role of the digital transformation for business dynamics across countries. The analysis has combined harmonised data on business dynamics for 15 countries[16] with the "global" indicator (see Section 2.) that measures digital intensity at the sectoral level, focusing on digital intensive sectors (sectors in the top quartile in either of the two periods considered) as compared to other sectors of the economy. Focusing on different measures of business dynamism (entry rates, exit rates, and the simultaneous job creation and job destruction by incumbent firms, i.e., job reallocation rates of incumbents) Calvino and Criscuolo (2018) highlight two stylised facts.

First, digital intensive sectors are on average more dynamic than other sectors of the economy. This is also illustrated in Figure A.2 in the Appendix, which shows that digital intensive sectors are characterised by higher average entry rates and job reallocation rates of incumbents, even after controlling for unobserved country-specific macro-economic shocks.[17] However, even though this is true for most countries, significant cross-country differences in the extent to which digital intensive sectors are more dynamic than other sectors of the economy exist. These will be discussed more in detail in one of the following sections, focusing on the role of policy.

Second, on average business dynamism has declined in digital intensive sectors, to some extent even faster than in other sectors of the economy. This is evident from Figure A.3 in the Appendix, which highlights the average within-country-sector trends in entry rates, focusing separately on digital intensive and other sectors of the economy. The figure highlights a sharp average decline in entry rates in digital intensive sectors, especially after 2001, which appears more prominent than the one occurring in other sectors of the economy.[18]

[16] Further details and a coverage table are available in Calvino and Criscuolo (2019).

[17] The figure focuses on manufacturing and non-financial market services, excluding the Coke and refined petroleum products and Real estate activities sectors. See the figure notes for more details.

[18] This is true in most countries analysed, but again significant cross-country differences exist. Similar dynamics are also evident when focusing on job reallocation rates, while exit rates have been on average more stable over time, with significant peaks in 2001 and during the global financial crisis (Calvino and Criscuolo, 2019).

A possible interpretation proposed to reconcile the observed dynamics is related to technological factors. Indeed, on the one hand digital technologies lower entry barriers and facilitate interaction, information flows and access to markets, creating opportunities for experimentation. On the other hand, new opportunities for entrants are highly widespread in the early stage of the diffusion of digital technologies – likely in the late 1990s and early 2000s. As time goes by, like in other innovative sectors, dominant products and services emerge, reducing the opportunities for new entrants and shifting innovation towards process improvements, with only fewer successful firms gaining market shares and thriving (Calvino and Criscuolo, 2019).[19]

This interpretation may be relevant to think about the possible implications of general-purpose technologies such as artificial intelligence and machine learning for business dynamism. On the one hand, these technologies may spur a new paradigm shift and a new wave of entry and reallocation, especially in sectors where these technologies originate, but also in sectors where they may bring changes that are more radical. The considerable amount of data required to benefit from these technologies might however represent a possible barrier to entry in this context. On the other hand, one might also think of the application of these emerging technologies as a shift to process innovation occurring within the latest stages of the digital transformation, further reinforcing the observed dynamics described above.

While these dynamics are evident when analysing together digital intensive sectors in both manufacturing and services, given the scope of this paper it is relevant to further focus on the specificities of digital intensive manufacturing sectors.

In this context, Figure 4 compares business dynamism in digital-intensive manufacturing sectors with other manufacturing sectors, controlling for unobserved country-specific macro-economic shocks, similarly to Figure A.2 in the Appendix (which has been discussed above).

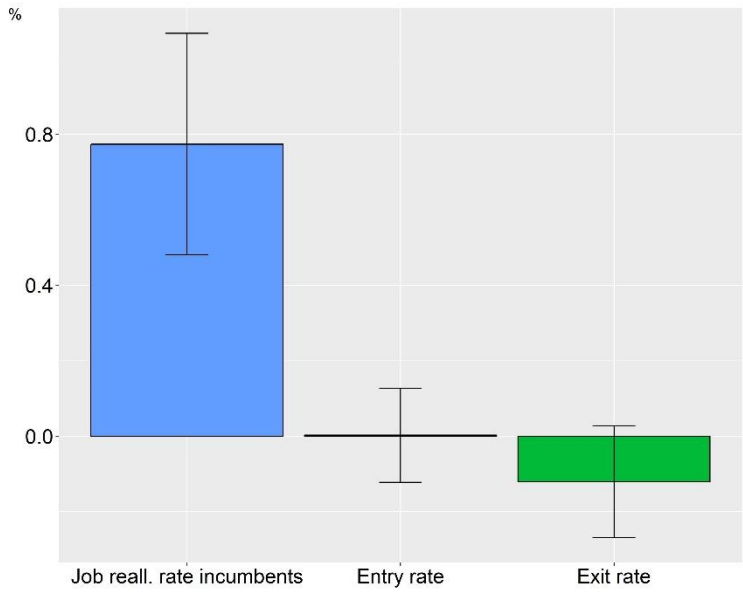
Figure 4 suggests that digital intensive manufacturing sectors have higher job reallocation rates of incumbents than other manufacturing sectors (about 0.8 percentage points higher), even if this difference is lower in magnitude with respect to the one reported in Figure A.2. Entry and exit rates in digital intensive manufacturing seem instead more similar to those observed in other manufacturing sectors.

Further focusing on manufacturing sub-sectors, pooling together countries and available years, suggests that the “Computer and Electronics” industry exhibits higher average and median job reallocation rates of incumbents in manufacturing. Entry and exit rates appear more homogeneous, with sub-sectors like “Furniture and other”, “Textile and apparel”, “Food and Beverage”, and “Computer and Electronics” exhibiting slightly higher average entry rates, and “Textile and apparel” exhibiting higher exit rates on average.

[19] This is consistent with the industry life-cycle framework proposed by Klepper (1996). These argument seem related not only to ICT-producing sectors but also and more generally to digital intensive sectors given the general purpose nature of digital technologies (Jovanovic and Rouseeau, 2005).

Figure 4. Business dynamics

Digital intensive manufacturing vs. other manufacturing sectors



Note: The bars report coefficients based on separate regressions where the dependent variables are alternatively job reallocation rates of incumbents, entry rates or exit rates, which are regressed on a digital intensity dummy (including digital intensive sectors as defined above). The regressions focus on the manufacturing sector and include country-year fixed effects. Confidence intervals (95%) are also reported based on robust standard errors. Period 1998-2015, temporal coverage varies by country in OECD DynEmp3 database, see Calvino and Criscuolo (2019).
Source: Calvino and Criscuolo (2019).

Furthermore, Figure 5 focuses on the average within-country-sector trends in entry rates, considering separately digital intensive manufacturing and other manufacturing sectors, similarly to Figure A.3 in the Appendix. The figure highlights an average decline in entry rates in digital intensive manufacturing sectors, especially after 2001, which appears slightly steeper than the one occurring in other manufacturing sectors. Differences between the trends observed for digital intensive manufacturing and other manufacturing sectors appear less significant than the ones observed comparing all digital intensive sectors (both in manufacturing and services) with other sectors (see Figure A.3 in the Appendix).

Analysing more in details the trends among manufacturing sub-sectors, especially focusing on digital intensive manufacturing sub-sectors, suggests that “Computer and Electronics” and “Machinery and Equipment” exhibit on average among the largest declines in entry rates, while these declines are less pronounced in the “Transport Equipment” sector.

In order to contextualise the findings specific to the manufacturing sectors, one should consider the following.

