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Abstract

The competitiveness of industries and countries is shaped more and more by technological advancement in the production and use of information and communications technology (ICT). This report considers the supply side of ICT goods and services. It studies the drivers of ICT production location and trade across countries with a focus on the relative position of the EU. The analyses clearly indicate that the EU must step up its efforts to accelerate the shift towards digital production and strengthening the ICT sector that produces the required technologies and services. In addition, from a trade policy perspective, a harmonised set of standards and regulatory framework is to be aimed at to minimise mismatches in technical specifications and requirements. This will lead to the diffusion of positive externalities and should allow for a smooth operation of the global value chains in these products.

Keywords: information and communications technology, digitalisation, production patterns, trade patterns

JEL classification: F14, O33, L11, L63

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1. Introduction

In the current era of digitalisation the competitiveness of countries, industries and firms is driven by technological advancement based on the application of information and communications technology (ICT), the use of ICT goods and services and ICT capital accumulation. Therefore, the role and effects of ICT – or 'digitalisation' in general – has been widely discussed over the past decades, either by emphasising its role in productivity growth or by examining potential implications for labour demand and needed skills. Specifically, there is a large evolving literature analysing the potential impacts on employment levels and structures (for recent contributions, see Autor and Salomons, 2018; Benzell et al., 2015; Sachs et al. 2015; Arntz et al., 2016; Chiacchio et al., 2018). However, comparatively less attention has been paid, and less in-depth analysis provided, regarding the supply side of ICT products and services and ICT production (as an example, see European Commission, 2009; JRC, 2017). One of the main arguments counteracting the negative impact of 'digitalisation' on employment levels (due to its huge labour-saving potential) is that such technologies and the respective capital inputs have to be produced, which can offset the labour-shedding effects of these developments to some extent – an aspect that is emphasised in the older literature, starting with David Ricardo. This is of particularly concern to Europe, with a low share of ICT value added generated compared with Asia and the US, which have become the leading producers. Therefore, this report looks more carefully at the supply side of the digital economy and ICT assets.

Looking at the production side, a study by the Joint Research Centre (JRC, 2017) puts the share of the ICT sector value added in the world total, according to its definition, at about 4% in the European Union (EU), compared with 16% in Taiwan, 9% in Korea, and still about 2 percentage points lower than in the US and Japan. Further, while the US share of gross output of operational ICT (NACE 26.1-26.4) manufacturing industries in the world total fell from 25% in 1995 to 9% in 2015 (see Figure 1), its value-added share in the world total only dropped from 28% to 21%. This also coincides with the emerging role in the sector of the two countries with the highest population density worldwide, namely China and India. In China, the US superstars have been heavily investing in this sector, and India is a source of offshoring and outsourcing of multinational enterprises (MNEs).

These global production structures also have implications for trade patterns in ICT products, and this has recently become a concern with respect to supply-chain shortages and strategic autonomy considerations of the EU. Liberalisation in trade and the globalisation process have resulted in the fragmentation of production across the world; they have led US producers of ICT to establish their manufacturing lines in countries with lower costs of production factors and they have driven up the employment of technicians and low-skilled workers and gross output growth in China and some East European countries. While middle-income trap countries feel a slowdown in economic growth, the US superstars gain in value by utilising their productive capacities, thus pushing the technology even further. The major value added in the sector is still produced in the headquarters in the US, where the R&D expenditures are used to facilitate the innovation process by high-skilled scientists stimulating the technological advancements in the sector. This is often reflected in the registration of new patents, which may be sold or transferred as intangible assets to the subsidiaries to maintain the level of competitive innovation and produce new products with new procedures.

This report looks carefully looks at these issues and is structured as follows. In the next section we present some descriptive statistics on the relative importance of ICT capital formation for growth. This is followed in Section 3 by a discussion of the most important patterns of production of ICT from an industry perspective. In Section 4 we outline the most important patterns and trends based on firm-level data. Trade in ICT products is then described in Section 5, and Section 6 concludes.

2. ICT capital formation and growth

2.1. INTRODUCTION

In this first section we discuss the relative importance of ICT capital as a driver of value-added growth, drawing on the empirical results in a recent research paper accompanying the EU KLEMS Release 2019 (Adarov and Stehrer, 2019). The EU KLEMS Release 2019[1] is a dataset which distinguishes 14 different capital asset types, including intangible assets outside the boundaries of national accounts (see Haskel and Westlake (2018) for a detailed discussion on the role of intangible assets). Importantly for this report, it allows differentiating between non-ICT and ICT capital. The latter group can be split into tangible assets (information technology and communications technology) versus intangible capital (software and databases). The focus of this section is to assess the contribution of ICT capital growth to value-added growth using a growth accounting framework. The data and methods are summarised in Stehrer et al. (2019) and the results are presented in Section 2.2. These data are then used further in an econometric exercise to identify the (positive) impact of ICT capital growth on real value-added growth (see Section 2.3).

2.2. GROWTH ACCOUNTING RESULTS

In this section, the growth performance of the two European country groups – the countries which have been EU members since 1995 (EU15) and the Central and East European countries which joined later (EU-CEE) – plus Japan and the US are considered, drawing on the EU KLEMS Release 2019 Analytical Database, i.e. including a larger set of intangible assets. Before presenting the growth accounting results, a quick overview of capital stock data is given.

Figure 1 shows the shares of tangible ICT and intangible ICT capital asset aggregates in total capital stocks and intensities with respect to the labour employed, also examining the changes between the pre- and post-crisis periods (for the countries for which the detailed capital asset composition is available in the EU KLEMS 2019). It should be noted that most of the capital stock value (about 90% on average) is attributed to Non-ICT capital, and in particular construction. Japan stands out from the rest of the sample with a smaller share of Non-ICT capital and particularly high shares of ICT, SoftDB and RD capital in the total capital stock (see Figure 1). European countries exhibit significant heterogeneity in terms of capital composition. While no significant changes are observed in the shares of tangible and intangible ICT capital in total capital stocks (there is a marginal increase in the share of SoftDB along with a slight decrease in the share of tangible ICT in total capital stock). Among the European countries, Austria, Sweden and Denmark appear to be the leaders at the digital capital frontier as measured by the importance of ICT and SoftDB relative to both total capital stocks.

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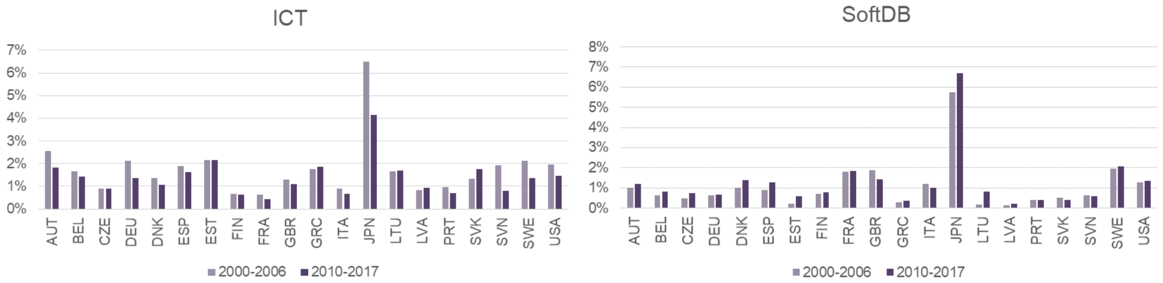
[1] The update has been funded by the European Commission (DG ECFIN) under service contract ECFIN-116-2018/SI2.784491. Data are available at www.euklems.eu.

Figure 1 / Composition of capital stocks by asset groups



Source: Own computations based on EU KLEMS 2019.

The growth accounting approach allows indicating the importance of various input factors on the value-added growth performance. These results are presented in Table 1, differentiating between the EU15 economies, the EU-CEE members, Japan and the US.[2]

Table 1 / Growth accounting results

		EU15*			EU-CEE	
	2000-2007	2008-2009	2010-2016	2000-2007	2008-2009	2010-2016
Value-added growth	2.31	-2.05	1.38	4.82	0.27	2.16
Hours worked	0.48	-0.78	0.25	-0.04	0.24	-0.05
Labour composition	0.19	0.25	0.26	0.40	0.16	0.38
Tangible Non-ICT	0.48	0.36	0.20	0.95	1.10	0.68
Tangible ICT	0.05	0.02	0.02	0.07	0.08	0.01
Intangible ICT	0.04	0.03	0.03	0.03	0.03	0.02
Intangible Non-ICT	0.10	0.05	0.10	0.09	0.12	0.12
TFP	0.97	-1.98	0.52	3.32	-1.46	1.00
		Japan			US	
	2000-2007	2008-2009	2010-2016	2000-2007	2008-2009	2010-2016
Value-added growth	1.21	-3.71	1.41	2.59	-1.50	2.07
Hours worked	-0.16	-1.58	0.08	0.28	-2.04	0.76
Labour composition	0.37	0.41	0.21	0.14	0.38	0.12
Tangible Non-ICT	0.15	-0.20	-0.09	0.73	0.08	0.48
Tangible ICT	0.18	0.05	0.01	0.16	0.09	0.04
Intangible ICT	0.17	0.01	0.03	0.07	0.04	0.05
Intangible Non-ICT	0.23	-0.02	0.09	0.19	0.11	0.17
TFP	0.27	-2.38	1.08	1.02	-0.17	0.45

Source: EU KLEMS Release 2019, own results.

Focusing on the pre- and post-crisis period, one can find a slowdown of value added in all countries, although it is less pronounced in Japan, which has, however, experienced slower growth rates over the whole period considered. Comparing the EU15 member states and the EU-CEE countries, one finds similar dynamic patterns, but growth rates are much higher (between one to two percentage points) in the EU-CEE countries. In particular, this pattern remained intact after the global financial and economic crisis.

2 Country aggregates are calculated using Törnqvist aggregates based on nominal GDP at current exchange rates.

However, the focus of this section is on the growth components. The broad picture suggests that growth before the crisis in the EU15, the EU-CEE countries and the US was largely driven by total factor productivity (TFP) growth. Hours worked and labour composition contributed relatively more in the EU countries than in the US. Further, investment in tangible assets (in particularly Non-ICT capital) played a significant role, especially in the EU-CEE economies. Non-ICT capital also contributed more to growth in the US compared with the EU15 member states. Growth of intangible assets played only a minor role, albeit showing positive contributions in all country groups. On the other hand, growth in Japan before the crisis was mostly driven by labour composition changes, ICT capital and intangible assets (particularly software and databases). As a percentage of GDP, the contributions of ICT assets to growth have been below 4% of total GDP growth in Europa, much higher in Japan (28%) and also higher in the US with about 8%.

The growth performance after the crisis shows a significant decline in the contribution of total factor productivity in the EU15, the EU-CEE and the US, whereas TFP growth picked up in Japan. The contributions of changes in the composition of labour remained relatively stable (with the exception of Japan). Growth of Non-ICT capital still played an important role in the EU-CEE countries and the US, but less so in the other two groups. Interestingly, the contributions of ICT asset growth to overall GDP growth recorded a slight decline for the EU countries after the crisis (about 2%); however, the contributions declined significantly for Japan (to 3%) and halved for the US (to about 4%). Table 2 presents the results for the individual EU member states (plus Norway) for which data are available.

Table 2 / Growth contributions of tangible and intangible ICT assets

		2000-2007			2008-2009			2010-2016	
	Value added	Tangible ICT	Intangible ICT	Value added	Tangible ICT	Intangible ICT	Value added	Tangible ICT	Intangible ICT
AT	2.65	0.03	0.06	-1.30	0.00	0.03	1.34	0.02	0.05
BE	2.36	0.03	0.02	-0.63	0.01	0.02	1.42	0.01	0.01
BG	5.71			2.31	-0.12	0.03	1.38	-0.05	0.02
CZ	4.57	0.07	0.04	-0.95	0.05	0.05	1.84	0.03	0.03
DE	1.84	-0.02	0.03	-2.71	-0.07	0.03	2.12	0.01	0.02
DK	1.89	0.08	0.06	-2.29	-0.01	0.04	1.51	0.06	0.03
EE	7.49			-9.99	0.02	0.04	3.48	0.07	0.03
EL	3.77			-1.87	0.07	0.00	-3.83	-0.05	-0.02
ES	3.74	0.20	0.06	-1.17	0.16	0.04	0.32	0.09	0.04
FI	3.45	0.04	0.05	-4.20	0.06	0.01	0.65	0.03	0.01
FR	2.19	0.02	0.06	-1.09	0.01	0.06	1.30	0.02	0.04
IE	5.16			-3.88	0.02	0.01	6.27	0.06	0.04
IT	1.49	0.03	0.02	-3.31	0.00	0.00	0.02	0.00	0.01
LT	7.35			-6.90	0.01	0.13	3.23	0.05	0.06
LU	4.44			-2.78	0.18	0.01	3.08	0.27	0.06
LV	8.05			-7.59	-0.04	-0.01	1.61	-0.03	0.02
NL	2.27	0.10	0.08	-0.32	0.06	0.05	1.23	0.03	0.07
NO	2.25	0.12	0.03	-0.48	0.09	0.07	1.37	0.01	0.03
RO	5.77			1.57	0.18	-0.02	2.55	-0.02	0.02
SE	3.27	0.11	0.07	-3.14	0.13	0.08	3.29	0.03	0.19
SI	4.44			-2.34	-0.06	0.01	1.04	-0.03	0.00
SK	5.33	0.09	0.01	0.24	0.18	-0.01	2.77	0.02	0.03
UK	2.82	0.10	0.04	-2.38	0.03	0.01	2.00	0.01	0.00

Sources: EU KLEMS Release 2019; own results.

2.3. ECONOMETRIC ANALYSIS

Based on these data, we perform an econometric analysis based on the EU KLEMS sample of countries, which, after dropping outliers Cyprus, Luxembourg and Malta, amounts to 23 countries over the period 2000-2017.[3] The specification is based on the log-differenced version of the Cobb-Douglas production function, which explains real value-added growth $\Delta \ln \mathrm{Y_{cjt}}$ as a function of the growth of real capital inputs ($\Delta\mathrm{lnK_{cjt}}$), the growth of labour inputs ($\Delta\mathrm{lnL_{cjt}}$) and the TFP growth term ($\Delta\ln \mathrm{A_{cjt}}$), calculated as a residual.

$$\Delta \ln \mathrm{Y_{cjt}} = \alpha\, \Delta\mathrm{lnL_{cjt}} + \beta\Delta\mathrm{lnK_{cjt}} + \Delta\ln \mathrm{A_{cjt}}$$

For the purposes of the analysis the capital input variable is split into components, so that the set Q = {ICT; SoftDB; NonICT; RD; OInnProp; EconComp} comprises the main capital asset groups (in terms of capitals services growth):

$$\Delta \ln \mathrm{Y_{cjt}} = \alpha\Delta\mathrm{lnL_{cjt}} + \sum_{\mathrm{q}\in\mathrm{Q}} \beta_q\, \Delta\mathrm{lnK_{qcjt}} + \Delta\ln \mathrm{A_{cjt}}$$

Alternative specifications also include hours worked and labour composition instead of labour services (as discussed above, the labour composition variable in the baseline specification is decomposed as $\Delta \ln \mathrm{L_{cjt}} = \Delta \ln \mathrm{LC_{cjt}} + \Delta \ln \mathrm{H_{cjt}}$). In order to control for unobserved heterogeneity at the country and sector levels and alleviate potential omitted variable issues, we also include fixed effects (country, sector, year fixed effects or their interaction, depending on the specification). The model is first estimated using country-level aggregates via fixed effects ('FE') as the baseline estimator (controlling for country fixed effects), and the pooled OLS ('POLS') and Arellano-Bover/ Blundell-Bond system GMM ('System GMM') are also reported as alternatives for comparison. The estimation results are reported in Table 3.

As expected, the growth of labour services, particularly its hours worked component, contributes positively to real value-added growth with high statistical significance and the marginal impact of about 0.6, implying that a 1 percentage point (pp) change in the growth of labour services is associated with a 0.6 pp change in value-added growth. Notably, among the different capital asset groups, only ICT and EconComp enter positively and are statistically significant. A 1 pp increase in the growth of the economic competencies assets translates into about 0.1 pp growth of value added. The marginal contribution of tangible ICT capital is 0.04 for the baseline specification, which implies that a 1 pp increase in the growth of tangible ICT capital leads to the growth of real value added of about 0.04 pp. Additional estimations with detailed asset types reported in Table 4 suggest that these results are largely attributed to CT and AdvMRes capital. Estimations at the sectoral level do not yield statistically significant results pertaining to the impact of ICT capital on real value-added growth.

3 The sample includes the following countries: AT, BE, CZ, DE, DK, EE, EL, ES, FI, FR, IE, IT, JP, LT, LV, NL, NO, PT, SE, SI, SK, UK, US.

Table 3 / Estimation results for value-added growth

	FE	FE	POLS	System GMM
	1	2	3	4
Labour services	0.573***		0.485***	0.609***
	(0.087)		(0.079)	(0.104)
Hours worked		0.623***		
		(0.092)		
Labour composition		-0.049		
		(0.176)		
ICT	**0.042*** **	**0.036*** **	**0.037** **	**0.058*** **
	(0.012)	**(0.010)**	**(0.014)**	**(0.013)**
NonICT	-0.152	-0.246	0.209	-0.264
	(0.212)	(0.205)	(0.205)	(0.238)
SoftDB	**0.003**	**0.003**	**0.005**	**0.004**
	(0.004)	**(0.004)**	**(0.005)**	**(0.004)**
RD	-0.010	-0.003	-0.044	-0.016
	(0.040)	(0.038)	(0.043)	(0.038)
OInnProp	0.016	-0.003	0.051	-0.020
	(0.044)	(0.041)	(0.045)	(0.039)
EconComp	0.123***	0.102***	0.093**	0.149***
	(0.043)	(0.035)	(0.044)	(0.050)
Value added, lag				0.121*
				(0.072)
Constant	0.022***	0.032***	0.017***	-0.006
	(0.004)	(0.004)	(0.004)	(0.004)
Observations	335	335	335	320
R-squared	0.764	0.784	0.718	

Note: Country, industry and year fixed effects are included in the FE models. All variables are included in log-differences. Standard errors clustered by country are included in parentheses. *, **, *** indicate statistical significance at the 10%, 5% and 1% levels respectively.
Sources: EU KLEMS Release 2019; own results.

Table 4 / Estimation results for value-added growth with detailed capital asset types

	FE	FE	POLS	POLS	System GMM	System GMM
	1	2	3	4	5	6
Labour services	0.521***		0.434***		0.559***	
	(0.077)		(0.082)		(0.085)	
Hours worked		0.581***		0.497***		0.607***
		(0.078)		(0.103)		(0.086)
Labour composition		-0.080		0.001		-0.226
		(0.177)		(0.164)		(0.269)
RStruc	-0.104	-0.151	-0.107	-0.163	-0.258*	-0.272*
	(0.118)	(0.113)	(0.130)	(0.140)	(0.154)	(0.139)
OCon	-0.125	-0.143	-0.005	0.007	-0.074	-0.091
	(0.149)	(0.143)	(0.158)	(0.159)	(0.138)	(0.139)
OMach	-0.020	-0.051	0.178**	0.157**	-0.058	-0.076*
	(0.050)	(0.048)	(0.077)	(0.074)	(0.053)	(0.046)
TraEq	0.016	0.005	0.029	0.026	0.010	0.006
	(0.039)	(0.036)	(0.041)	(0.044)	(0.059)	(0.053)
IT	**0.020**	**0.012**	**0.014**	**0.014**	**0.038****	**0.022**
	(0.015)	**(0.013)**	**(0.016)**	**(0.015)**	**(0.017)**	**(0.015)**
CT	**0.034*****	**0.034*****	**0.036*****	**0.033*****	**0.034*****	**0.032*****
	(0.006)	**(0.007)**	**(0.007)**	**(0.007)**	**(0.007)**	**(0.007)**
Cult	0.005	0.008	0.001	-0.000	-0.005	0.001
	(0.007)	(0.006)	(0.009)	(0.009)	(0.009)	(0.008)
RD	-0.006	-0.005	-0.031	-0.023	-0.012	-0.002
	(0.038)	(0.036)	(0.037)	(0.035)	(0.032)	(0.031)
Soft_DB	**0.004**	**0.003**	**0.008**	**0.009**	**0.004**	**0.004**
	(0.005)	**(0.005)**	**(0.007)**	**(0.007)**	**(0.005)**	**(0.005)**
OIPP	0.009	0.007	0.027**	0.023**	0.008	0.005
	(0.012)	(0.010)	(0.011)	(0.011)	(0.008)	(0.008)
AdvMRes	0.121***	0.098***	0.073**	0.057*	0.146***	0.122***
	(0.029)	(0.029)	(0.030)	(0.032)	(0.042)	(0.038)
Design	-0.017	0.008	0.015	0.004	-0.053	-0.025
	(0.076)	(0.077)	(0.064)	(0.061)	(0.095)	(0.087)
POCap	0.006	-0.009	0.028	0.033	0.009	0.004
	(0.045)	(0.048)	(0.031)	(0.035)	(0.054)	(0.056)
VT	0.036*	0.025	0.029*	0.024	0.040***	0.032**
	(0.017)	(0.015)	(0.014)	(0.015)	(0.015)	(0.013)
Value added, lag					0.085	0.044
					(0.085)	(0.087)
Constant	0.021***	0.032***	0.015***	0.021***	-0.004	0.002
	(0.004)	(0.005)	(0.004)	(0.004)	(0.006)	(0.006)
Observations	335	335	335	335	320	320
R-squared	0.779	0.797	0.746	0.759		

Note: Country, industry and year fixed effects are included in the FE models. All variables are included in log-differences. Standard errors clustered by country are included in parentheses. *, **, *** indicate statistical significance at the 10%, 5% and 1% levels respectively.
Sources: EU KLEMS Release 2019; own results.

3. The production side of ICT technology at aggregate level

3.1. INTRODUCTION

This chapter provides an overview of the ICT sector from the production side, globally and in leading countries, with a special emphasis on the situation in European countries. The focus is on the cross-country performances of ICT industries and their changes over time. For this we employ the definition of the OECD (2007), which demarcates the ICT sector with a view to measuring the supply side of this increasingly important segment of the economy. It is essential to emphasise this, because large parts of the literature that address the economic impacts of ICT technologies and the phenomenon of digitalisation (explicitly or implicitly) deal with the *use* of such technologies, that is, the demand side. The mushrooming literature on the effects of the installation of industrial robots on employment (Acemoglu and Restreop, 2017; 2018; Autor and Salomons, 2018; Chiacchio et al., 2018; Dauth et al. (2017); Firgo et al., 2018; Ghodsi et al., 2020) is a case in point. Industrial robots, for example, are most intensively used in the automotive industry. This may have productivity-enhancing effects as well as employment effects in both the industry and in the upstream and downstream industries. But at the same time it is also clear that although car makers are intensive users, they are typically not the producers of industrial robots or ICT technologies more generally. Another good example is the banking industry, a frontrunner in the application of electronic communication (e.g. e-payment systems) and another heavy user of ICT, but for the most part it is not the creator of these technologies or the underlying innovations and R&D efforts.

While the interest in the demand side of ICT stems from the numerous implications for productivity, employment and other macroeconomic indicators, the supply side is essential for at least two reasons. First, as the economy undergoes a digital transformation in which firms increasingly switch to ICT-driven production processes, the industries which produce the necessary ICT infrastructures and provide the relevant ICT services should flourish. In other words, the ICT-producing sector can be expected to comprise the lead industries of the ‘digital revolution’. Hence, the ICT-producing industries are presumably as important for the overall economic development as was the textile industry in the eighteenth century, iron and steel in the late nineteenth century or the semi-conductor industry in the 1970s and 1980s (microcomputer revolution).[4] The reason why (at least in a structuralist perspective) having strong domestic lead industries spurs economic growth is that these industries create a virtuous circle between the necessary skills and the goods that are in high demand. Therefore countries which hold comparative advantages in ICT industries are likely to benefit from the (expected) expansion of these industries – directly and via demand spillovers to the rest of the economy (see Reinert, 2007 for a historical perspective on lead sectors such as shipbuilding; see Rennstich, 2008 for a discussion in the context of the digital transformation). Second, lead sectors are typically R&D-intensive and innovative

[4] The importance of semiconductors and microprocessors during the automation revolution illustrates the close connection between the latter and the digital revolution, which is typically associated with the growing introduction of cyber-physical systems that connect the physical and digital world of production.

industries characterised by an oligopolistic market structure. Therefore, lead sectors are also 'strategic sectors' with a high potential for economic rents (see e.g. Brander and Spencer, 1985; Krugman, 1986).

Against this background this paper draws on the 2019 version of the PREDICT dataset, described further in the next section (see also JRC, 2017), to analyse the EU's positions in the production of ICT goods and services with regard to production, value added, employment, R&D and productivity relative to its main competitor countries, including the US, Japan, China and Korea.

3.2. DEFINITION OF THE ICT SECTOR AND THE PREDICT DATASET

The analysis of the ICT sector in this section is entirely based on the PREDICT dataset,[5] which was explicitly developed for the purpose of investigating various aspects of this increasingly important part of the economy. More precisely, we make specific use of the 2019 version of the dataset, which covers the period 1995-2018 and comprises 41 countries, including all EU member states,[6] although not all indicators for all the countries are available over the entire sample period. However, the entries for the years 2017 and 2018 are nowcasts estimated by the JRC (2018) and are only available for the aggregates of the ICT sector and for a limited number of indicators. Therefore large parts of the analysis have to be limited to the time span until 2016.

The dataset covers a wide array of indicators, out of which we use gross output, value added, employment (measured in persons), labour productivity and business expenditure on R&D (BERD). The PREDICT dataset offers two definitions of the ICT sector, which both follow the OECD definition of the sector (OECD, 2007). These are the *comprehensive definition* and the *operational definition* (JRC, 2017). The former employs a more detailed industry decomposition, which allows circumventing the ICT sector in full alignment with the OECD definition. The operational definition relies on a cruder industry structure, which has the advantage that the required data are available for a larger set of countries. This is why this paper makes use of the operational definition, although it also shows that the differences between the two definitions are rather small (Table 5).

5 The database is available at: https://data.jrc.ec.europa.eu/dataset/6c6f7ce7-893b-48e9-b074-2baaa4b6c7d8/resource/4625572c-eb0e-409d-aa60-33e0243e52e9

6 The United Kingdom is still considered to be an EU member state in this section, which was true over the sample period.

Table 5 / Definition of the ICT sector in the PREDICT dataset

(a) Comprehensive definition

NACE Rev.2 code	ICT sector code	Industry description
	B	**ICT manufacturing industries**
261	BA	Manufacture of electronic components and boards
262	BB	Manufacture of computers and peripheral eq.
263	BC	Manufacture of communication eq.
264	BD	Manufacture of consumer electronics
268	BE	Manufacture of magnetic and optical media
465	**TW**	**ICT trade industries**
	C	**ICT services industries**
610	CA	***Telecommunications***
611	CA1	Wired telecommunications activities
612	CA2	Wireless telecommunications activities
613	CA3	Satellite telecommunications activities
619	CA4	Other telecommunications activities
	CB	***Computer and related activities***
582	CB1	Software publishing
620	CB2	Computer programming, consultancy, related act.
631	CB3	Data processing, hosting and related act; web portals
951	CB4	Repair of computers & communication eq.
	A=B+TW+C	**ICT Total**

(b) Operational definition

NACE Rev.2 code	ICT sector code	Industry description
	B'	**B'. ICT manufacturing industries**
261	BA	Manufacture of electronic components and boards
262	BB	Manufacture of computers and peripheral eq.
263	BC	Manufacture of communication eq.
264	BD	Manufacture of consumer electronics
	C	**C. ICT services industries**
61	CA	***Telecommunications***
582, 62, 631, 951	CB	***Computer and related activities***
	A'=B'+C	**A'. ICT Total (operational)**

Note: Industries according to NACE Rev. 2 classification.
Source: JRC, 2017, Tables 1 & 2.

The main difference between the two definitions in terms of scope is that the operational definition does not include the magnetic and optical media industry (NACE 268) and the ICT trade industries (NACE 465). Hence, according to the operational definition, the ICT sector comprises large parts of the electronics industry, telecommunications services and computer services, including related services.[7]

For the EU, Norway and Japan systematic data on both the comprehensive and the operational definition are available, which allows for a quantitative comparison of the size of the ICT sector according to the two definitions. These comparisons are shown for value added, gross output and employment, to the extent that such data are available (Table 6).

[7] For a detailed discussion of the different possibilities to delineate the digital economy, see IMF (2018).

Table 6 / Comparison of the comprehensive and the operational definition of the ICT sector

European Union (EU)

	value added			*gross output*			*employment*		
year	**compr.**	**oper'l**	**diff**	**compr.**	**oper'l**	**diff**	**compr.**	**oper'l**	**diff**
2000	428	387	9.6%	898	828	7.9%	5.57	4.97	10.6%
2005	506	464	8.3%	1,076	997	7.4%	5.68	5.09	10.4%
2010	540	494	8.5%	1,151	1,059	8.0%	5.89	5.33	9.6%
2015	629	578	8.0%	1,315	1,225	6.9%	6.47	5.90	8.8%
2016	642	591	7.9%	1,318	1,230	6.7%	6.59	6.01	8.8%

Norway

	value added			*gross output*			*employment*		
year	**compr.**	**oper'l**	**diff**	**compr.**	**oper'l**	**diff**	**compr.**	**oper'l**	**diff**
2000	5.6	5.1	9.1%	14	13	6.8%	0.07	0.06	15.3%
2005	7.6	7.0	8.1%	15	14	5.7%	0.07	0.06	12.1%
2010	10.7	9.7	9.9%	21	20	6.2%	0.08	0.07	13.4%
2015	11.4	10.7	6.2%	22	21	4.5%	0.08	0.07	9.7%
2016	11.4	10.7	6.1%	22	21	4.3%	0.08	0.07	8.8%

Japan

	value added			*gross output*			*employment*		
year	**compr.**	**oper'l**	**diff**	**compr.**	**oper'l**	**diff**	**compr.**	**oper'l**	**diff**
2000	369	322	12.7%	732	663	9.5%	2.51	2.12	15.7%
2005	261	229	12.3%	505	455	9.9%	2.46	2.10	14.6%
2010	299	272	8.8%	591	549	7.2%	2.55	2.25	11.9%
2015	260	235	9.6%	504	466	7.5%	2.42	2.12	12.5%
2016	289	262	9.6%	564	522	7.5%	2.40	2.10	12.5%

Note: compr. = comprehensive definition; oper'l = operational definition; diff = difference expressed in per cent of the comprehensive definition. Value added and gross output are nominal values in EUR billion. Employment in millions.
Sources: PREDICT dataset; authors' elaboration.

The differences between the two definitions are not negligible and are in the magnitude of around 10% for (nominal) value added and somewhat lower in the case of gross output. The differences are slightly larger for Japan but show the same declining trend over time.

These differences are mainly explained by the ICT trade industries that are excluded from the operational definition. Apart from the greater data availability, the operational definition of the ICT sector is also preferable if one is interested in the production side of ICT, to which the ICT trade industries do not really contribute (since they serve a distributional function).

The differences are again larger in terms of employment, indicating that the ICT trade services industries are characterised by lower labour productivity compared with the rest of the ICT sector.

While Table 6 shows nominal values for gross output and value added, much of the subsequent analysis is based on real values. This implies that the price deflators provided in the PREDICT dataset will be exploited as well. Unfortunately, deflators are not provided for all sectors, such as the ICT services sector, for example. The missing deflators are calculated using the value added weighted deflators of the industries included in the sector. Moreover, no deflators are provided for the nowcast estimates.

Hence, the averages of the industry- and sector-specific yearly changes in the deflator over the period 2010-2016 are imputed as deflators for the years 2017 and 2018.