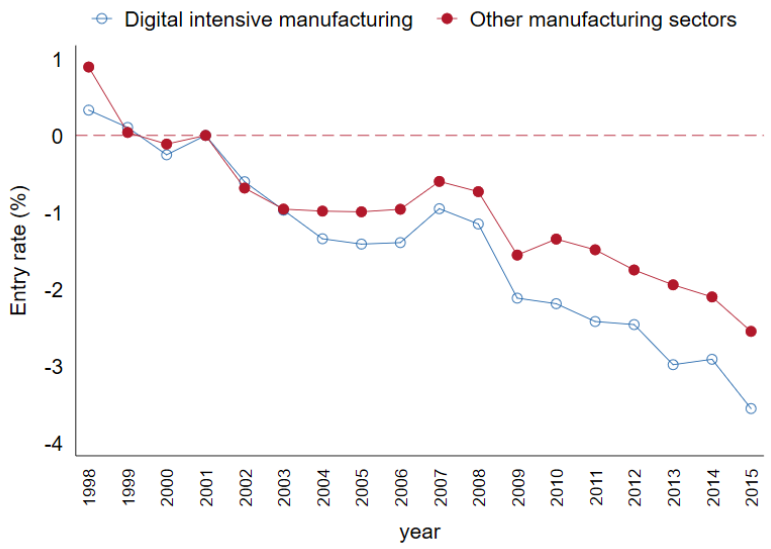
Manufacturing sectors tend to have in general lower entry rates than services sectors. These sector-specific dynamics can depend on a range of factors including industry’s capital intensity, the presence of significant economies of scale, sunk costs, or concentration (Siegfried and Evans, 1994; Audretsch, 1991), or the nature and evolution of its technological base (Audretsch, 1995; see also Santarelli and Vivarelli, 2007).

Importantly, in line with the interpretation discussed above, the stage of development of the industry is likely to play an important role in determining sectoral differences in business dynamism, in particular in entry rates, with sectors in a later stage of their life-cycle exhibiting lower entry (Klepper, 1996).

This may indeed be the case for many manufacturing sectors, and may be part of the reasons why there are smaller differences between average entry rates in digital intensive manufacturing and other manufacturing sectors.

Figure 5. Entry rates – average changes within country-sectors

Digital intensive manufacturing vs. other manufacturing sectors



Note: The figures are based on the year coefficients of regressions within country-sector, focusing on the manufacturing sectors. They report average within-country-sector trends of entry rates, focusing separately on manufacturing sectors in the "Digital intensive" and "Other sectors" groups. The baseline year is set to 2001. Each point represents cumulative change in percentage points since 2001. Owing to methodological differences, figures may deviate from officially published national statistics. Data for some countries are still preliminary.
Source: OECD *DynEmp3* database, November 2018.

5. Industry concentration

The increasing productivity advantage of the top firms and the more moderate business dynamism documented above might lead to an increasing part of economic activity to become concentrated among a small number of leading companies. Indeed, several studies indicate that it has increased in both manufacturing and services in the United States (Furman and Orszag, 2015; Gutiérrez and Philippon, 2017; Grullon et al., 2017 and Autor et al., 2017a) and Japan (Honjo, Doi and Kudo, 2014). The evidence for other parts of the world is to date limited and inconclusive, but a new OECD report suggest that a similar increase also took place in Europe (Bajgar et al., 2019a). This section briefly presents trends in manufacturing for Europe and North America based on a matched Orbis-Worldscope-Zephyr database of financial and ownership information.

Industry concentration captures the weight of the largest business entities in the economy. The entities in question are often firms, but this report analyses the role of the largest business groups. This approach has the advantage that it takes into account the fact that multiple firms are often part of the same business group. For each industry, it measures concentration as the share of the industry's total sales by the 8 business groups with the largest sales in that industry). In principle, the total sales of each industry could be calculated by summing sales across all firms in the microdata at hand. The choice of industry denominator is non-trivial – using total sales of the firms in the data at hand is not appropriate when the coverage of firms varies across industries or over time, as is the case with the Orbis database used in the analysis. For this reason, we instead derive the industry denominator from the industry-level database OECD STAN, which provides information that is comparable across industries and countries over time.

The data indicate a noticeable increase in manufacturing industry concentration for both Europe and North America over the period (Figure 6). Over the period 2000-2014, 71% of 2-digit manufacturing industries in Europe and 65% in North America saw their concentration increase. Over the period, concentration levels increased by 3-4 percentage points in the average European industry, compared to around 6-8 percentage points in the average North American industry.[20]

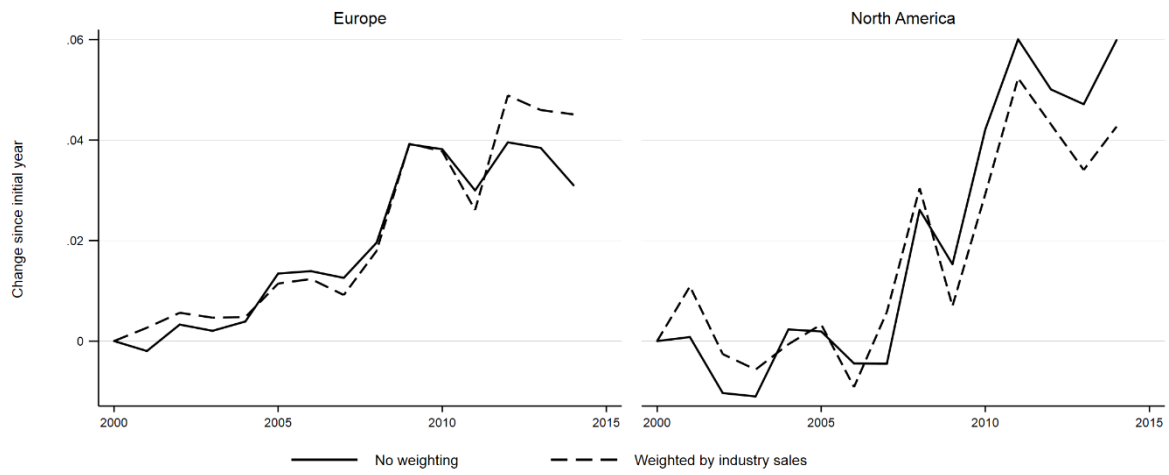
The results might suggest a stronger increase in North America. However, it is important to note that the observed increase for North America are somewhat stronger than what, for example, Autor et al. (2017b) find for the US (admittedly using firm-level rather than business group-level concentration), which suggests that this could very well be due to the data limitations for North America of the ORBIS database. In particular, North American firms have poor coverage of subsidiary financial information, which reduces our ability to apportion business group activity when they have large (missing) domestic subsidiaries.

Trends in industry concentration can reflect or have implications for a range of economic phenomena. Increasing industry concentration may indicate technological change or globalisation allowing the most productive firms to expand (Autor et al., 2017b). An increasing scale of a few firms may also mean fewer buyers in input markets and local labour markets – monopsony – potentially impacting contractual terms for suppliers and

[20] For Europe, weighting strengthens the growth in concentration by about 0.5 percentage points, implying that larger industries are showing somewhat faster increases in concentration. For North America, we find the opposite – a slightly lower increase in the weighted average concentration.

workers (OECD, 2008; OECD, forthcoming). In addition, lobbying is more likely to be undertaken by larger firms and by firms in concentrated markets, which may inform policy differentially in concentrated industries (Dellis and Sondermann, 2017). Last but not least, high concentration may impact firm risk-taking behaviour if they are seen as "too big to fail".

Figure 6. Weighted & Unweighted Average Manufacturing Industry Concentration (CR8) in Europe & North America



Note: The countries for Europe include BE, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LV, NL, NO, PL, PT, SI and SE, and the countries for North America include CA and US. Included industries cover 2-digit manufacturing and non-financial market services. Concentration metrics reflect the share of the top 8 firms in each industry (CR8). The graphs can be interpreted as the cumulated *absolute* changes in levels of sales concentration for the mean 2-digit sector within each region. For instance, in 2014 the mean (unweighted) North American industry had 6 percentage point higher sales concentration than in 2000. Weighted figures reflect industry concentration weighted by the industry's share in region total sales, such that larger industries are weighted more heavily.

Industry concentration is also sometimes seen as a proxy for the degree of competition. While industry concentration can be used as an initial indicator to screen for changes in the degree of competition, by itself it can say little about whether or not market competition is changing.[21] Looking at a range of additional metrics – such as mark-ups (discussed in Section 6.) and business entry and exits (Section 4.) – provides a better indication of whether there are changes in the competitive environment.