A useful feature of the PREDICT dataset is that, while focused on the ICT sector, it also includes the same information for sector aggregates such as the manufacturing sector or the services sector and the total economy. This allows, inter alia, calculating the relative importance of the ICT sector in the EU economy as well as in other countries.

3.3. THE ROLE OF THE ICT SECTOR AT THE GLOBAL LEVEL

Digital technologies are crucial to most capital goods, industrial products and everyday life. The ICT industries are key enablers of both production and the knowledge systems, and EU policies have therefore attributed a strategic role to digital technologies in the promotion of growth, innovation and competitiveness. As a result, the dynamics of the ICT sector and its relative size are key indicators for the economy. This applies to individual countries and regions as well as to the world as a whole because of its impact on the technological frontier and productivity growth. For this purpose, the world is composed of the EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US.

Before examining the size of the ICT sector, we provide a short overview of the composition of the ICT sector (Table 7). According to the (operational) OECD definition, the ICT sector employed some 40 million people worldwide in 2016, who produced value added worth EUR 2.7 trillion, more than three times the amount recorded for 1995. Characteristic for a 'lead sector', both value added *and* employment expanded in the ICT sector. Importantly, this holds true for the ICT sector as a whole as well as for each individual ICT industry.

Another striking feature that emerges from this sectoral decomposition is that the ICT sector is dominated by the services industries – telecommunications and computer (plus related) services – which account for between two thirds and three quarters of its value added and employment. The various electronics industries, i.e. the ICT manufacturing industries, contribute only about one quarter to one third of the ICT sector's total value added and employment.[8] Among the ICT manufacturing industries, electronic components and telecommunications equipment are the largest sectors. In the ICT services sector, the relative importance of telecommunications services and computer services varies over time. In terms of value added, the share of computer services increased substantially from 26% in 1995 to 43% in 2016. The corresponding employment share also rose, albeit more moderately, from 39% in 1995 to 43% in 2016.

8 The corresponding shares of the ICT manufacturing industries of the ICT sector's total gross output are slightly higher, given the bigger role of inter-industry transactions (both domestically and internationally) and hence of material inputs in this part of the economy.

Table 7 / Comparison of the comprehensive and the operational definition of the ICT sector

(a) Nominal value added

	nominal value added					
	EUR billion			in % of ICT Total		
	1995	2000	2016	1995	2000	2016
B'. ICT manufacturing industries	263	495	655	31.1%	30.8%	23.9%
Electronic components and boards	123	240	369	*14.6%*	*14.9%*	*13.5%*
Computers and peripheral eq.	51	87	86	*6.1%*	*5.4%*	*3.1%*
Communication eq.	64	136	144	*7.5%*	*8.4%*	*5.3%*
Consumer electronics	22	29	52	*2.6%*	*1.8%*	*1.9%*
C. ICT services industries	581	1,113	2,087	68.9%	69.2%	76.1%
Telecommunications	360	601	893	*42.6%*	*37.4%*	*32.6%*
Computer and related activities	222	512	1,193	*26.2%*	*31.9%*	*43.5%*
A'. ICT Total	844	1,608	2,741	100.0%	100.0%	100.0%

(b) Employment

	employment					
	persons million			in % of ICT Total		
	1995	2000	2016	1995	2000	2016
B'. ICT manufacturing industries	4.90	9.09	14.05	34.2%	37.5%	35.5%
Electronic components and boards	2.00	4.46	7.54	*14.0%*	*18.4%*	*19.0%*
Computers and peripheral eq.	0.72	1.64	2.71	*5.0%*	*6.8%*	*6.9%*
Communication eq.	0.99	1.58	2.26	*6.9%*	*6.5%*	*5.7%*
Consumer electronics	0.47	1.14	1.53	*3.3%*	*4.7%*	*3.9%*
C. ICT services industries	11.17	15.14	25.56	77.9%	62.5%	64.5%
Telecommunications	5.56	6.77	8.72	*38.8%*	*27.9%*	*22.0%*
Computer and related activities	5.61	8.37	16.83	*39.2%*	*34.5%*	*42.5%*
A'. ICT Total (operational)	14.34	24.23	39.61	100.0%	100.0%	100.0%

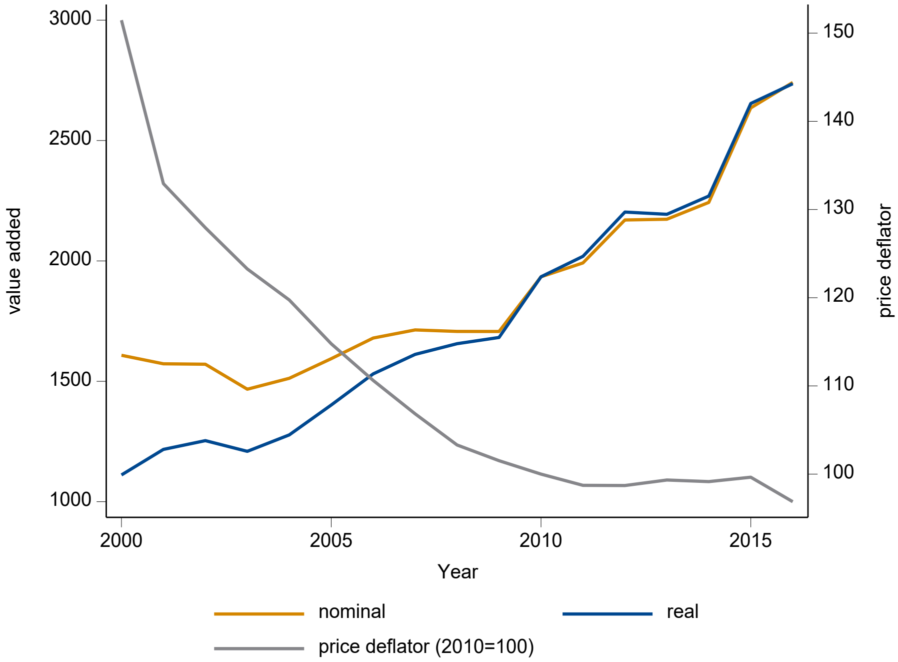
Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Employment data for China is missing for 1995.
Sources: PREDICT dataset; authors' elaboration.

One important aspect when analysing the ICT sector are price developments. Price developments matter because the global prices of many ICT goods and services decline over time (Figure 2). The decline in the (value added-based) price of outputs produced by the ICT sector was particularly pronounced between 2000 and 2010.[9] Thereafter the price deflator more or less stagnated. This price development means that before the base year, which is 2010, value added in real terms is significantly lower than the corresponding nominal values.[10] For example, in the year 2000 the real value added of the global ICT sector amounted to EUR 1.111 billion, compared with EUR 1.608 billion in nominal terms. Hence, the distinction between real and nominal values is important, especially for the analysis of the dynamics over time.

[9] The analysis in real terms is limited to the period starting 2000 and above, as the price deflators of some countries for the years 1995 to 1999 appear to be unrealistically high or low. This includes the transition economies, for which the PREDICT dataset reports implausibly low price deflators, as well as the US, which features extremely high price deflators for the period 1995-1999.

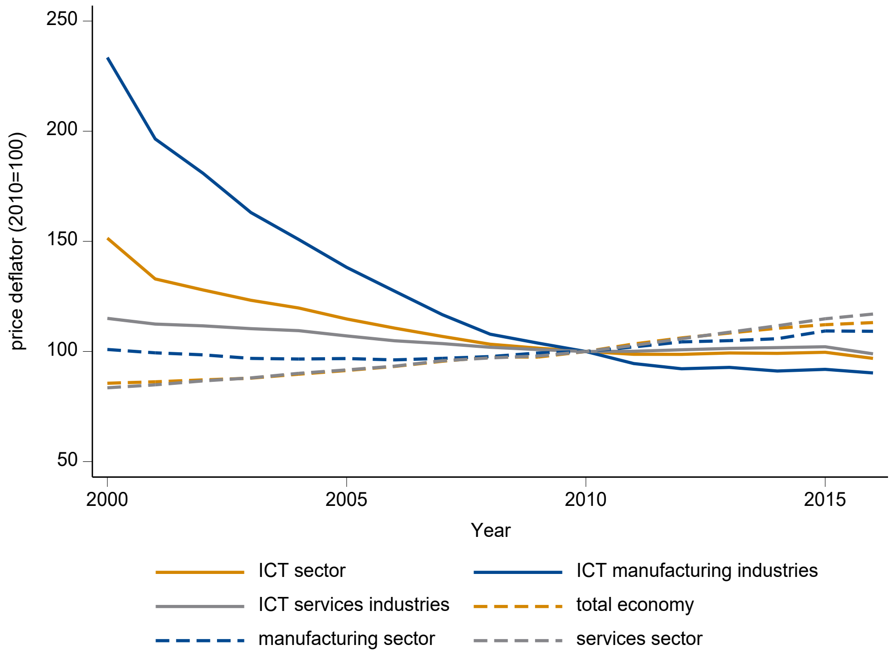
[10] The same applies to gross output.

Figure 2 / Nominal and real value added and price deflators for the ICT sector



Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Real value added at the world level is calculated as the value added weighted average of the national (industry-level) price deflators.
Sources: PREDICT dataset; authors' elaboration.

Figure 3 / Price deflators in the ICT sector and the overall economy



Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Real value added at the world level is calculated as the value added weighted average of the national (industry-level) price deflators. Services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

The declining price level in the ICT sector is also important, because it is in contrast with the overall price development of the global economy. While inflation was generally subdued over the past two decades, especially in developed countries, the overall price deflator shows a mild positive trend (Figure 3). The opposing price trends are observable in the total ICT sector in comparison with the total economy as well as in the main sub-sectors, the ICT manufacturing sector and the ICT services sector, although the decline in prices was much more pronounced in the ICT manufacturing sector. This pattern is typically explained by the fact that manufacturing goods are highly tradable goods, which implies tougher competition on the one hand and higher productivity growth on the other hand. Whether this explanation is also applicable to the ICT services sector would be an interesting subject for further research, because many ICT services are also tradable or provided by globally operating MNEs via foreign subsidiaries. Therefore, the differences in the price development between the global ICT manufacturing sector and the ICT services sector may be explained by higher productivity growth in the manufacturing industry.

Before taking a closer look at productivity trends, it is interesting to consider the ICT sector's growth performance, again benchmarking it against the total economy (Table 8). Such a comparison is insightful in many respects. First of all, it confirms the characterisation of the ICT sector as a lead sector, because growth was much higher there than in the economy as a whole, irrespective of whether one looks at employment, real value added or real output. For example, real valued added grew by 5.8% annually in the ICT sector, compared with 1.7%[11] in the overall economy (i.e. global GDP).

Table 8 also illustrates the importance of price developments. Both the nominal value added and the nominal gross output developments would suggest that the total economy grew faster than the ICT sector, which is, however, entirely due to the diverging price trends. The employment figures show clearly that the ICT sector developed more dynamically, adding 3% more jobs each year, compared with 0.7% employment growth annually for the total economy. The distinction between ICT manufacturing industries and the ICT services industries shows that real value-added (and gross output) growth was stronger in the former, while employment growth was higher in the latter. This pattern points to the higher capital intensity of the ICT manufacturing sector compared with the services part of the ICT sector, and to stronger labour productivity growth.

[11] At 1.7% annually, the global growth rate for the period 2000-2016 found in the PREDICT dataset is considerably lower than the 2.8% average found in the World Bank's Word Development Indicators for real GDP growth. While it is not entirely clear where the difference comes from, it does not alter the results with regard to the substantial growth differential between the ICT sector and total GDP.

Table 8 / Compound annual growth rates of the ICT sector and the total economy, 2000-2016

	Employment	value added		gross output	
		nominal	real	nominal	real
ICT sector	3.12%	3.39%	5.79%	3.02%	5.48%
ICT manufacturing	2.76%	1.76%	7.47%	2.28%	7.77%
ICT services	3.33%	4.01%	4.55%	3.48%	4.17%
Total Economy	0.67%	3.69%	1.69%	4.03%	1.97%
Manufacturing	0.95%	3.10%	2.31%	4.12%	3.17%
Services (except trade)	2.21%	3.69%	1.44%	3.62%	1.33%

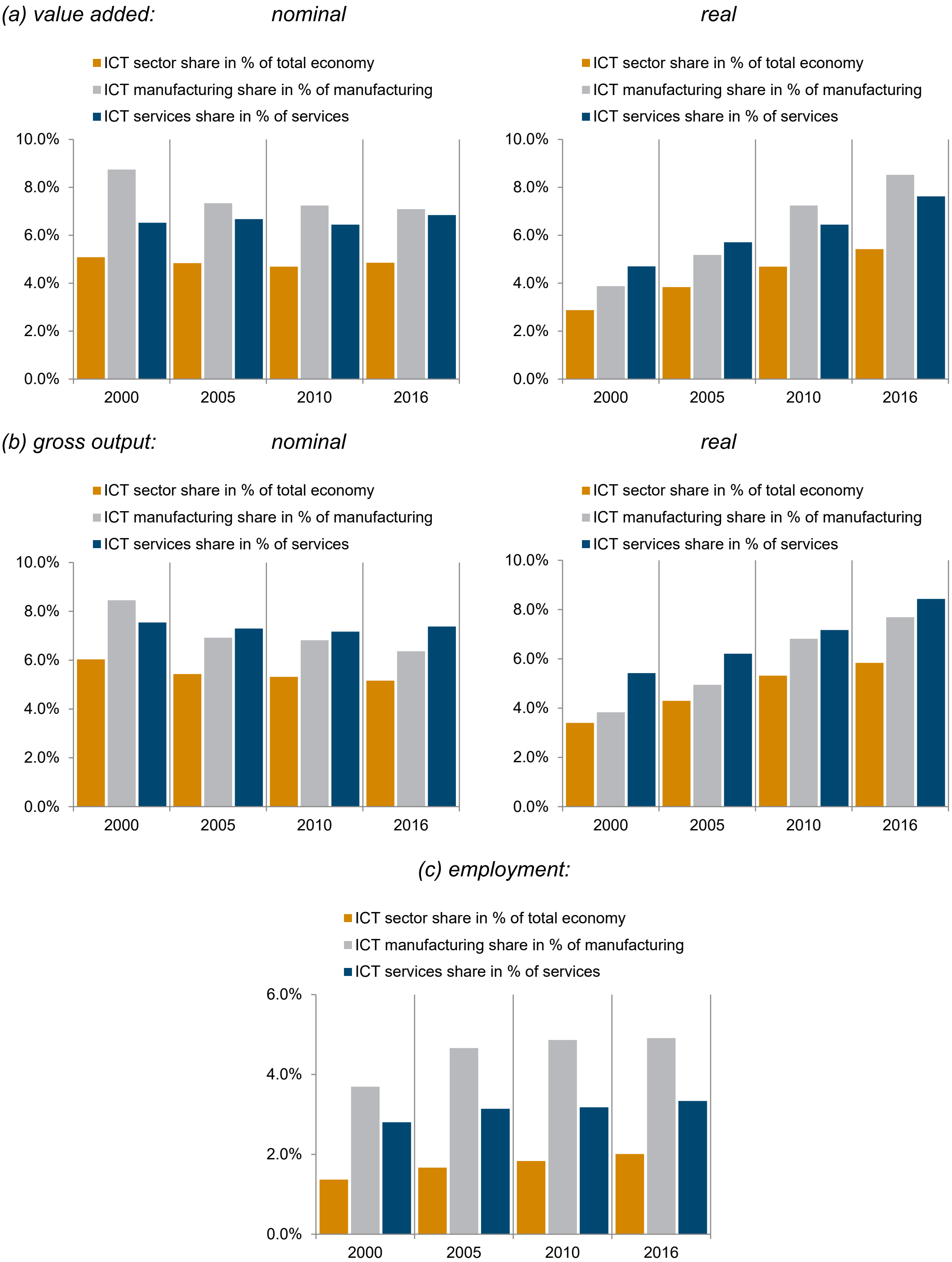
Note: Growth rates are compound annual growth rates. Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Real value added at the world level is calculated as the value added weighted average of the national (industry-level) price deflators. Services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

Given the evidence so far that the ICT sector is something of a lead sector, it is also interesting to investigate its importance in the overall economy (Figure 4). At the global level, it accounted for about 5.5% of real GDP (value added), 5.8% of gross output and 5.5% and 3.3% of employment in 2016. Interestingly, the shares for the ICT manufacturing industries in the total manufacturing sector and the ICT services industries in the total services sector, excluding trade services, is higher than for the total ICT sector. This can be explained by the fact that in these calculations the services sector excludes trade services, because the ICT trade services are not part of the ICT sector (operation definition) either (see section 3.2).

Reflecting the growth dynamics described above, the share of the ICT sector in the overall economy increased over time in real terms (value added and output) and in terms of output, but not in nominal terms. It also seems that the growing importance of the ICT sector in the global economy has been a continuous process that was only marginally (if at all) affected by the global financial crisis of 2008-2009.

At this stage it is useful to point out that all the developments at the global level are potentially also influenced by the changing relative importance of countries in the worldwide ICT sector.

Figure 4 / The role of the global ICT sector in the global economy

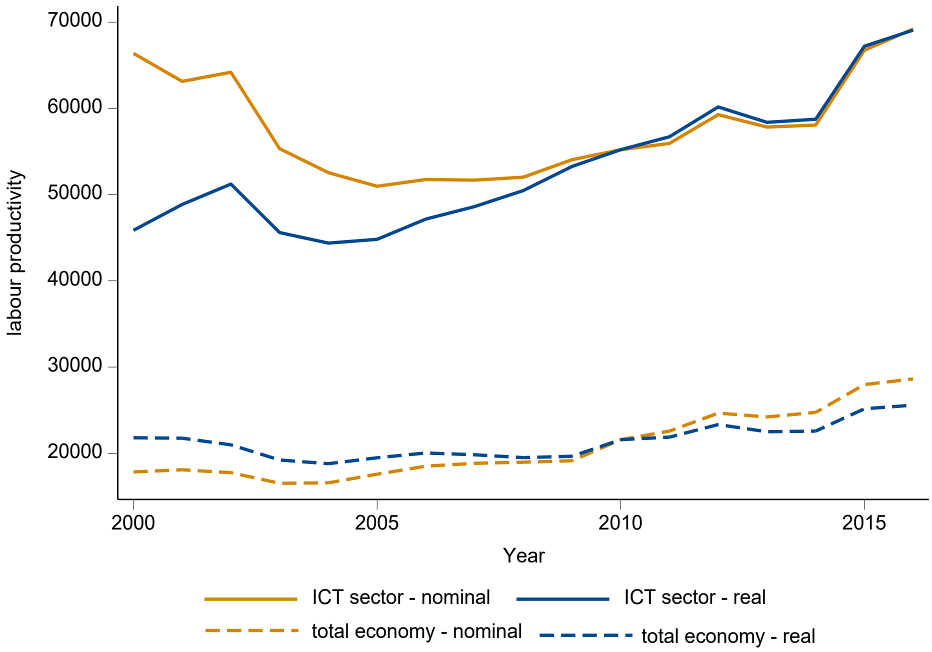


Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Real value added at the world level is calculated as the value added-weighted average of the national (industry-level) price deflators. Services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

The fundamental reasons for the superior growth performance of the ICT sector (and its sub-sectors) compared with the overall economy are its higher labour productivity, higher labour productivity growth (Figure 5) and higher R&D intensity (Figure 6), that is, business expenditure on R&D (BERD) as a share of GDP.

Not only is labour productivity in the ICT sector considerably higher than in the overall economy, its growth is also much stronger in real terms. The growth trajectory of labour productivity in the ICT sector and of total labour productivity seems to be synchronised but generally more dynamic in the former. This was true in particular in the most recent years, 2015 and 2016.

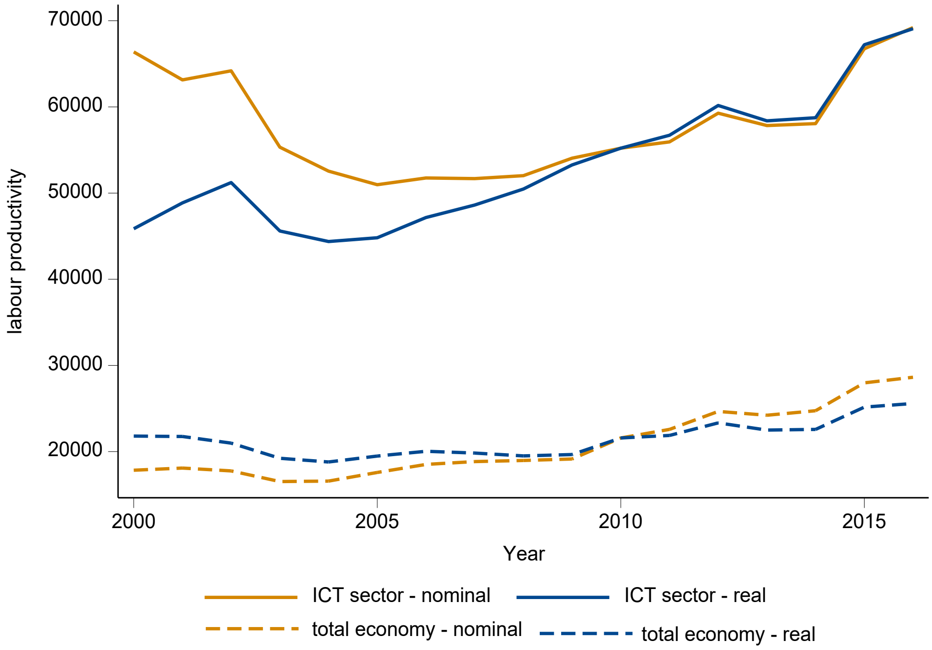
Figure 5 / Development of global labour productivity, ICT sector and overall economy, 2000-2016



Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Labour productivity at the global level is the weighted average over the constituting countries.
Sources: PREDICT dataset; authors' elaboration.

The same pattern can be observed in the development of global R&D intensities (Figure 6). As expected, the R&D intensity of the ICT sector is much higher than that of the overall economy, which is why it is generally considered to be a sector of strategic importance. Moreover, in real terms there is a clear upward trend in R&D intensity for the ICT sector – despite the already elevated level – whereas the economy as a whole is essentially characterised by a flat line.

Figure 6 / R&D intensity of the ICT sector and of the overall economy, 2000-2016



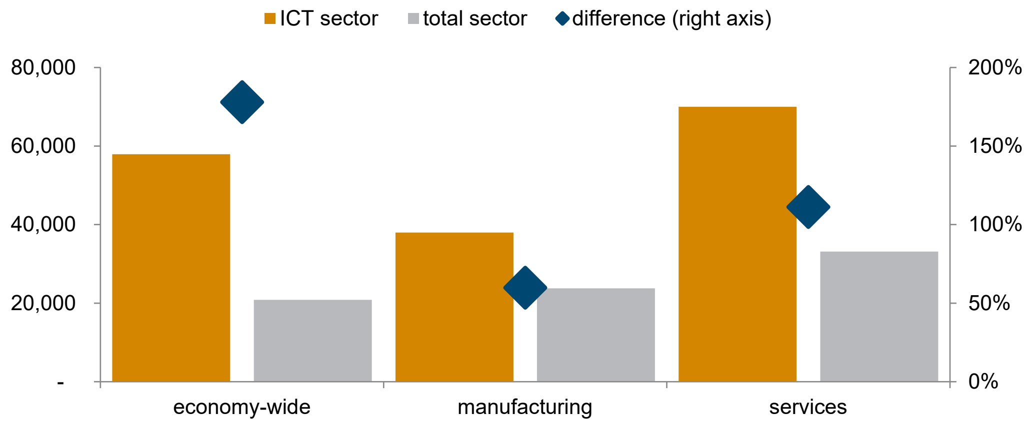
Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. R&D intensity at the global level is the (BERD-based) weighted average over the constituting countries.
Sources: PREDICT dataset; authors' elaboration.

At least as telling as the development over time is the direct comparison between labour productivities across (sub)-sectors (Figure 7). Based on averages over the period 2000-2016, it turns out that labour productivity in the ICT sector in real terms,[12] at EUR 53,280, is two-and-a-half times higher than the economy-wide labour productivity (EUR 21,391). Looking at the sub-sectors, it is also interesting to note that the ICT services sector, with EUR 67,142, enjoys higher real labour productivity than the ICT manufacturing sector (EUR 32,658). In both ICT sub-sectors real labour productivity is considerably higher than in the corresponding broad sectors of the economy. The productivity advantages of ICT sub-sectors amount to 37% for manufacturing and 96% for services. The labour productivity advantage of the ICT services sector vis-á-vis the ICT manufacturing industries is much more pronounced than in the comparison between the overall manufacturing sector and the overall services sector. In fact, the result that labour productivity in ICT services exceeds that of the services sector is partially because the services sector here excludes the trade services industries. Moreover, this productivity constellation for the global economy is not found in all countries, as will be discussed in the next section, although it holds for the ICT sub-sectors. This emphasises that especially the ICT services industries are very distinct from many other parts of the broader services sector.

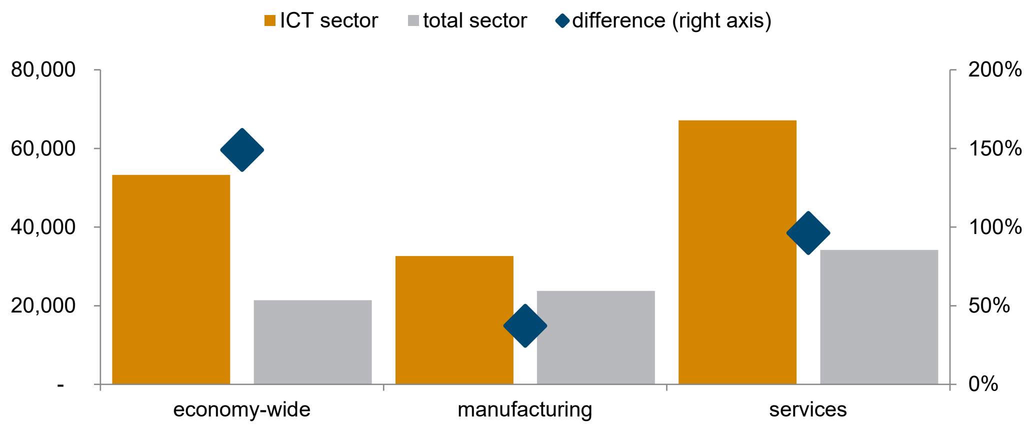
[12] The patterns are qualitatively the same for the nominal labour productivities, as can be seen in Figure 6 (a).

Figure 7 / Global labour productivity in the ICT and main economic sectors, averages 2000-2016

(a) nominal labour productivity



(b) real labour productivity

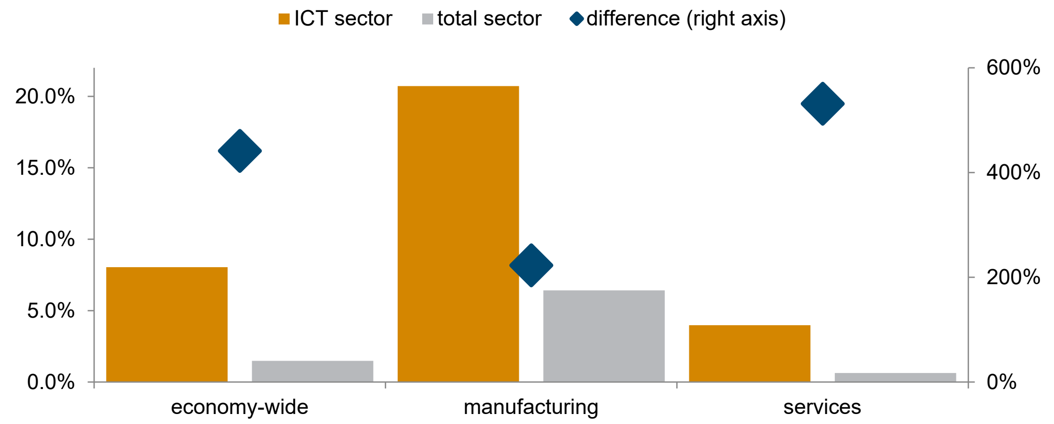


Note: Difference amounts to difference between the ICT sub-sector (for total economy, the manufacturing sector and the services sector) and the corresponding broad sector. Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Labour productivity at the global level is the weighted average over the constituting countries. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

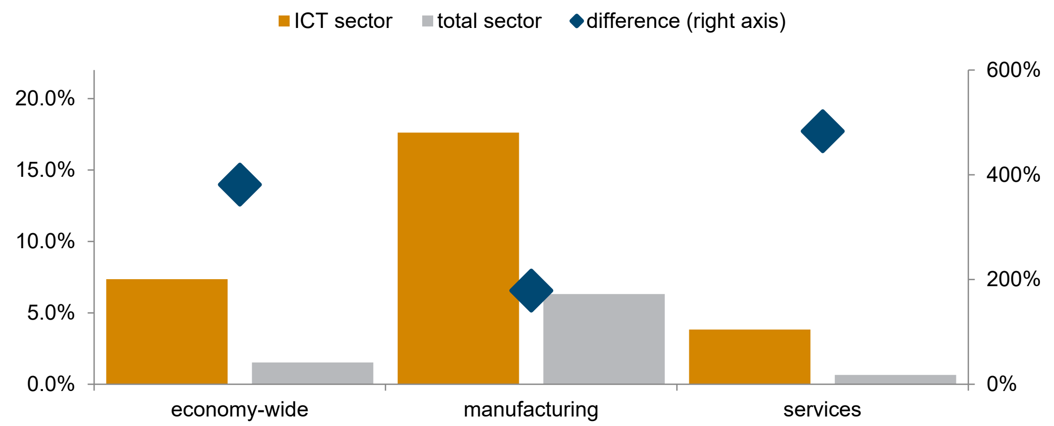
The difference between the ICT sector and the total economy in terms of technology-intensity that is reflected in the labour productivities is even more pronounced for R&D. The real R&D intensity, defined as the ratio of expenditure for business R&D over value added, of the global ICT sector amounted to 7.3% on average over the period 2000-2016, far exceeding the corresponding value for the total economy (1.5%) (Figure 8). Interestingly, and despite the significantly higher labour productivity of the ICT services industries compared with the ICT manufacturing industries, the latter have by far the highest R&D intensities (17.6% in real terms), dwarfing not only the R&D intensity of the overall manufacturing sector (6.3%) but also that of the ICT services industries (4%). It is certainly also the case that the R&D intensity of the overall manufacturing sector is considerably higher than that of the overall services sector, which in turn is owed to higher capital intensity of the former.

Figure 8 / Global R&D intensity in the ICT and main economic sectors, averages 2000-2016

(a) nominal R&D intensity



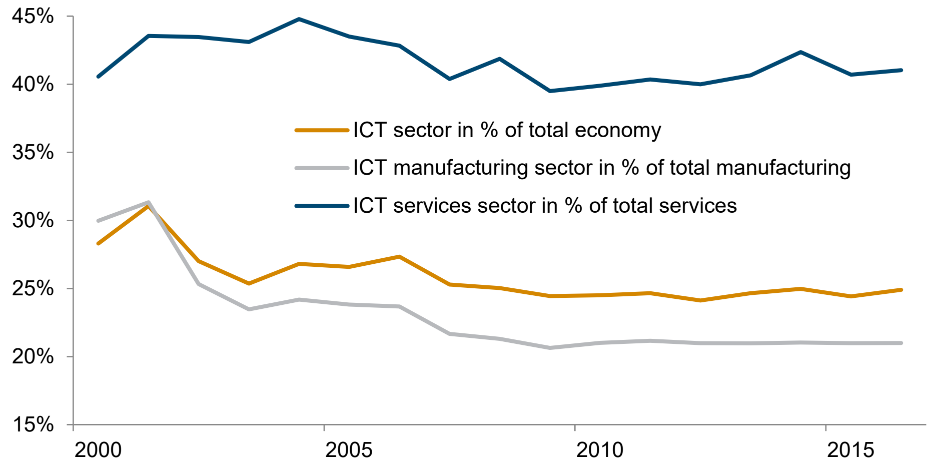
(b) real R&D intensity



Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. R&D intensity at the global level is the (BERD-based) weighted average over the constituting countries. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

Notwithstanding the comparatively lower R&D intensity of the ICT services sector, it is also true that at more than 40% it accounts for a very large share of R&D undertaken in the services sector (Figure 9). Since the manufacturing sector is much more R&D-intensive than the services sector, the share of the ICT manufacturing sector is generally much lower, standing at about 20% in 2016. Overall, the ICT sector accounted for about one quarter of the overall business expenditure on R&D worldwide. For the purpose of comparison, the ICT sector's value-added share is just above 5%, whereas its employment share is about 3.5% (see Figure 4 above). Hence, this extremely high R&D share underlines the importance of the ICT sector for technological developments and confirms once more its role as a high-tech lead sector.