As of now, it is not clear what leads to the observed increase in concentration. Some argue that the increase in concentration is good news for the economy. An economic shock (e.g. the spreading of digital technology or integration of global markets) may have allowed

[21] The imprecision flows from the fact that to get from industry concentration to market competition one needs to be confident that a) there is a reliable relationship between industry concentration and market concentration (see OECD, 2018, and Werden & Froeb, 2018), b) that market concentration is a good indicator of market power (often not the case in differentiated product or geographic markets, platform markets and innovative markets); and c) that market power reflects a lack of competitive intensity rather than being a sign of competition in action.

efficient and innovative firms ("superstars")[22] to increase their productivity, boost their market shares and possibly also acquire other companies; this would represent a reallocation of labour and capital towards more productive firms (Jovanovic and Rousseau, 2008), leading to greater aggregate productivity. An opposing view suggests that the largest companies might have become too powerful, and their position in the market too hard to contest. This, coupled with declining entry rates (Calvino et al., 2018) could lead to less innovation and a slower productivity growth both directly via less radical innovation from entrants and indirectly via lower competitive pressure on incumbents to innovate (Aghion et al., 2005). The increased concentration could also be a sign of weaker competition. This explanation could be in line with the increase in mark-ups observed in some countries and industries (see Section 6.).

[22] See Autor et al. (2017b) and Van Reenen (2018).

6. Mark-ups

The measures of competitive environment presented in Sections 4. and 5. indicate some weakening in the business dynamism of the manufacturing sector in the context of the digital transformation. The present section assesses the relationship between changes in competitive environment and the digital transformation by focusing on mark-ups a commonly used measure of market power, and in particular on changes in mark-up pricing. Mark-ups, defined as the ratio of unit price over marginal cost, are different from unity when markets are not perfectly competitive, e.g. when products are differentiated or there are barriers to entry. However, high mark-ups can also be related to other features of production, such as large fixed costs, a high degree of innovation, a high value of embedded intangibles (Martins et al., 1996), or international linkages (e.g. De Loecker and Warzynski, 2012).

Previous literature (Martins et al., 1996) has analysed the impact of imperfections in product markets on the price setting of firms, and estimate mark-ups extending the methodology first proposed by Hall (1986), and later modified by Roeger (1995). They relate mark-ups with the structure of the industry and explore the evolution of mark-ups over the business cycle across 14 OECD economies for manufacturing and selected services sectors for the 1980-1992 period. They show that departures from perfect competition are very common in the manufacturing sector, but even more in service sectors. Moreover, although high mark-ups might be a sign of lack of competition, they may also be related to the market structure prevailing in an industry. De Loecker and Eeckhout (2017) show the evolution of mark-ups since the 1950s for the United States and point to a broad-based increase in mark-ups across all sectors of the economy since the 80s driven by an increase in high mark-up firms. They interpret this as evidence of increased market power and link it to the observed slowdown in output; decrease in labour share, labour flows, labour force participation and in low skill wages. Calligaris et al. (2018) link the increase in mark-up to the digital transformation and investigate potential factors that can account for this link. They show that: i) mark-ups are increasing over the period considered, on average across country; ii) this result is driven by firms at the top of the mark-up distribution, while the bottom half of the distribution exhibits a flat trend over time; (iii) mark-ups are higher in digital-intensive sectors than in less-digitally intensive sectors; (iv) mark-up differentials between digitally-intensive and less-digitally-intensive sectors have increased significantly over time.

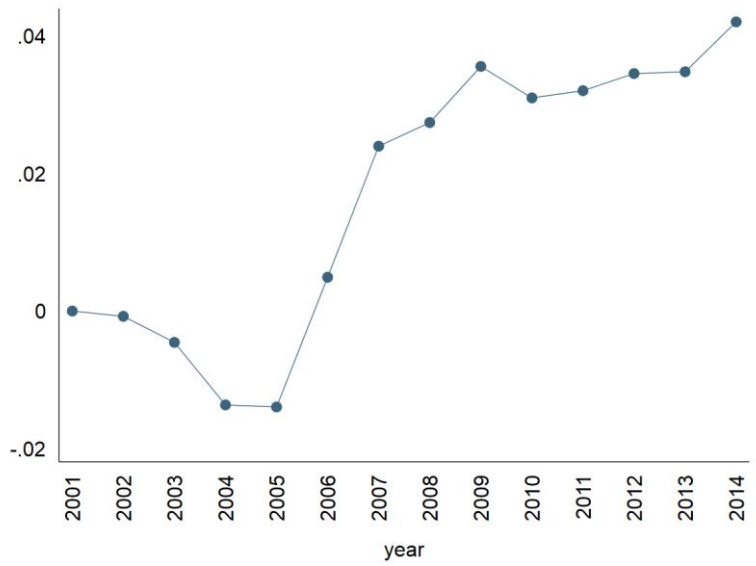
The analysis conducted in this section is based on Calligaris et al. (2018). The evolution of firm mark-ups is examined across 25 countries (Australia, Austria, Belgium, Bulgaria, Denmark, Estonia, France, Finland, Hungary, Germany, Indonesia, India, Ireland, Italy, Japan, Republic of Korea, Luxembourg, the Netherlands, Portugal, Romania, Slovenia, Spain, Sweden, the United Kingdom, United States) for the period 2001-2014, and is then linked to the measure of "digital intensity" of sectors mentioned before. The firm-level data are sourced from the commercial dataset Orbis® by Bureau van Dijk (BVD). Firm-level mark-ups are estimated as proposed in the work of De Loecker and Warzynski (2012), who build on Hall (1986); then it has been tested whether differences in mark-ups across industries are related to differences in industries' exposure to digitalization.[23] Differently from Calligaris et al. (2018), this report: i) specifies the firm-specific production function

[23] For further details about methodology and data adopted, please see Calligaris et al. (2018).

exclusively as a Cobb-Douglas based on gross output and three inputs (labour, capital, and intermediates), generally considered the most stable production function in the literature; ii) focuses exclusively on the manufacturing sector; iii) in line with the rest of the report, distinguishes between digital-intensive vs non-digital-intensive manufacturing sectors, where sectors are classified as digital intensive if, based on the methodology introduced in Section 1. they are in the top quartile of the sector distribution in terms of digital intensity either at the beginning or at the end of the period.

We first describe the evolution of mark-ups over time. We report trends in firm level mark-ups over the period 2001-2014 across 25 countries in the manufacturing sector. Figure 7 plots the unweighted average log mark-ups indexed to 0 in 2001, which for small changes is directly interpretable as percentage changes. The figure shows that, after a first period of small decrease up to 2005, mark-ups in manufacturing have been increasing by around 4% between 2005 and 2014. A similar increase is also reported in a recent study by De Loecker and Eeckhout (2017), who estimate mark-ups over a longer time horizon for publicly-traded companies in the United States. When focusing on the manufacturing sector, rather than on the combination of manufacturing and non-financial market services (Calligaris et al., 2018), the increase in mark-ups starts only in 2006 and its growth is about half that computed for both sectors, suggesting that on average mark-ups have increased more in services than in manufacturing. Similar graphs for each 2-digit (STAN A38) manufacturing industry are reported in Figure A.4 in the Appendix. There are significant differences across manufacturing sectors in the extent to which mark-ups have increased with some, such as textile, showing very large increase in mark-ups; while others, such as pharmaceutical experiencing declining or stable trends in mark-up.

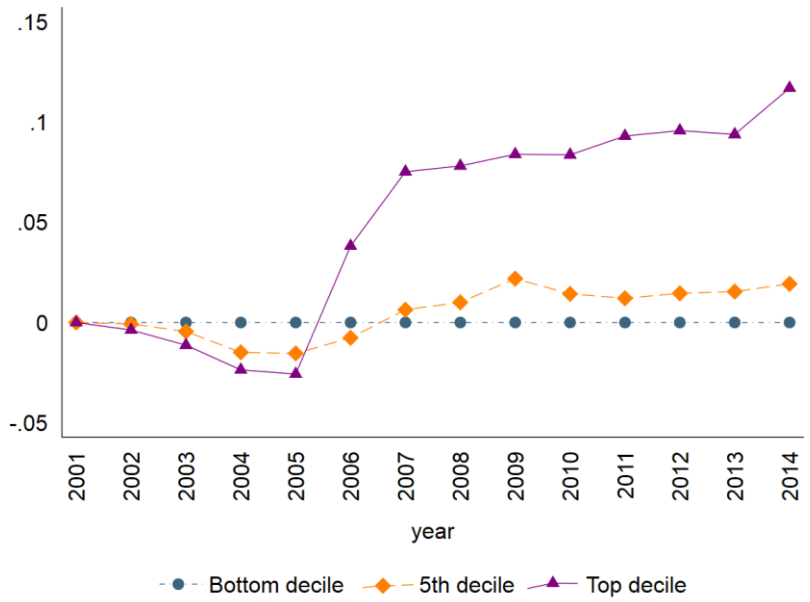
Figure 7. Average of firm log mark-up: growth 2001-2014 - Manufacturing



Note: Unconditional averages of firm-level log mark-ups, for all firms in the manufacturing sector included in the sample. The figure plots log-mark-ups and indexes the 2001 level to 0, hence the vertical axes represent log-differences from the starting year which, given the magnitudes, approximates well for growth rates.
Source: Elaboration on Calligaris et al. (2018).