Figure 9 / R&D shares of the ICT (sub-) sectors in the economy, manufacturing and services



Note: Based on nominal business expenditure on R&D. Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

The combined analysis of global labour productivity and R&D intensity as two major indicators for the technology intensity of an industry or sector delivers an interesting result: the ICT services industries managed to achieve very high labour productivity despite limited R&D intensity, which is comparatively low. The explanation for this could be either a lack of competition (possibly due to the 'winner takes all' type of competition) and significant economic rents accruing to the 'superstar firms' of the ICT services sector, or to the differences in the composition of the workforce, i.e. a more highly skilled workforce in the ICT services sector. The most likely explanation is that it is the result of a combination of these two factors.

3.4. THE ICT SECTOR IN A CROSS-COUNTRY PERSPECTIVE

Having discussed the characteristics and the developments of the global ICT sector, this section takes a look at the ICT sectors of the main ICT-producing economies. These are the EU, the US, Japan and Korea, as well as China and India as two of the key emerging economies in the ICT industry. Taken together, these six economies account for about 90% (or more) of the global ICT sector in terms of value added, output and employment. As will be shown, the growth dynamics and relative importance of the ICT sectors in the main producer countries vary considerably and partly deviate from the global trend.

3.4.1. Importance and growth dynamics of the ICT sector

The global ICT sector has been portrayed as a lead sector because of its impressive growth dynamics in terms of both employment and real value added. In advanced economies, including the EU, the growth performance of the ICT sector is not particularly outstanding, however, at least not as far as employment generation is concerned. In the EU the average annual employment growth in the overall ICT sector in the period 2000-2016 amounted to a meagre 1.2% (Table 9). This is still considerably higher than employment growth in the total EU economy, but it is much lower than the world average in the ICT sector (3.1%). A similar situation prevailed in the US and Japan, where employment growth was actually negative. In Korea employment growth was somewhat more dynamic but still below the global growth rate.

The reason for the anaemic employment growth in the ICT sectors of advanced economies is found in the industry's manufacturing segment. In the EU, the US and Japan employment growth was strongly negative – even more negative than in the overall manufacturing sector. Among the reasons were the high productivity of ICT manufacturing industries and the offshoring activities of MNEs. The flip side of these employment trends in advanced economies were high employment growth rates in emerging economies, above all in China and India. In these countries employment growth in the ICT sector exceeded 6% and 5%, respectively, in their manufacturing ICT industries.

Mirroring the global picture, the ICT sector is clearly expanding in terms of nominal[13] and even more so in terms of real value added and also output. Given the EU's concern about falling behind the US in key enabling technologies such as ICT, it is reassuring that the European ICT sector grew at par with that of the US in terms of real value added. A grain of salt is that the manufacturing part of the ICT sector was underperforming in comparison with the US. Interestingly, the real value added and output of the ICT services sector grew faster in the EU than in the US.

[13] An exception here in Japan, where value added and output growth was slightly negative between 2000 and 2016.

Table 9 / Compound annual growth rates of the ICT sector in main producer countries, 2000-2016

(a) Advanced economies

	Employment	value added nominal	value added real	gross output nominal	gross output real
European Union					
ICT sector	1.19%	2.69%	5.01%	2.51%	4.82%
ICT manufacturing	-3.53%	-2.65%	1.40%	-3.52%	0.50%
ICT services	2.09%	3.58%	5.34%	4.10%	5.87%
Total Economy	0.48%	2.77%	1.36%	2.78%	1.37%
Manufacturing	-1.01%	1.84%	1.30%	1.97%	1.42%
Services (except trade)	1.36%	3.17%	1.60%	3.33%	1.76%
United States					
ICT sector	-0.56%	2.13%	4.99%	0.61%	3.43%
ICT manufacturing	-4.13%	-1.41%	4.75%	-4.55%	1.42%
ICT services	0.36%	3.19%	3.95%	2.15%	2.90%
Total Economy	0.48%	2.61%	0.66%	2.31%	0.36%
Manufacturing	-2.07%	0.99%	-0.01%	0.76%	-0.24%
Services (except trade)	1.03%	3.08%	0.78%	2.96%	0.66%
Japan					
ICT sector	-0.07%	-1.29%	3.19%	-1.48%	2.99%
ICT manufacturing	-2.96%	-3.29%	4.98%	-3.59%	4.65%
ICT services	1.85%	-0.30%	1.17%	0.10%	1.57%
Total Economy	0.12%	-1.04%	-0.41%	-0.88%	-0.25%
Manufacturing	-1.17%	-1.47%	0.14%	-1.10%	0.52%
Services (except trade)	1.11%	-0.75%	-0.37%	-0.56%	-0.17%
Korea					
ICT sector	2.31%	4.38%	7.03%		
ICT manufacturing	1.45%	4.89%	8.46%		
ICT services	3.11%	3.52%	4.67%		
Total Economy	1.35%	4.75%	2.54%	5.08%	2.87%
Manufacturing	0.30%	4.94%	3.98%		
Services (except trade)	3.02%	5.22%	2.39%		

(b) Emerging economies

	Employment	value added nominal	value added real	gross output nominal	gross output real
China					
ICT sector	6.18%	15.59%	18.66%	16.07%	19.15%
ICT manufacturing	5.76%	14.10%	20.30%	15.62%	21.90%
ICT services	6.89%	17.16%	15.49%	17.48%	15.81%
Total Economy	0.46%	13.60%	9.70%	14.24%	10.31%
Manufacturing	2.06%	12.68%	10.71%	14.49%	12.48%
Services (except trade)	3.32%	15.62%	10.03%	15.17%	9.60%
India					
ICT sector	6.15%	13.04%	12.54%	11.46%	10.97%
ICT manufacturing	5.63%	5.24%	5.51%	4.97%	5.24%
ICT services	6.23%	13.91%	13.22%	12.93%	12.25%
Total Economy	1.05%	9.09%	3.41%	8.29%	2.65%
Manufacturing	1.62%	7.99%	3.55%	7.13%	2.74%
Services (except trade)	3.21%	10.16%	6.54%	10.07%	6.44%

Note: Growth rates are compound annual growth rates. Real value added is calculated using country-specific (industry-level) price deflators. Services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

Still, it is somewhat disturbing that a globally expanding sector such as the ICT sector is not capable of creating more employment throughout the EU (as well as other advanced economies). Much of the new jobs in ICT industries – both manufacturing and services – seem to appear in China and India, part of which is related to relocation of production activities of multinational firms in developing countries. Both countries also posted double-digit average annual growth rates of real value added and real output for the period 2000-2016. While these figures may be influenced by comparatively low base values (in 2000), it is still an impressive development in one of the most technology-intensive sectors. Comparing the growth rates of China and India, it is also interesting to see that China experienced higher growth in ICT manufacturing industries, whereas India recorded higher growth rates in its ICT services industries. This is in line with the notion of China being the 'factory of the world' and India being a more services-oriented economy, sometimes referred to as the 'office of the world'. It should be noted, though, that China has clearly outgrown its role as a mere factory economy and developed considerable technological capabilities through both imitation and absorption of foreign technologies and its own substantial R&D efforts.

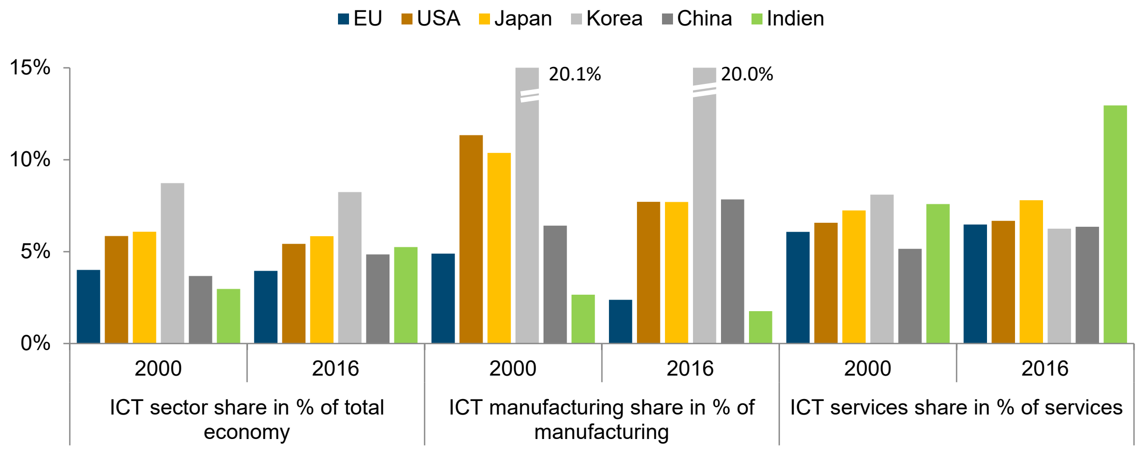
While the growth dynamics of the ICT sector are by and large comparable across the advanced economies, the relative importance of this sector varies considerably (Figure 10). Focusing first on the EU and considering real value added, the share of the ICT sector amounted to less than 5% in 2016. While this constitutes a significant increase compared with 2000, it is also a fact that the ICT sector plays a smaller role in the EU economy than in its major competitor countries. In the US and Japan the ICT sector contributed about 6% to the national GDP, with the corresponding share in Korea being 10%. These figures are compatible with the conclusions by the IMF (2018) regarding the size of the digital sector, which, the report claims, is generally still less than 10% in most economies when measured by valued added, income or employment.[14] While the ICT sector as defined here and the IMF's definition of the digital sector do not fully overlap, they nevertheless comprise a similar set of industries.

The perceived technological gap between the EU and the US is a long-standing concern of EU industrial policy (e.g. Eaton et al. 1998; Foster et al., 2013, Landesmann and Stöllinger 2020). The fact that the ICT sector in the EU economy is comparatively small is of particular concern given the close relationship between ICT and the digital economy, which is one of the strategic priorities ('flagship initiatives') of the EU's 2020 growth strategy.

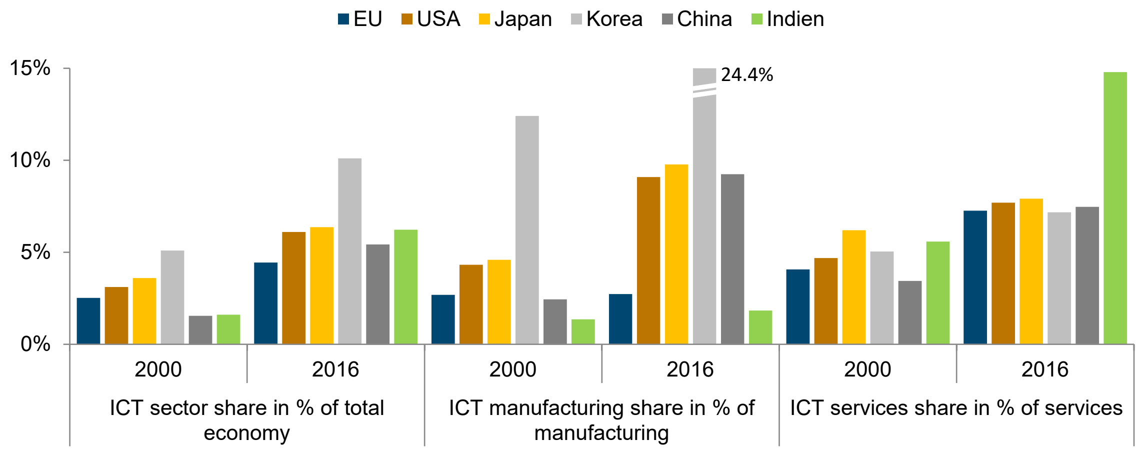
[14] The data are of course also in line with those reported by the Joint Research Centre in their PREDICT Key Facts Report (JRC 2017).

Figure 10 / The role of the ICT sector in the main ICT producing economies

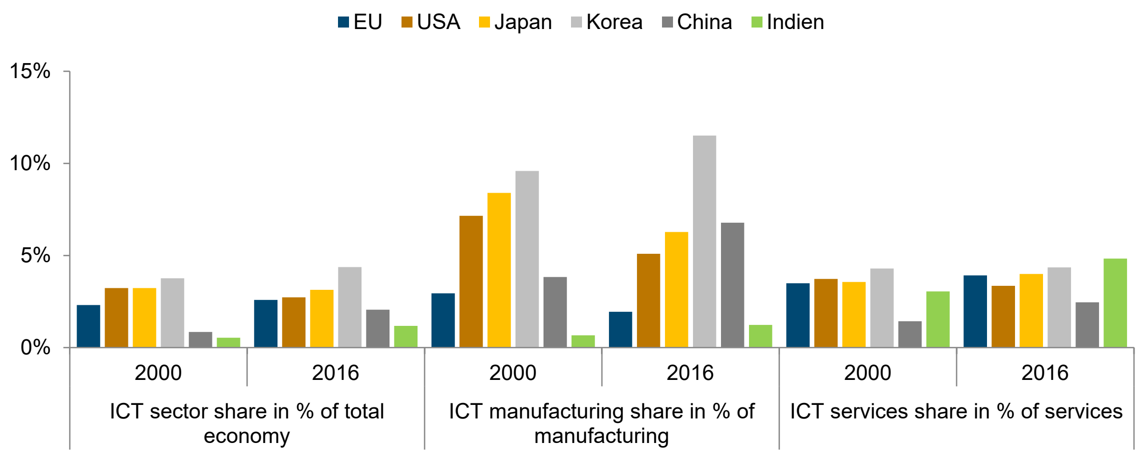
(a) Nominal value added



(b) Real value added



(c) Employment



Note: Services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

The transformation towards a digital economy is further elaborated in the 'Digital Agenda for Europe' (European Commission 2018), recently updated and specified in a communication by the Commission (European Commission 2020a), and the EU's updated industrial policy strategy (European Commission, 2020b) calls not only for the transition to a green economy but also to a digital economy.

Against the background of these policy objectives, the relatively modest role played by the ICT sector in the EU economy would indicate that great efforts are needed to boost the expansion of the ICT sector. This is true for both the manufacturing and the services part of the ICT sector, although the difference compared with main competitor countries is particularly striking where manufacturing is concerned. Focusing again on the gap with the US, Figure 9 illustrates clearly that in 2016 the EU was lagging behind especially in the ICT manufacturing sector, irrespective of whether real or nominal value added or employment are considered. In terms of employment, for example, the share of the ICT manufacturing sector amounted to 2% in the EU, compared with 5% in the US. This comparison is certainly influenced by the fact that the US manufacturing sector has shrunk considerably over the past decade and is therefore modest in size, but the comparison with other countries, such as Japan or Korea, shows that this is not the only explanation for this result. The gap between the EU and the US in the ICT services sector is smaller (and in the case of employment non-existent). As pointed out in the context of the growth dynamics, this relatively good positioning of the EU in the services segment suggests that the data require further scrutiny, given the frequently voiced concern that the EU economy lacks a sufficient number of leading software and online platform providers, with German software company SAP being a rare exception (see EPSC 2019).