Interestingly, once firms are grouped by their mark-up levels[24], the average growth in mark-ups appears to be mainly driven by those firms that enjoy the highest level of mark-ups (i.e., firms in the top decile of the mark-up distribution). Note that deciles of the distribution are defined relative to the rest of the firms in each particular 2-digit-year sector. Figure 8 plots average percentage changes in mark-ups for the top, the bottom and the median decile of the mark-up distribution. While the bottom and the median decile exhibit a flat trend, the top decile increases over time by almost 3 times the average mark-up. Said differently, this analysis suggests that it is firms with the highest levels of mark-ups that increasingly enjoy larger mark-ups vis-à-vis firms belonging to the rest of the mark-up distribution. The average mark-up growth depicted in Figure 7 seems therefore to be mainly driven by firms belonging to the top part of the mark-up distribution.

Figure 8. Log Mark-up growth over time (2001-2014) in different parts of the distribution.



Note: Unconditional averages of firm-level log mark-ups in the chosen part of the distribution of mark-ups. Deciles of the distribution are defined relative to the rest of the firms in each 2-digit-year industry. All firms in the manufacturing sector included in the sample. The figures plots log-mark-ups and indexes the 2001 level to 0, hence the vertical axes represent log-differences from the starting year.
Source: Elaboration on Calligaris et al. (2018).

An important question is to what extent these trends are related to the digital transformation. In order to do so, an econometric analysis has been performed to separate

[24] In each 2-digit-year sector, firms were divided firms into 10 deciles over the mark-up distribution. For example, the 10% of firms with the highest mark-ups belong to the "Top decile", whereas the 10% of firms with the lowest mark-ups belong to the "Bottom decile". In Figure 2, the average across all countries and manufacturing industries is plotted year by year for the top, the median, and the bottom decile of the distribution.

the relationship between a sector's digital intensity and firms' mark-ups from other confounding factors.[25]

Table 3 reports differences in mark-ups for manufacturing firms operating in digital intensive sectors relative to less digital intensive sectors conditional on other firm characteristics, such as age, capital intensity, productivity and country-year of operation. In the manufacturing sector, firms in the high-digital sectors are found to display on average lower mark-ups than firms operating in low-digital sectors, everything else held constant. The estimates suggest that firms operating in a "top-digital intensive" manufacturing sector exhibit 1.3%[26] lower mark-up than firms belonging to less digital intensive manufacturing sectors. This result is in line with Calligaris et al. (2018). Although they show that overall (i.e., looking at both manufacturing and non-financial market services) there is a positive and strong relationship between mark-ups and digital intensity of the sector, they also find that the correlation between digital intensity and mark-ups is much stronger in services than in manufacturing. In addition, in the manufacturing sector companies operating in less digital intensive industries display higher mark-ups than those operating in more digital intensive industries. The fact that firms in the high-digital industries display on average lower mark-ups than firms operating in low-digital industries likely reflects the fact that manufacturing companies in high digital intensive sectors are also strongly integrated in global markets, and face stronger competition than companies in other manufacturing (and services) sectors.

Table 3: Baseline regression

	Log Mark-ups
Top-digital Intensive	-0.013***
	(0.001)
Log(age)(t-1)	-0.040***
	(0.001)
Log(K/Sales)(t-1)	0.080***
	(0.003)
Log(tfp)(t-1)	0.025***
	(0.001)
Observations	596,034
R-squared	0.177
Country-year FE	YES
Cluster	Firm Level
Weights	NO

Note: Results of estimating OLS regressions where the dependent variable is a firm's log-mark-ups. "Top digital intensive" is a dummy variable with value 1 if the sector is in the top quartile of digital intensity instead. Errors are clustered at the company level. *** p<0.01, ** p<0.05, * p<0.1.
Source: Elaboration based on Calligaris et al. (2018).

To summarise, three basic results have been presented in this section. Looking at mark-ups generally, two trends emerge: i) on average, mark-ups are increasing over the period 2005-2014; and ii) this result seems to be driven by those firms that belong to the top part of the

[25] For details about the methodology adopted see Calligaris et al. (2018).

[26] -1.3%=exp(-0.013)-1. See Halvorsen and Palmquist (1980).

mark-ups distribution, the rest exhibiting essentially a flat trend over time. Distinguishing between top-digital intensive and less digital intensive industries, it is further observed that in the manufacturing sector (iii) mark-ups are lower in the digital intensive sectors than in less digital intensive sectors.

7. Mergers and acquisitions

At the same time as some of the indicators discussed in the previous sections indicate a declining business dynamism, the pace of acquisitions is reaching record highs. Globally the number of mergers and acquisitions (M&As) has more than doubled between 2003 and 2015 and their value today is at a similar level as at the peak of the dot-com bubble and during the run-up to the Great Recession (Bajgar et al., 2019a). Some of the M&As indicate industry consolidation, but many others serve as a channel for diffusion of digital technologies, as witnessed by a particularly large number of M&As by manufacturing companies targeting digital start-ups. This section describes the changing trends in the global M&A strategies of manufacturing firms.

Whilst some M&As are motivated by market access or economies of scale, others are driven by access to new technologies and structural change. By acquiring competitors (horizontal integration), firms can achieve higher profits and lower costs through economies of scale and scope. For example, consider the acquisition of SABMiller by Anheuser-Busch InBev or the proposed Bayer-Monsanto merger. However, M&As can also be a mechanism to acquire new digital technologies and facilitate their diffusion to new firms and sectors. For example, the acquisition of San Francisco-based start-up Cruise Automation turned General Motors from a laggard in the race for a driverless car into one of the front-runners[27]. John Deere acquired Blue River Technology to apply machine learning to the big agricultural data collected from sensors on their machines.

For M&A deals of manufacturing acquirors, we find a somewhat slower growth of M&As than acquirors from other sectors (Figure 9). Globally, we find that there has been a more than 50% increase in the number of M&As between 2003 and 2015 – slower growth than M&As overall (which have more than doubled) or acquisitions by services sector firms (which have tripled).

In recent years, manufacturing firms have been increasingly buying and investing in target firms that operate in digital-intensive service sectors (again see Figure 9). This indicates the importance of digital technologies for manufacturing firms. In addition, it highlights the fact that the lines between manufacturing and services are increasingly blurred and manufacturing firms depend to a great extent on services activities, either undertaken internally or purchased from other firms (Arnold et al., 2011; OECD, 2018).

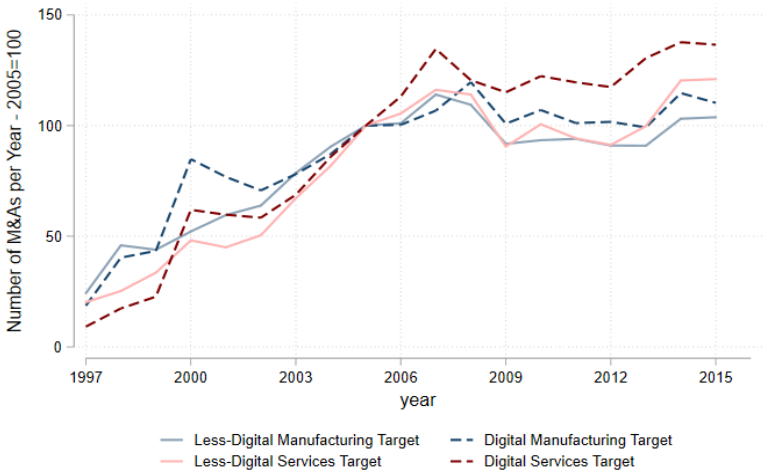
"Data processing" and "Software publishing", in particular, are an increasingly frequent target of M&As by manufacturing firms. In fact, they are among the five 3-digit sectors that have seen the fastest growth as targets of M&As by manufacturing firms in recent years (Figure 10). Unsurprisingly, the "Computer and electronics" industry is most active in buying them, but firms from many other manufacturing industries are also active in investing in data processing and software publishing firms (Figure 11). Importantly, firms in all displayed manufacturing industries undertook more M&As of firms in these two 3-digit sectors in the period 2011-2015 than in the period 2000-2004.

The difference between trends in investments into targets in digital as opposed to less digital sectors has been particularly pronounced for cross-border M&As (Figure 12). This

[27] https://www.bloomberg.com/news/articles/2017-11-30/how-gm-bought-its-way-to-the-front-of-the-driverless-car-pack

indicates that M&As are becoming increasingly global, and manufacturing firms looks globally when seeking digital technology and talent.

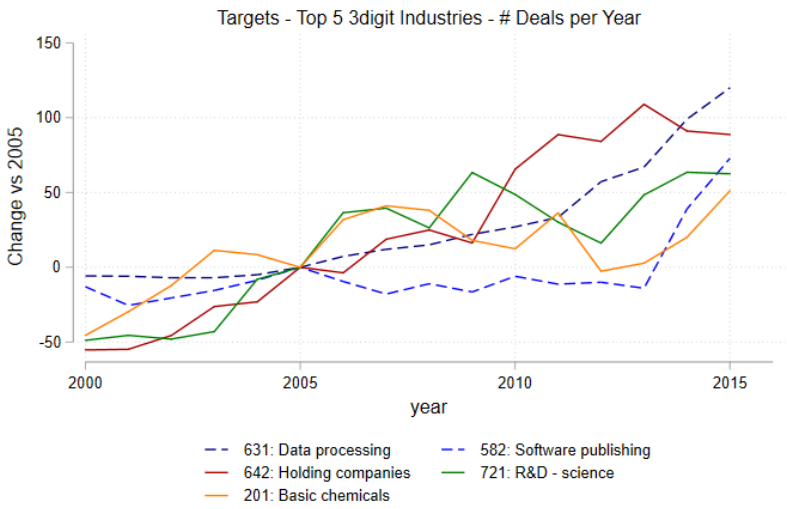
Figure 9. Growth of M&As by manufacturing firms by digital intensity and macro-sector of the target firm industry



Note: The M&A data reflects the annual total number of genuine acquisitions and minority stakes by manufacturing acquirors, involving target and acquiror firms in the non-farm business sector. The M&A data has global coverage from 2003 onwards, statistics before that point should be interpreted cautiously. Number of M&As of each type has been normalised to 2005.

Source: Authors' calculations using Zephyr M&A Database.

Figure 10. 3-digit industries with fastest growth of M&As by manufacturing acquirors

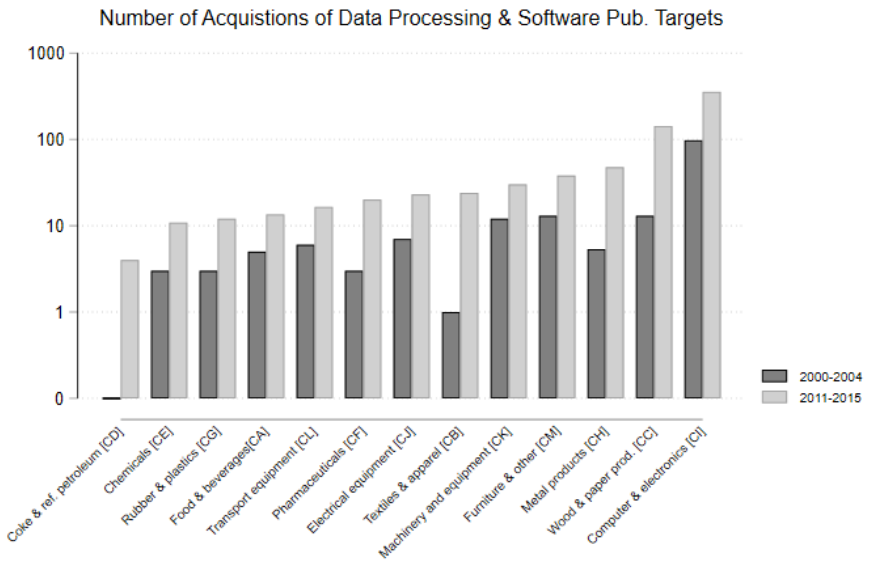


Note: The M&A data reflects the annual total number of genuine acquisitions and minority stakes by manufacturing acquirors, involving target and acquiror firms in the non-farm business sector (i.e. NACE rev.2 codes 10-82). The M&A data has global coverage from 2003 onwards, statistics before that point should be interpreted cautiously. Numbers represent proportional changes relative to 2005.

Source: Authors' calculations using Zephyr M&A Database.

Figure 11. Number of M&As of Data Processing and Software Publishing targets

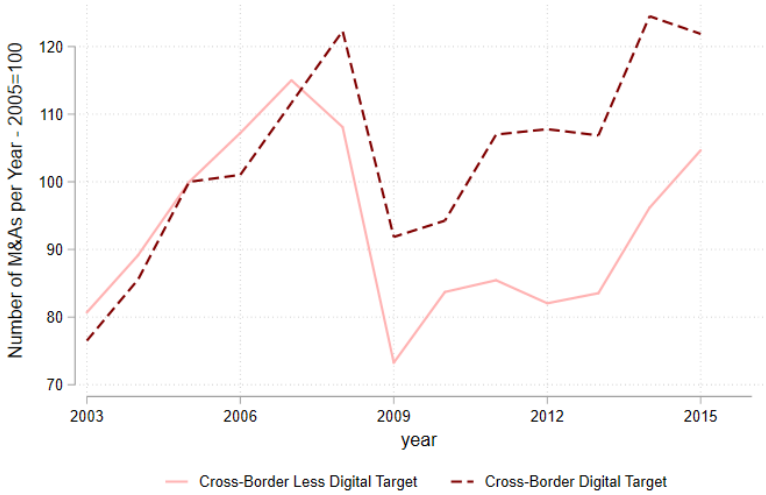
2000-2004 vs. 2011-2015



Note: The M&A data reflects the annual total number of genuine acquisitions and minority stakes by acquirors operating in each manufacturing industry. The graph shows M&As of target firms in the "Data processing" (631) and "Software publishing" (582) 3-digit industries.

Source: Authors' calculations using Zephyr M&A Database.

Figure 12. Growth of M&As of targets in digital-intensive industries by manufacturing firms: domestic vs. cross-border



Note: The M&A data reflects the annual total number of genuine acquisitions and minority stakes by manufacturing acquirors, involving target and acquiror firms in the non-farm business sector. The M&A data has global coverage from 2003 onwards, statistics before that point should be interpreted cautiously. Number of M&As of each type has been normalised to 2005.

Source: Authors' calculations using Zephyr M&A Database.

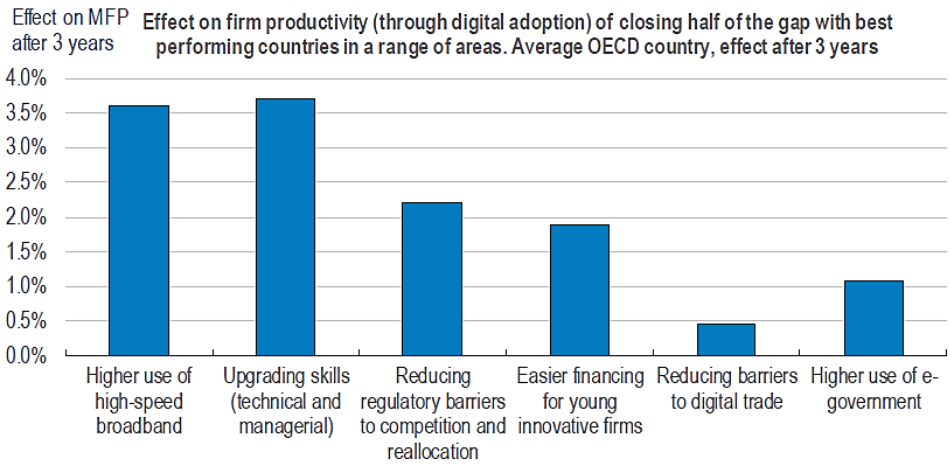
8. What role for policy?