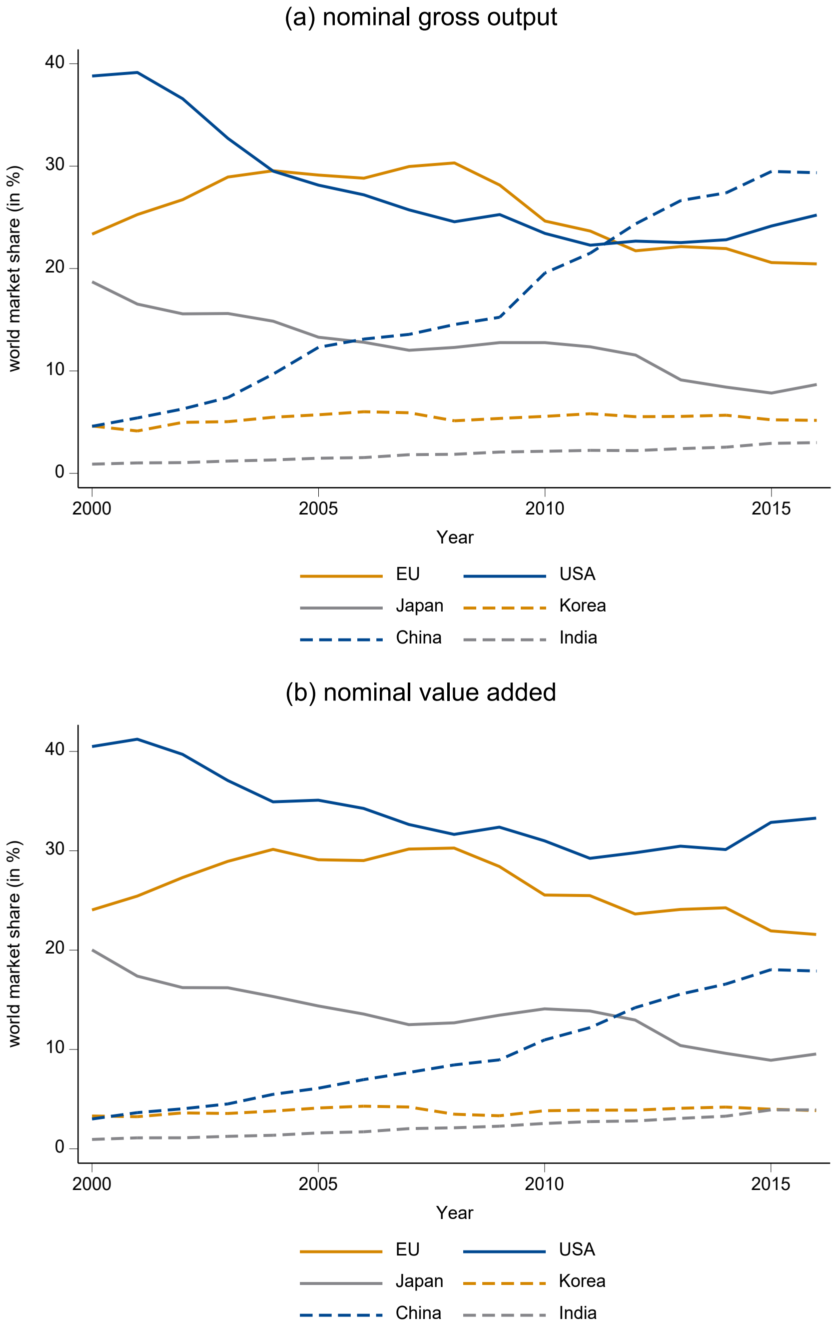
3.4.2. Productivity and world market shares in the ICT sector

While the relative size of a sector is likely to reflect its international competitiveness, more direct performance indicators are sector productivity, which reflects the aggregate productivity of firms, and world market shares, a measure for success in international markets.

Starting with the world market shares of gross output (panel a) and value added (panel b) – both nominal – in the ICT sector, Figure 11 shows a rather typical pattern that *qualitatively* resembles the trends in global GDP shares and overall gross output shares after the past two decades. The economic triad, the EU, the US and Japan, experienced a marked decline in their world marked shares in the gross output of ICT goods and services produced, which is mirrored by strongly growing world market shares for China and much more modest gains for India (over the period 2000-2016). Korea managed to keep its world market share in the ICT sector more or less constant albeit at a low level.

An important recent modification of these broad trends is that in the early 2010s the US was able to stop and reverse the declining trend in its world market share not only in the ICT sector but also in the overall economy. After 2016 such a trend reversal is no longer observable.

Figure 11 / Development of world market shares, ICT sector and overall economy, 2000-2016

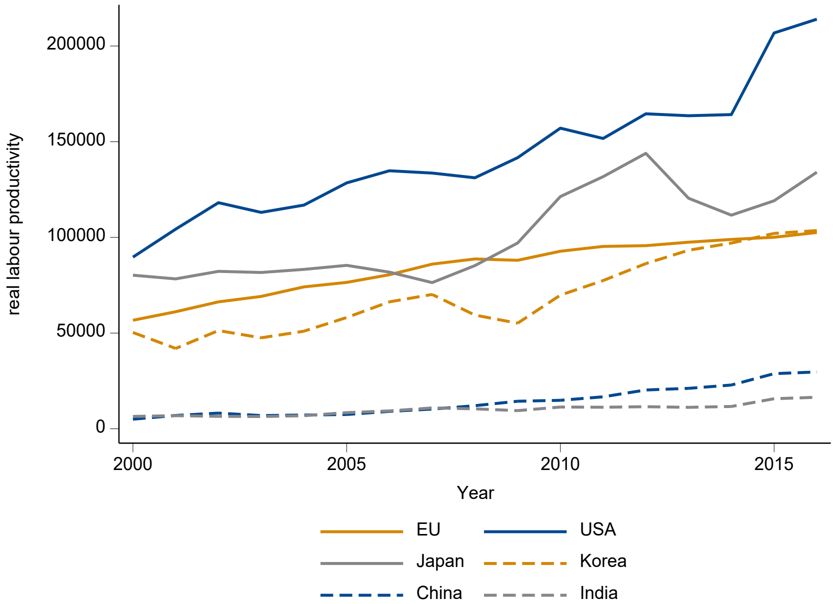


Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Labour productivity at the global level is the weighted average over the constituting countries.
Sources: PREDICT dataset; authors' elaboration.

A comparison of the trends in gross output and value added also illustrates that the former probably overstates the strong position of China in the ICT sector. In terms of gross output, China had a world market share of 30% in 2016, clearly surpassing the share of the US (25%) and even more clearly that of the EU (20%). Looking at value added, the data show a different picture, whereby in 2016 the US remained the undisputed market leader, responsible for one third of global value added generated by the ICT sector. The EU's share of global value added by the ICT sector accounted for about 22%, only slightly more than its gross output share, making it the second most important producer, followed by China. One reason for the significant difference in the output and value added-based ICT market shares of the US and the rather limited difference in the EU could be different outsourcing strategies. In the EU a much larger part of the offshoring activities of MNEs are regional in scope, giving rise to regional global value chains (GVCs) that imply joint production by EU member states. In other words, intra-EU offshoring does not drive a wedge between gross output and value added-based world market shares of the EU.

In any case, the trend depicted in Figure 11 is a reminder of the urgent need for realising the European Digital Agenda and a reinforced European industrial policy strategy, including massive investment support that provides a push for the digital transformation of the production processes, incorporating cyber-physical systems of production.

Figure 12 / Real labour productivity of the ICT sector in main producer countries, 2000-2016



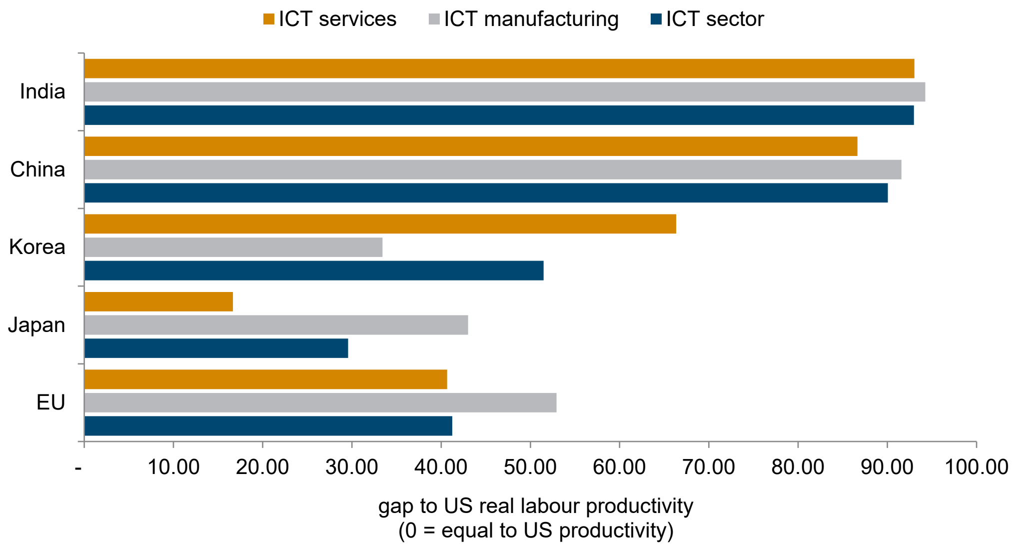
Note: Global economy comprises the following economies: EU, Australia, Brazil, Canada, Switzerland, China, India, Japan, Korea, Norway, Russia, Taiwan and the US. Real labour productivity calculated using national sector-specific price deflators.
Sources: PREDICT dataset; authors' elaboration.

The developments of the real labour productivities in the six main ICT-producing regions are interesting in many ways (Figure 12). First of all, the productivity differences in the ICT sector in the developed producer countries are extremely high, much higher than for the global average (which was found to be EUR 53,280 on average in 2000-2016), and above all much higher than in China and India. While the productivities are trending upwards in all countries, there is significant variance in the dynamics. Mirroring the different sizes of the ICT sector in the EU and the US as well as in the world market shares, US labour productivity in the ICT sector (EUR 214,000) was, according to the PREDICT data, more than double that in the EU (EUR 102,600) in 2016. This implies a considerable widening in the productivity gap compared with 2000. With a short exception, real labour productivity in the EU was also inferior to Japanese productivity, and by 2015 Korea had also caught up with the EU in terms of labour productivity.

Another striking feature of Figure 12 are the low labour productivities of China and India. Apart from the much lower real labour productivity in these economies per se, the offshoring activities of (mainly Western) MNEs tend to intensify the productivity differences, as it leaves 'high-powered' ICT sectors in the US, the EU and Japan, while emerging economies in their role as 'factory economies' (Baldwin and Lopez-Gonzalez, 2015) perform the actual production activities, which tend to have a lower potential for generating value added and hence result in lower productivities (Stöllinger, 2019).

The extent of both the EU's productivity gap with the US and leading Asian competitor as well as the massive distance of China and India from the 'ICT productivity frontier' is depicted in Figure 13 for the ICT sector and the two main sub-sectors, with all gaps referring to the period averages (2000-2016).

Figure 13 / Real labour productivity gaps to the US in the ICT sector, average 2000-2016



Note: Labour productivity gap (LP^{GAP}) of country *j* to the US is calculated as $LP_j^{GAP} = (LP_{US} – LP_j) / LP_{US} * 100$ where a value of 0 indicates labour productivity equal to that of the US. The average for China comprises the period 2006-2016; the average for India comprises the period 2000-2013.
Sources: PREDICT dataset; authors' elaboration.

The figure shows that the EU's ICT productivity gap with the US exceeds 40% overall and for the ICT services sector, while the gap amounts to more than 50% for ICT manufacturing. In general, US productivity advantages are suggested to be huge also compared with other main producer countries. In fact, it is only in the Japanese ICT services sector that the productivity gap vis-à-vis the US is less than 20%.

While one potential explanation for these massive productivity differences could be different methods of calculating the price deflators (e.g. due to the US applying hedonic pricing methods that try to incorporate quality aspects in the calculation of deflators), it turns out that the productivity gap between the EU and the US is of similar size in terms of nominal labour productivity. This rules out these types of methodological differences as a source for the striking differences in productivity. A potential explanation could be the different behaviour of firms with respect to expenditure on R&D, which is discussed next.

3.4.3. The ICT sector's contribution to business R&D

Investment in R&D is a key activity to remain at the technological frontier as well as a major production factor (next to physical capital and R&D personnel). This becomes clear in the latest version of the System of National Accounts (SNA 2008), where expenditure on R&D is recorded as investment feeding into the stock of intangible assets.

As shown in Table 10, the dominance of the US with regard to the shares in overall R&D expenditure by businesses may indeed be a main reason for the productivity advantage enjoyed by the US ICT sector. By 2016 the US accounted for almost half of global R&D expenditure in the ICT sector, showing an upward trend in the most recent years. Moreover, the US share in global R&D expenditure exceeds the country's share in overall R&D expenditure by a wide margin (48% versus 37% in 2016). The opposite is true for the EU, where the share of European companies in R&D in the ICT sector is both declining and significantly below the EU's share in total R&D (14% versus 22% in 2016). The situation is similar in both sub-sectors, the ICT manufacturing and the ICT services sector, with EU companies accounting for a particularly low share in the former (8% of the global total in 2016).

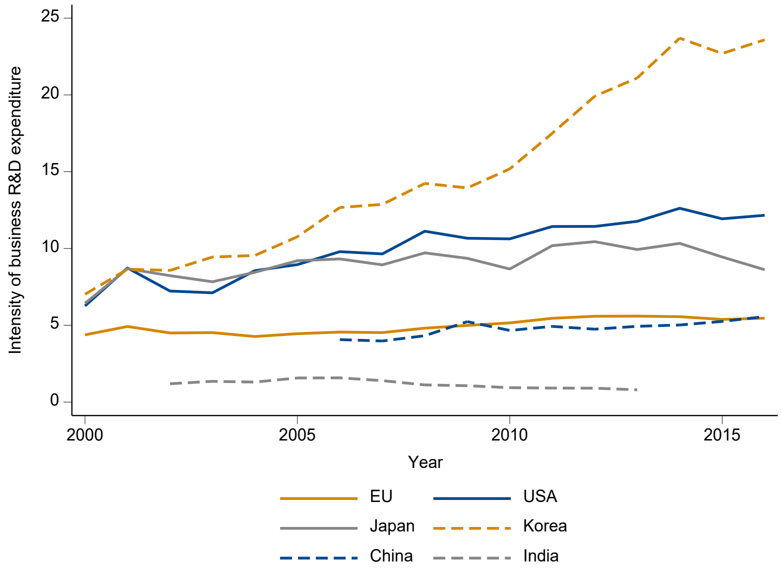
Table 10 / Share of main producer regions in global expenditure on business R&D, nominal values, 2000, 2006, 2013, 2016

	ICT sector	Total economy	ICT manufacturing sector	Manufacturing sector	ICT services sector	Services sector
			European Union			
2000	17.0	22.9	14.6	22.3	22.9	31.7
2006	18.8	27.5	16.1	25.8	23.3	32.3
2013	16.1	24.5	10.6	21.7	24.8	32.0
2016	13.7	21.9	8.0	19.3	22.5	28.7
			United States			
2000	45.3	45.2	38.8	40.3	61.5	53.8
2006	44.8	39.6	35.7	37.9	60.0	46.8
2013	44.3	34.2	36.8	32.5	56.4	42.9
2016	48.0	37.3	41.0	34.8	58.7	48.8
			Japan			
2000	28.7	22.6	35.2	29.0	9.0	7.8
2006	19.0	18.3	26.6	22.2	6.4	7.9
2013	12.0	13.8	16.3	16.9	5.1	5.6
2016	9.3	12.2	12.0	14.8	5.2	5.7
			Korea			
2000	3.6	2.0	4.1	2.4	2.0	1.1
2006	6.9	3.5	10.2	4.4	1.5	1.0
2013	9.9	4.5	14.9	5.5	1.9	1.3
2016	9.8	4.6	15.0	5.8	1.7	1.3
			China			
2000		1.5	1.4	1.7		0.5
2006	3.5	4.3	4.9	5.1	1.3	1.2
2013	9.9	15.6	13.6	19.0	4.0	4.3
2016	12.5	18.2	17.3	22.1	5.2	5.7
			India			
2000		0.2				
2006	0.3	0.4	0.0	0.4	0.8	0.4
2013	0.3	0.6	0.0	0.5	0.8	0.5
2016		0.7				

Note: R&D intensity is the share of business expenditure on R&D in value added in each country. China: data for 2005 not available; India: data for 2000 and 2016 not available. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

Impressive is (once more) the R&D performance of the Chinese ICT sectors. Starting from negligible shares in the year 2000 (for 2000-2005 data are only available for the ICT manufacturing sector), China contributed almost 13% to worldwide business R&D expenditure in the ICT sector and 17% in the sector's manufacturing segment in 2016. This is yet another piece of evidence suggesting that China is no longer solely acting as the factory of the world but has developed substantial R&D capacities. In contrast, in this comparison India plays a marginal role when it comes to ICT R&D, including in the ICT services sector, where it accounted for less than 1% of the sub-sector's global R&D expenditures in 2016. These 'world market shares' in R&D are probably a better reflection of the leading role of US companies in the realm of ICT than the corresponding value-added shares. The reason for this is that the functional division of labour leads to a situation where comparatively little production takes place within the US because it is regularly offshored to low-wage destinations, which consequently leads to lower US shares in (especially) gross output and (also) value added.