The digital transformation towards industry 4.0 will affect manufacturing in various ways. Even though digital technologies have the potential to have a strong positive impact on firm productivity, they remain unevenly adopted across countries and industries and create new challenges for the economy. In this context, policies matter greatly. Indeed, the scope for public policy to affect aggregate productivity is considerable: it ranges from specific policies to increase the diffusion of knowledge (e.g. policies in IP rights, mobility of workers, etc.) to policies targeted specifically to increase the absorptive capacity of laggards (e.g., policies supporting R&D and export promotion, sustaining entrepreneurial managerial capital, increasing skills at all levels of the workforce).These policies can promote productivity growth through increasing technology adoption and diffusion, specifically for less productive firms to help them to catch up. Additionally, they should increase the business dynamism of digital intensive sectors to enable a more efficient allocation of resources.

A recent OECD study by Gal et al. (2019) focuses on the productivity effects of digital adoption. It shows that adoption of digital technologies such as high-speed broadband and cloud computing is positively associated with industry-level productivity. Importantly, the effects are particularly strong in manufacturing, consistent with findings of Dhyne et al. (2018). The effects are also high in industries which are intensive in routine tasks and, thus, allow for more automation. The higher effects for manufacturing and routine-intensive industries are true for all technologies examined in the study except high-speed broadband, the effects of which likely work through channels other than automation. Policies that enhance the availability of the digital infrastructure can thus promote productivity growth. Good regulatory frameworks facilitating investments in broadband and pro-competitive reforms in the telecommunication sector that reduce prices could be examples of such reforms. Nevertheless, the study also indicates that the most productive firms within a sector also benefit more from the adoption and diffusion of digital technologies, further increasing the divergence between firms (see also Andrews et al. 2016) suggesting the importance of policies that can help lagging firms staying abreast of the latest digital advancements

Another recent OECD work by Andrews et al. (2018) and Sorbe et al. (2019) provides more evidence on the type of policies that could lead to such productivity-enhancing adoption. It informs a policy framework that aims at increasing the inclusiveness of technology adoption and diffusion, specifically to help less productive firms to catch up. Figure 13 quantifies how such improvements in the policy environment could translate into firm productivity growth. In this framework, structural policies should aim to promote the roll-out of high-speed broadband infrastructure and develop capabilities to adopt technology, such as skills and particularly the quality of managerial capital. Complementary policies to strengthen the incentives to adopt technologies (i.e. increase competitiveness of the business environment) are also important, for instance, through reducing regulatory barriers to competition and increased availability of finance for start-ups.

Figure 13. A range of policies can support digital adoption and productivity



Note: Estimated effect on the multi-factor productivity (MFP) of the average firm of a range of policy and structural factors. The effect of "Higher use of high-speed broadband" on productivity combines the direct and indirect effects. "Upgrading skills" covers participation in training (for both high and low-skilled), quality of management schools and adoption of High Performance Work Practices (HPWP). "Reducing regulatory barriers to competition and reallocation" includes lowering administrative barriers to start-ups, relaxing labour protection on regular contracts and enhancing insolvency regimes. "Easier financing for young innovative firms" covers the development of venture capital markets and the generosity of R&D tax subsidies. For each of the underlying indicators, it is assumed that half of the gap to the best performing country in the sample is closed. It is also assumed that policy factors in each group are largely independent from each other. Results are presented for the average OECD country.

Source: Sorbe et al. (2019).

To build capabilities within the economy, there is a need for investments in human capital, both within organisations and more broadly among workers in an economy (OECD, 2019). The quality of management and organisational capital can be increased through public education and training. To do so, governments have to raise awareness, frame management schools, spread good practices and provide digital tools for firms. Additionally, policies should increase the availability of technical ICT skills through education and training, especially of low-skilled workers. Education ministries can hereby promote basic digital literacy through continuous vocational training, adult learning and on-the-job training. This would specifically help to reduce the skill shortage of less productive firms and enable better job matching. In addition, increasing e-government services can encourage a wider ICT use, foster civic engagement and enhance public sector efficiency.

Efficient incentives within the market setting can also encourage a broader adoption of technologies across firms. Such incentives include flexible labour markets, competitive product markets and the availability of risk capital. Reducing entry barriers such as administrative burdens for start-up firms, and the heavy costs on hiring and firing, as well as making the insolvency regime more efficient, would facilitate resource reallocation. Policies should also encourage the access of capital for young innovative firms such as develop the venture capital market, or R&D tax subsidies. Lastly, it is crucial to reduce barriers to cross-border digital trade to increase the access to new markets. International dialogue is needed to reduce regulatory barriers through new agreements on trade.

Policies to promote dynamism are identified in an OECD study by Calvino and Criscuolo (2019), who propose six policy areas that help to ensure business dynamism in digital intensive sectors. First, improving education and training enhances the supply and quality of entrepreneurs. Second, the access to finance for young and innovative firms needs to be developed through e.g. venture capital at seed and early stages. Third, stimulating potential returns to entrepreneurship is an important driver of entry. Fourth, in order to stimulate entry regulatory barriers and administrative burdens for start-ups need to be reduced. Fifth, it is necessary to assure a level playing field. This includes for example a high efficiency of contract enforcement and business regulations. Lastly, high costs of experimentation and failure should be avoided. This is specifically the case for inefficient bankruptcy procedures. Interestingly, the policies helping increase business dynamism for digital intensive sectors are closely linked to the ones creating incentives within the market setting to increasingly adapt technological process. Consequently, those policies may be particularly suitable as they could simultaneously achieve the two objectives of creating incentives to adopt technologies and increasing business dynamism of digital intensive sectors.

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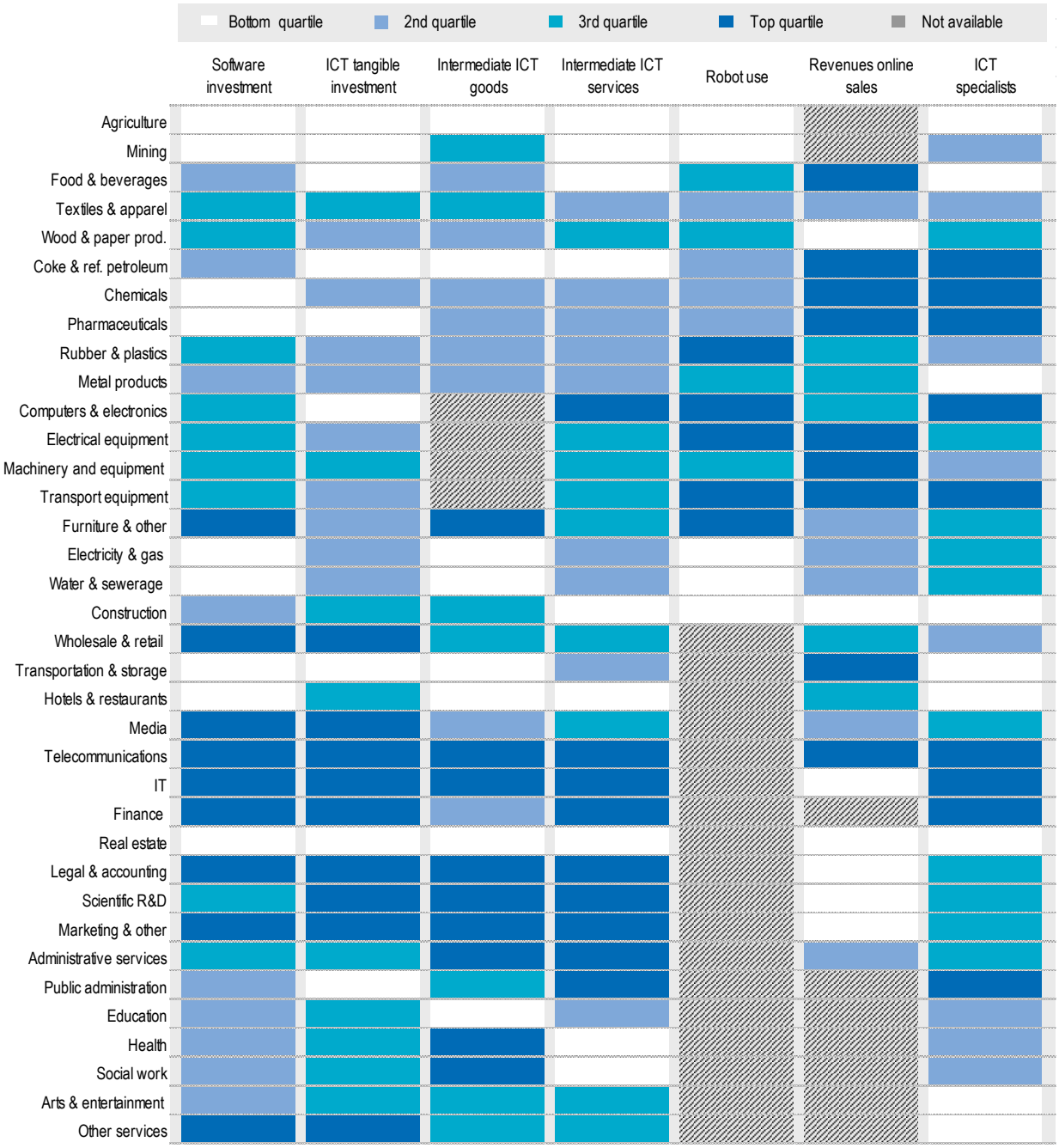
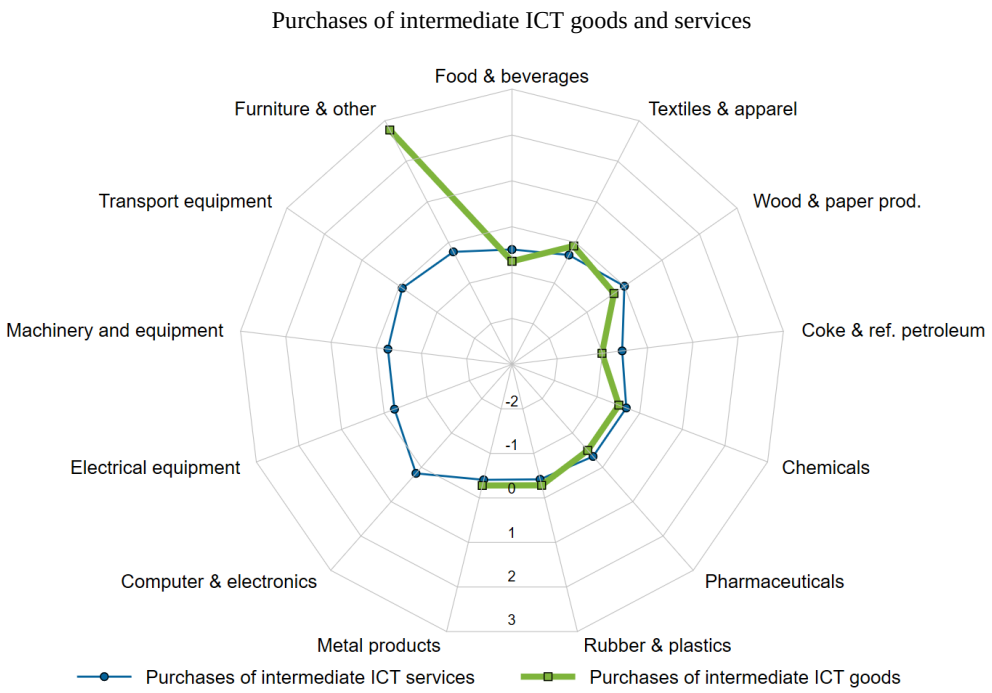
Annex A.

Table A.1. Sectoral taxonomy of digital intensity, by indicator, 2013-15



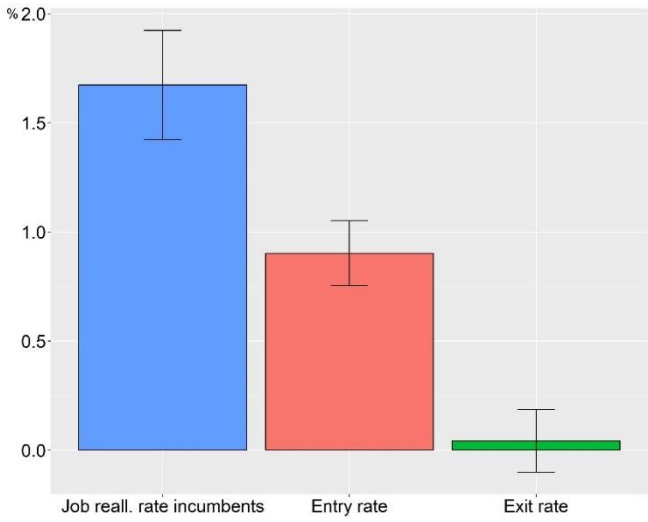
Note: All underlying indicators are expressed as sectoral intensities. For each indicator, sectoral values represent averages across countries and years (for the period 2013-15 only). The colour of the cells in the table corresponds to the quartile of the sectoral distribution to which the sector belongs.
Source: Calvino et al. (2018).

Figure A.1. Standardised digital intensity indicators - Manufacturing



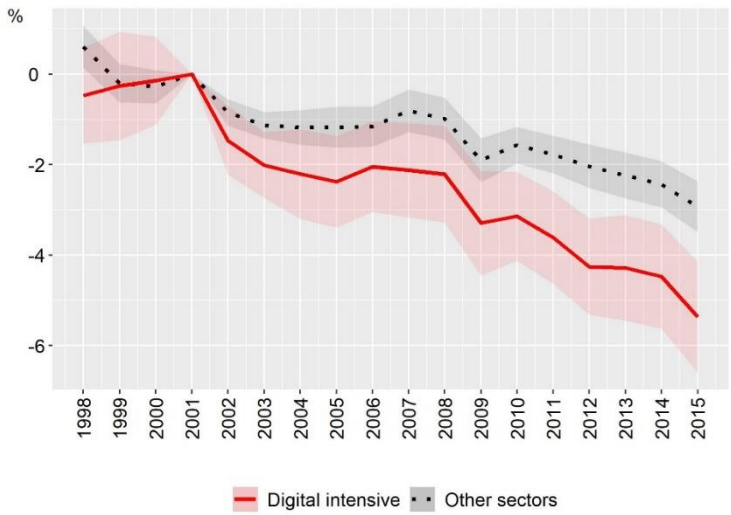
Note: the graph illustrates the standardised components of the taxonomy of digital intensity for the different manufacturing sectors. See Calvino et al. (2018) for details.
Source: authors' elaboration based on Calvino et al. (2018).