Figure 14 / R&D intensity in the ICT sector in the main producer countries, 2000-2016



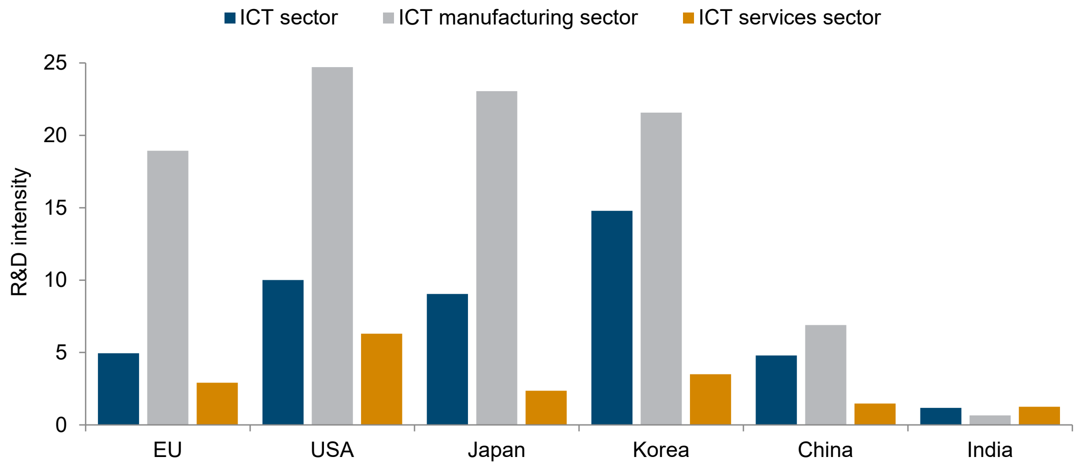
Note: R&D intensity is the share of business expenditure on R&D in value added in each country. China: data for the years 2000-2005 not available. India: data for the years 2000-2002 and 2014-2016 not available.
Sources: PREDICT dataset; authors' elaboration.

Another interesting metric is the R&D intensity of the ICT sector. Figure 15 shows that in this respect Korea outperforms the US (ranking second) thanks to strong increases between 2000 and 2014. Again, the EU as a bloc seems to fall behind due to a less dynamic development of the ICT sector's R&D intensity, which hovered around 5% over the period 2000-2016. This means that by 2016 the EU was more or less at par with China in this respect.

What should be kept in mind, though, is that R&D intensity also depends on the structure of the economy. For example, it seems that extremely high R&D intensity at the economy level is influenced by the fact that the country has a comparatively small trade services industry – at least compared with the US. This becomes obvious in Figure 15, which shows that over the period 2000-2016 R&D intensity in the US was on average higher than in Korea in the manufacturing ICT sector *and* in the ICT services sector – where the latter excludes the trade services industries – but not in the overall ICT sector, where the trade services industries are included. Likewise, R&D intensity in the EU was higher than in China in both ICT sub-sectors, but both economies recorded almost identical R&D intensities for the overall ICT sector.

Hence, R&D intensities, while highly informative for the position of countries in the production of new ICT technologies, need to be carefully interpreted with the influence of the overall structure of the economy in mind, which may or may not be relevant for the performance of the ICT sector. This, however, does not change the fact that the EU underperforms in terms of R&D intensity when compared with other developed producer countries (with the exception of the Japanese ICT services sector). This is rather bad news for the high-aiming objectives of the EU's Digital Agenda and related policy fields, such as industrial policies aiming at the digital transformation.

Figure 15 / R&D intensity in the ICT sector and main sub-sectors, averages 2000-2016



Note: R&D intensity is the share of business expenditure on R&D in value added in each country. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

3.5. A LOOK INSIDE THE EU: THE ICT SECTORS OF THE EU MEMBER STATES

While the high degree of economic integration attained justifies considering the EU as one economy, it is at the same time composed of a large set of diverse and highly heterogeneous economies with different specialisation patterns and technological capacities. Therefore, this section supplements the discussion in the previous section by briefly outlining member states' positions in the ICT sector within the EU.

In this respect, a first observation is that, given the existing differences in economic size, the four largest member states (Germany, France, Italy and the UK[15]) accounted for about 60% of EU-wide real value added generated by the EU ICT sector in 2018 (Table 11). In the case of employment, the corresponding share was still 50%.

A striking feature of the figures in Table 11 is that the share of the so-called 'new member states' (which are those that joined the EU in 2004 or later) in EU-wide ICT employment is considerably higher (20% in 2018) than their real value-added share (9% in 2018). This points to significant productivity differences in the EU, which will be discussed further below. This is true for both the ICT manufacturing sector and the ICT services sector, whereby the share of the former tends to be larger. That is a characteristic which the new member states, comprising mostly CEE countries, share with Germany and also Italy. The opposite pattern is found for France and the UK as well as the other 15 member states (i.e. those joining the EU before 2004, except the four largest economies).

[15] Across the sample period, the UK was still an EU member.

Table 11 / Member states' shares in EU-wide ICT sector value added and employment, 2000 and 2018

(a) real value added

	ICT sector		ICT manufacturing		ICT services	
	2000	2018	2000	2018	2000	2018
Germany	19.4	20.3	23.0	32.0	18.5	18.8
France	17.6	16.0	15.1	10.7	18.3	16.0
Italy	10.6	9.2	5.9	10.4	11.8	8.9
United Kingdom	20.2	17.1	14.5	8.2	21.7	17.4
Other EU15	28.3	28.5	38.4	26.8	25.7	30.6
New member states	3.9	8.9	3.1	11.9	4.1	8.4

(b) employment

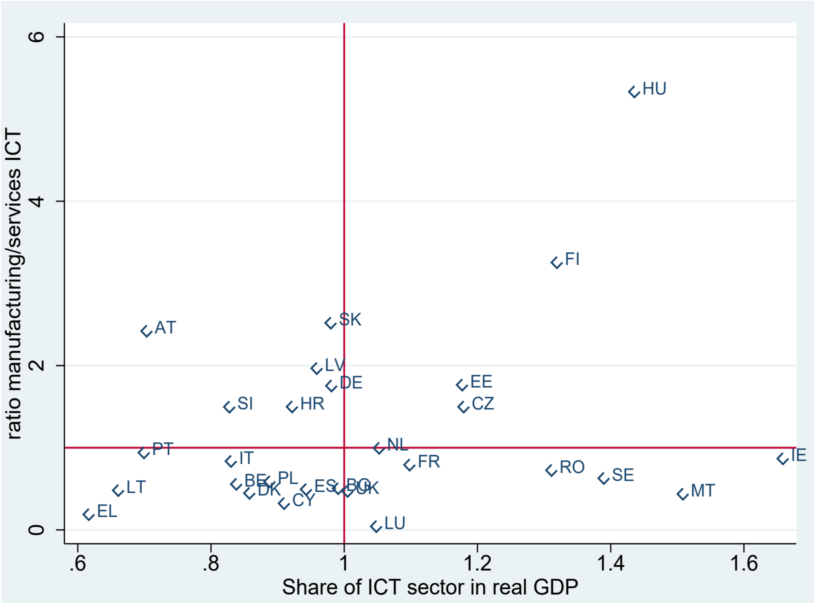
	ICT sector		ICT manufacturing		ICT services	
	2000	2018	2000	2018	2000	2018
Germany	17.0	17.4	17.9	22.0	16.8	17.0
France	13.7	12.2	9.2	7.0	15.0	12.7
Italy	11.1	9.6	8.2	10.6	11.9	9.5
United Kingdom	18.2	17.1	13.9	6.9	19.4	18.2
Other EU15	25.4	23.7	27.6	17.6	24.8	24.4
New member states	14.6	19.9	23.3	35.9	12.1	18.2

Note: Other EU15 comprises Austria, Belgium, the Netherlands, Luxembourg, Ireland, Spain, Portugal, Denmark, Sweden, Finland, Greece. New member states comprises Bulgaria, Romania, Croatia, Czechia, Slovakia, Hungary, Poland, Slovenia, Estonia, Latvia, Lithuania, Cyprus, Malta. Ireland: data for 2015-2018 extrapolated.
Sources: PREDICT dataset; authors' elaboration.

When identifying the ICT specialisation patterns within the EU, it is useful to look not only at the share of the ICT sector in the total economy but also at the relative importance of the two sub-sectors. This is done in Figure 16, which shows member states' (total) ICT sector shares (in terms of value added) relative to the EU on the horizontal axis and the ratio between the real value added generated by the ICT manufacturing sector and the ICT services sector, also relative to the corresponding ratio in the EU.

Therefore, economies that have a relatively large ICT sector are found further to the right in Figure 16. Examples would be Ireland, Sweden or Finland. The relatively high importance of the ICT sector may be due to a focus on ICT manufacturing industries, which would result in a high ICT manufacturing to services ratio and put countries at the upper part of the figure. Examples for countries with large ICT manufacturing sectors with a manufacturing focus are Hungary, Finland and Estonia. Member states with large ICT manufacturing sectors and a specialisation in ICT services (to be found on the lower right part) include Ireland, Sweden and also France. Note that three of the four largest EU economies, i.e. Germany, Italy and also the UK, do not feature particularly large ICT sectors. These specialisation patterns (or rather a lack of specialisation in ICT industries) in major economies are part of the explanation for the subdued performance of the EU in comparison with its main global competitor countries (see Section 3.4). Note also that there are some countries (e.g. Greece, Latvia, Portugal and also Austria) which risk missing the digital transformation if the size of the ICT sector can serve as an indicator for an economy's preparedness for such a transformation.

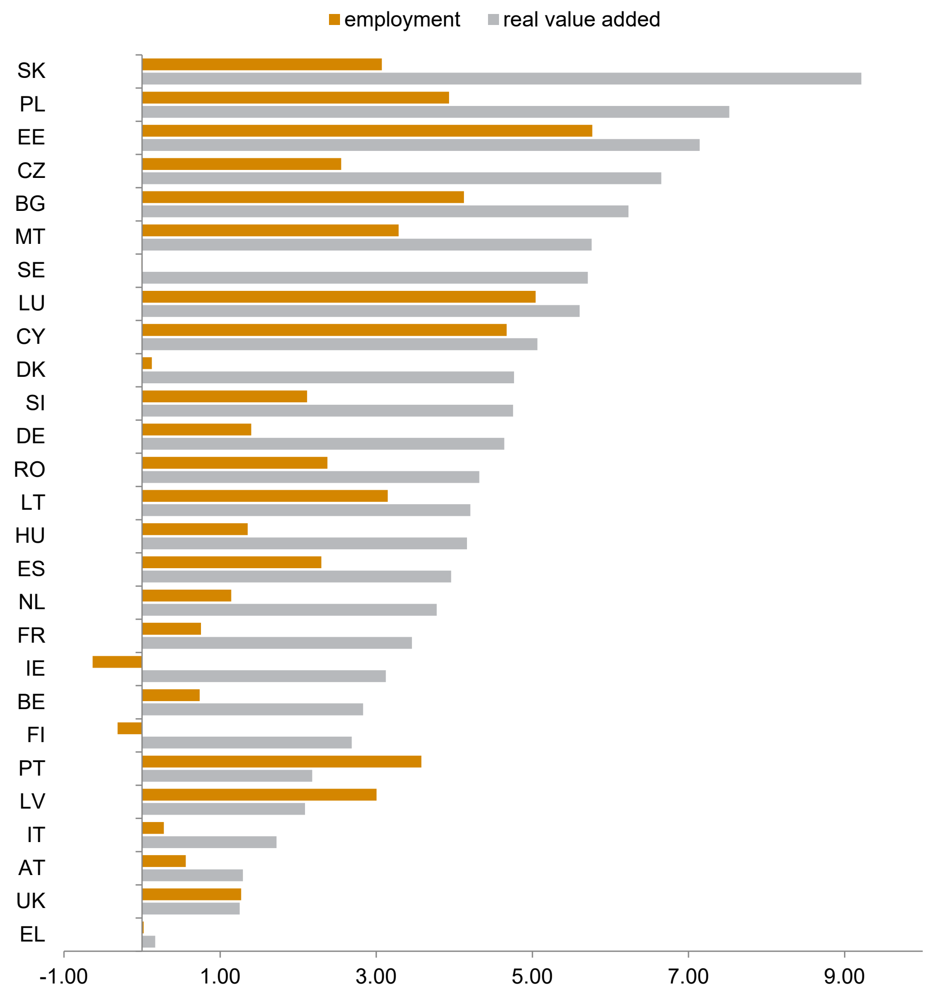
Figure 16 / Specialisations of EU member states in the ICT sector relative to the EU average, 2016



Note: Based on real value added. Share of ICT in real GDP is real value added of the ICT sector in total real value added relative to the EU. The ratio manufacturing/services is the ratio of real value added in the manufacturing ICT sector to the real value added in the services ICT sector relative to the EU. In both cases a value of 1 is equal to the EU average.
Sources: PREDICT dataset; authors' elaboration.

Turning to the growth dynamics in the ICT sector, Figure 17 shows that the EU-wide average (real value added-based) growth rate of the ICT sector (5% for the period 2000-2016) is driven mainly by the catch-up process of CEE member states plus Sweden, which is an important ICT producer country in the EU.

Figure 17 / Compound annual growth rates of the ICT sector across member states, 2000-2018

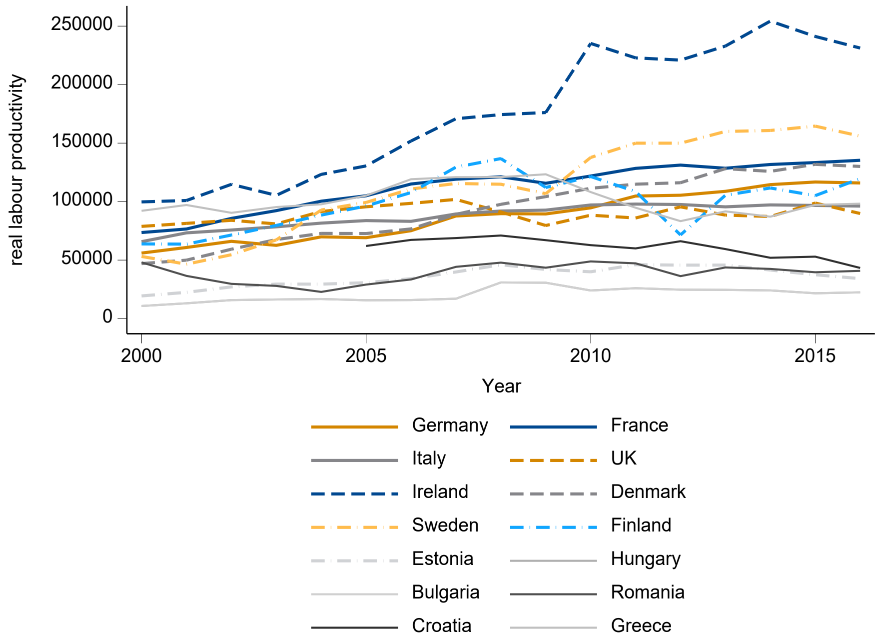


Note: Growth rates are compound annual growth rates. Real value added is calculated using country-specific (industry-level) price deflators. Services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

Reflecting the situation found for the EU as a whole, the sector's growth dynamics in terms of employment are much more moderate, especially in the EU15, which includes all major producer countries.