Figure A.2. Business dynamics – digital intensive vs. other sectors



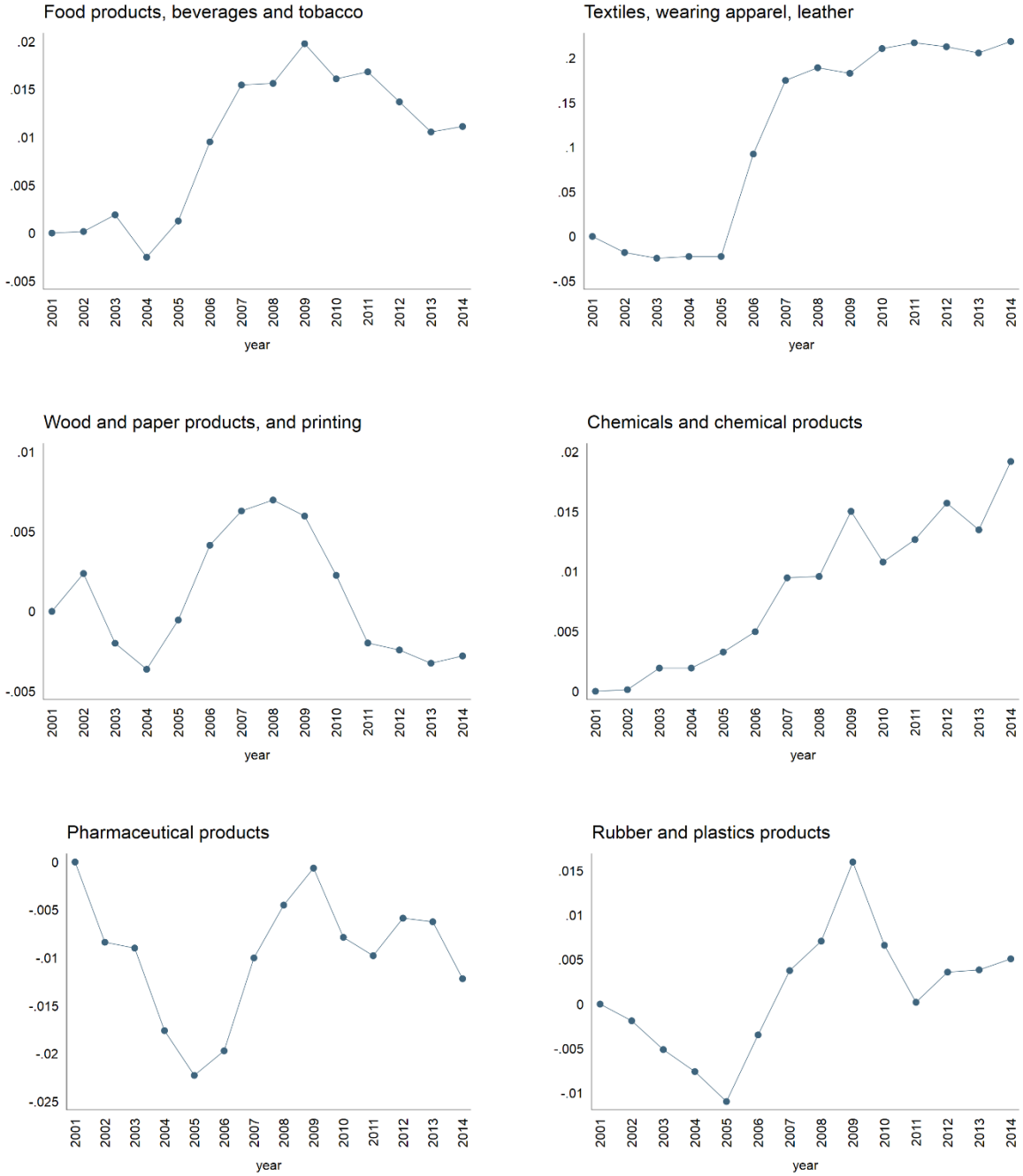
Note: The bars report coefficients based on separate regressions where the dependent variables are alternatively job reallocation rates of incumbents, entry rates or exit rates, which are regressed on a digital intensity dummy (including digital intensive sectors as defined above). The regressions include as controls a manufacturing vs. services dummy and country-year fixed effects. Confidence intervals (95%) are also reported based on robust standard errors.
Source: Calvino and Criscuolo (2019).

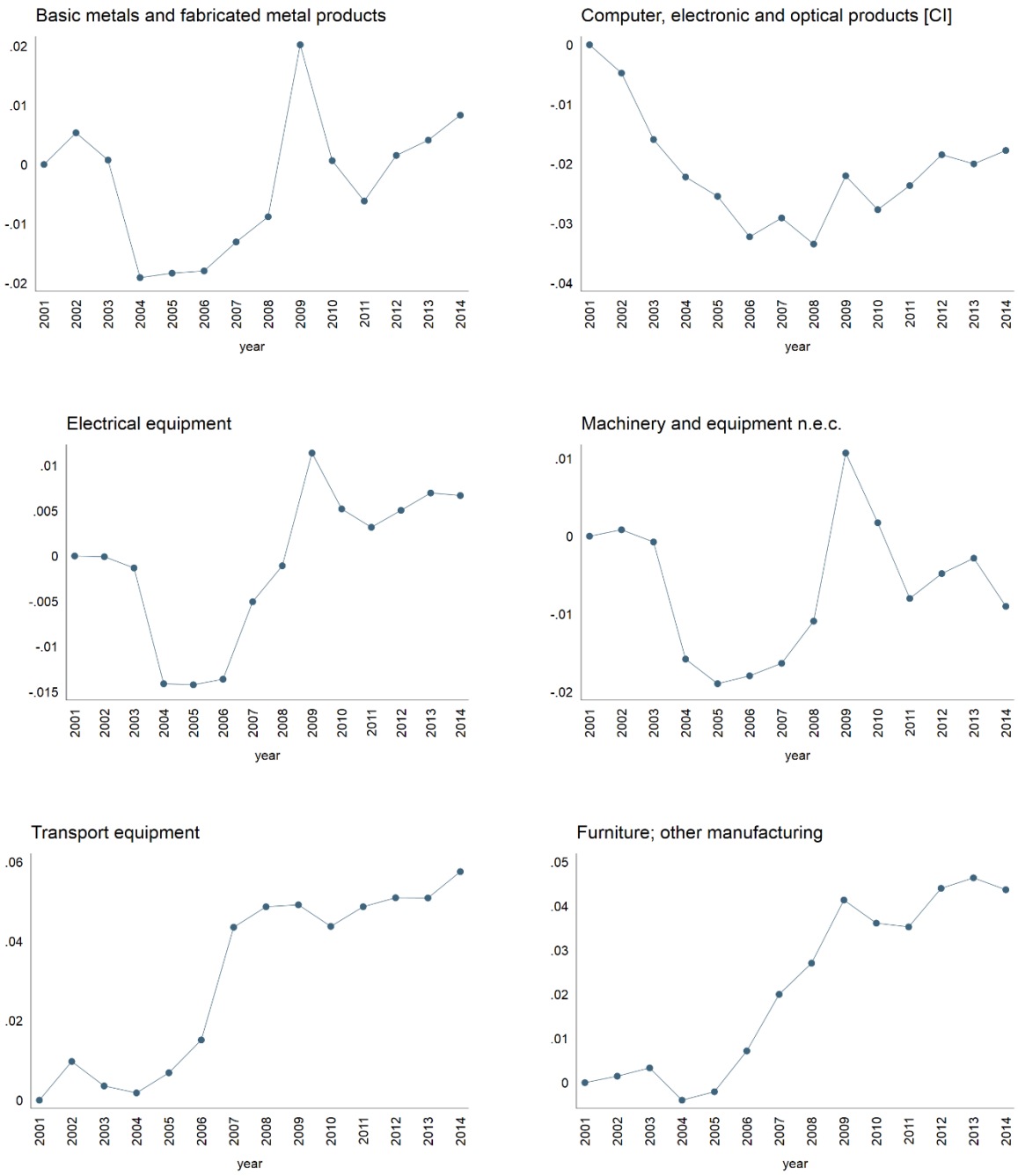
Figure A.3. Entry rates – average changes within country-sectors



Note: The figures are based on the year coefficients of regressions within country-sector, with and without interaction with the digital intensity dummy. They report average within-country-sector trends of entry rates, focusing separately on sectors in the "Digital intensive" and "Other sectors" groups. Digital intensive sectors are reported with a solid line and other sectors with a dashed line. Confidence bands (95%) are also reported based on robust standard errors. The baseline year is set to 2001.
Source: Calvino and Criscuolo (2019).

Figure A.4. Average of firm log mark-up in each A38 sector: growth 2001-2014.





Note: Unconditional averages of firm-level log mark-ups, by 2-digit manufacturing industries. The figure plots log-mark-ups and indexes the 2001 level to 0, hence the vertical axes represent log-differences from the starting year which, given the magnitudes, approximates well for growth rates.
Source: Elaboration on Calligaris et al. (2018).