As mentioned earlier, the EU economy is characterised by a high degree of heterogeneity across member states, which is particularly pronounced when it comes to productivities. Figure 18 illustrates that the differentials in (real) labour productivity diverged considerably between 2000 and 2016, leading to a situation in 2016 where these productivities varied from EUR 22,456 in Bulgaria to EUR 231,300 in Ireland. This implies a productivity ratio of roughly one to ten between the member state with the lowest and the highest productivity.

Figure 18 / Real labour productivities in the ICT sector, selected EU member states, 2000-2016



Note: Based on real value added.
Sources: PREDICT dataset; authors' elaboration.

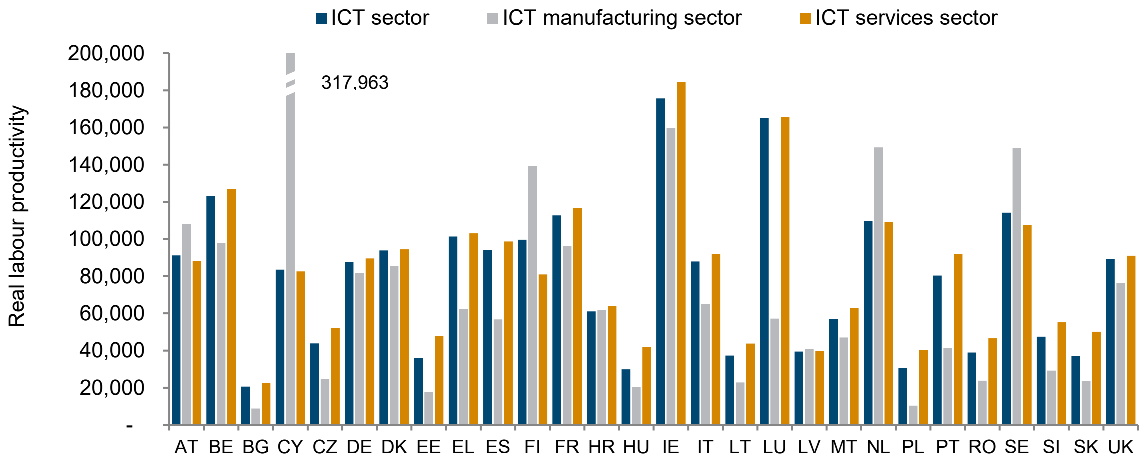
This constellation naturally has implications for EU internal cohesion on the one hand, and international competitiveness vis-à-vis major competitor countries on the other hand. With a view to cohesion, this diverging development (which is not only driven by strongly rising productivities in leading economies but also by stagnating or even declining trends, e.g. in Croatia) is hardly satisfactory and risks leaving several members states behind, if not as users of ICT goods and services, then at least as producers of ICT goods and services.

On the assumption that in all likelihood not all member states will operate at the productivity frontier, the existing differential allows at least some member states, especially Ireland and Sweden, to move closer to the productivity frontier, currently defined by the US.

The data for the ICT sub-sectors confirm the large productivity differentials (Figure 19). Interestingly, in the countries with the highest labour productivities, notably Sweden and Finland,[16] the productivity in the ICT manufacturing sector exceeds the level in the services segment. This is generally not the case in the CEE member states (e.g. Hungary, Czechia, Slovakia), not even in those countries that were identified as having comparatively large ICT sectors (e.g. Hungary). The most likely explanation for this is that firms in different countries fulfil different functions within international value chains.

[16] The situation of Ireland is different because the country's sector-level productivity is strongly influenced by US subsidiaries, which includes numerous headquarters responsible for the European market.

Figure 19 / Real labour productivity in the ICT sector and main sub-sectors, averages 2000-2016



Note: Real labour productivity is value added-based. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

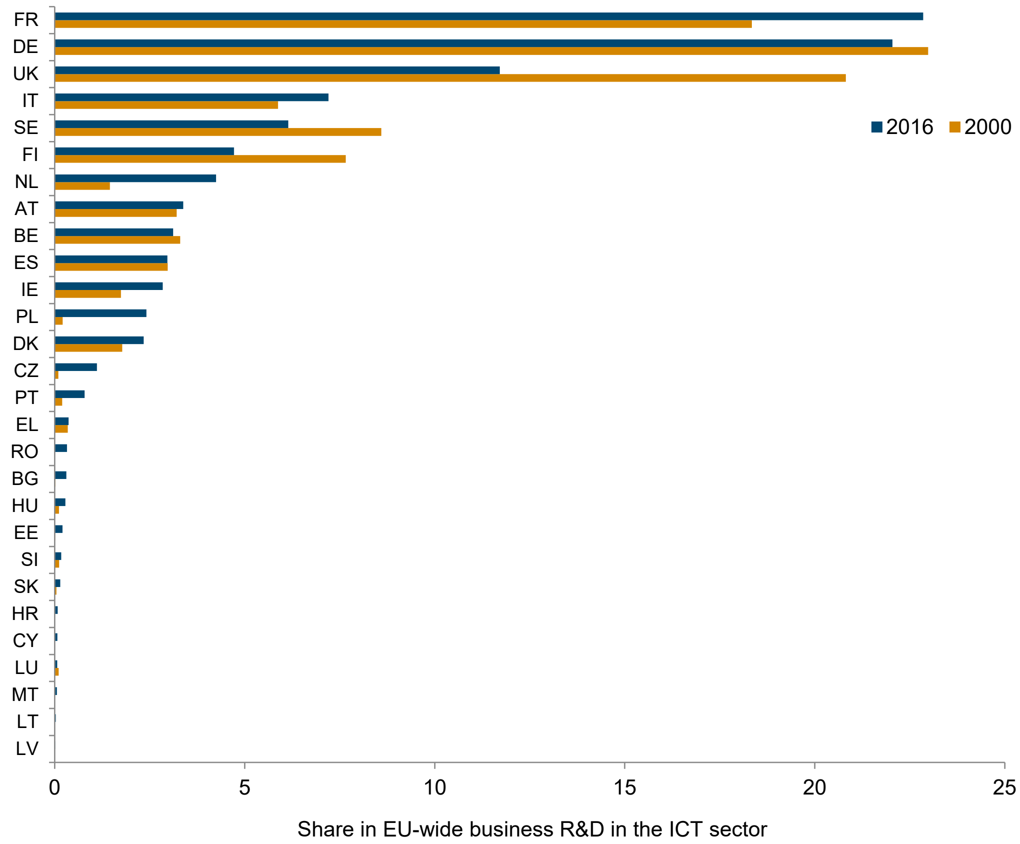
It should be noted, though, that at this level of aggregation (with broadly defined sectors) productivity differences do not translate directly into international competitiveness and world market shares (otherwise the US should hold much larger shares). Rather, these substantial productivity differences also reflect (at least partly) the fact that member states specialise in different industry niches (product specialisation) and above all in different functions within global (or regional) value chains (functional specialisation).

The different functional specialisation patterns become apparent in the data on business R&D expenditure. First, R&D tends to be even more concentrated than value added or employment, and this is also the case in the EU ICT sector (Figure 20). Germany, France, Italy and the UK accounted for 62% of the sector's expenditure on business R&D, and adding Sweden and Finland increases the share to almost three quarters in 2016.

Most importantly, CEE member states have negligible R&D shares, which points to their role as factory economies within European value chains, with the EU core countries (such as Germany or France) taking responsibility for headquarter and R&D functions (Stöllinger 2019).

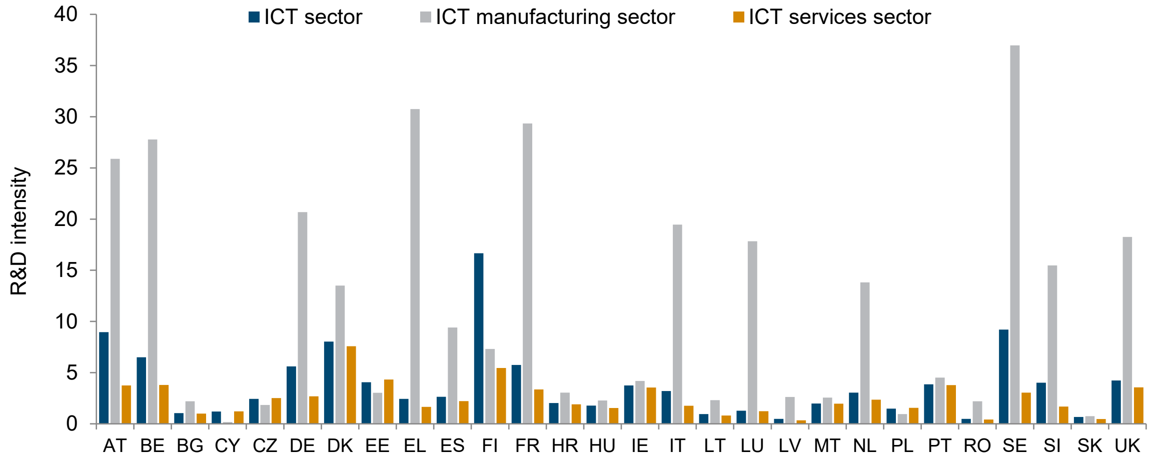
Second, there are massive differences in member states' R&D intensities in the ICT sector. The most interesting aspect of these data are the peaks in the R&D intensities in the manufacturing segment of the ICT sector, which are present in the high-productivity countries (e.g. Sweden and Finland) and the four largest EU economies, but not in the CEE member states. This confirms the assertion made above that the CEE economies – even within the ICT manufacturing sector – perform different functions than the EU15 countries.

Figure 20 / EU member states' shares in EU-wide expenditure on business R&D, 2000 and 2016



Note: Based on nominal expenditure on business R&D (BERD).
Sources: PREDICT dataset; authors' elaboration.

Figure 21 / R&D intensity in the ICT sector and main sub-sectors, averages 2000-2016



Note: R&D intensity is the share of business expenditure on R&D in value added in each country. The services sector excludes trade services industries.
Sources: PREDICT dataset; authors' elaboration.

4. ICT production from a firm-level perspective

4.1. INTRODUCTION

This section provides an overview of the supply side of ICT industries derived from firm-level data. The descriptive analysis is based on a large panel of companies around the world.

The use of ICT in production processes was a key determinant of economic growth during the second part of the twentieth century, and over the past years the ICT sector has grown at an even faster pace. The internet is an indispensable tool for business activities. The availability of devices with high computational power has led to rapid economic development in fields such as big data and artificial intelligence (AI), which are used in many other sectors of the economy. Policy makers and companies tend to pay a lot of attention to emerging technologies. It is therefore necessary to describe how ICT companies perform and produce ICT goods and services around the globe. Superstars such as Apple Inc., the Microsoft Corporation, Alphabet Inc. and AT&T are major examples of ICT firms which have grown substantially in the past decades.

The key to the success of these growing superstars has been their ability to be constantly innovative. Innovative processes allow companies to introduce new products, services and production procedures, which ultimately gives them a larger market share in the global economy (Friedrich et al., 2011). In this section we therefore also provide a snapshot of the productivity and innovative processes of firms dealing in ICT over the years in the most significant ICT-producing regions. Labour productivity and total factor productivity are the main indicators of firms' productivity. R&D expenditure as the input of innovative processes and the number of granted patents as the output of these innovative process are used as the main proxies for innovation in ICT firms. It indicates a positive relationship between the innovative process and productivity. We focus on the productivity and innovative processes of the leading ICT producers over the period 2001-2018. We use R&D expenditure as the input of the innovative process and the number of granted patents as its output. Our findings imply that policy makers should aim to improve innovative activities.

4.2. DATA

Our data are collected from the Orbis database provided by the Bureau van Dijk. It consists of 182,145 companies active in the ICT sector of 39 countries[17] in 2009-2018. A list of these countries is provided in Appendix Table A.1 in the Appendix. ICT firms are selected based on their core sector of activity, and ICT manufacturing and services sectors are borrowed from the operational definition provided by the technical report of the Joint Research Centre (JRC) of the European Commission on the 2018 PREDICT database (Benages et al., 2018). These sectors are based on the operational definition of ICT sectors that are presented in panel (b) of Table 5 in section 3 above, where we also clarify which sectors are considered 'ICT manufacturing' and which 'ICT services'.

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17 In the case of China, we exclude observations with less than 10 employees because of noisy data.

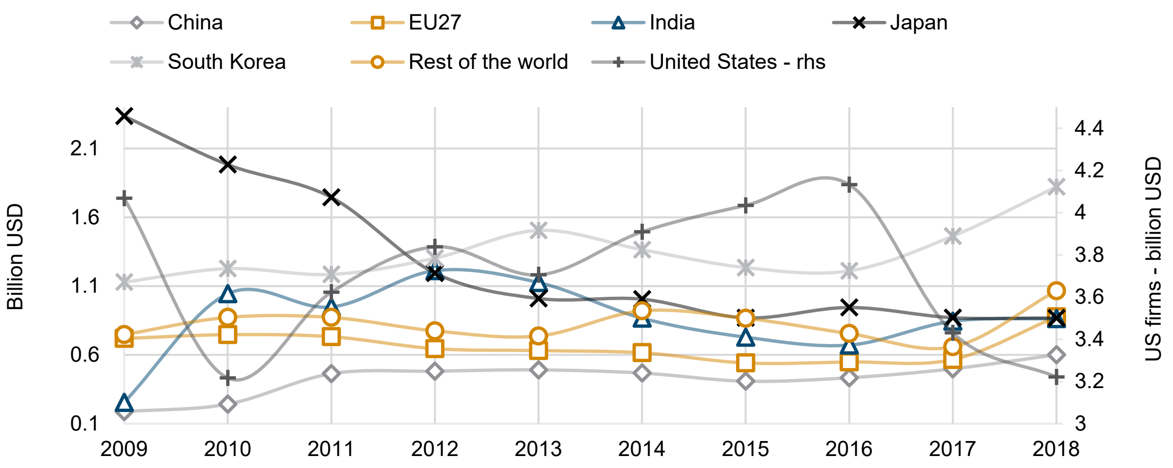
Outliers in the data are filtered by excluding extreme values using a boxplot technique. Furthermore, some firms with extremely large turnover values which list very few employees and are mostly located in China are also excluded from the analysis. We use labour productivity as a proxy for productivity, defined as the ratio of turnover to the number of employees. For ICT manufacturing sectors we also use TFP estimated using Ackerberg et al. (2015); see Appendix B for details. As mentioned above, we use R&D expenditure and the number of granted patents for the innovative process.

To make the data comparable across countries and over the years, we express them in constant 2015 US dollars using price deflators and exchange rates. The first source is the Structural Analysis (STAN) database provided by the OECD, which gathers deflators for gross output, intermediate goods and capital goods by sector of activity. Then, where the data from OECD STAN are missing, the Eurostat database is used, which provides deflators (producer price index) of capital and intermediate goods in aggregate and gross output for each sector separately. We use price deflators sourced by National Statistics, Republic of China (Taiwan) for Taiwan.[18] Exchange rates are given by Orbis.

4.3. FIRM-LEVEL COMPARISONS BETWEEN SELECTED REGIONS PRODUCING IN ICT SECTORS

Figure 22 depicts the evolution of the average turnover of each region's large ICT firms with at least 250 employees in both the manufacturing and the services sector over the period 2009-2018. Firms active in the US have much higher levels of turnover, which is on average about USD 3.7 billion and more than four times the average turnover of large ICT firms in other regions.

Figure 22 / Average turnover of large ICT firms with more than 249 employees by region in billion USD, 2009-2018

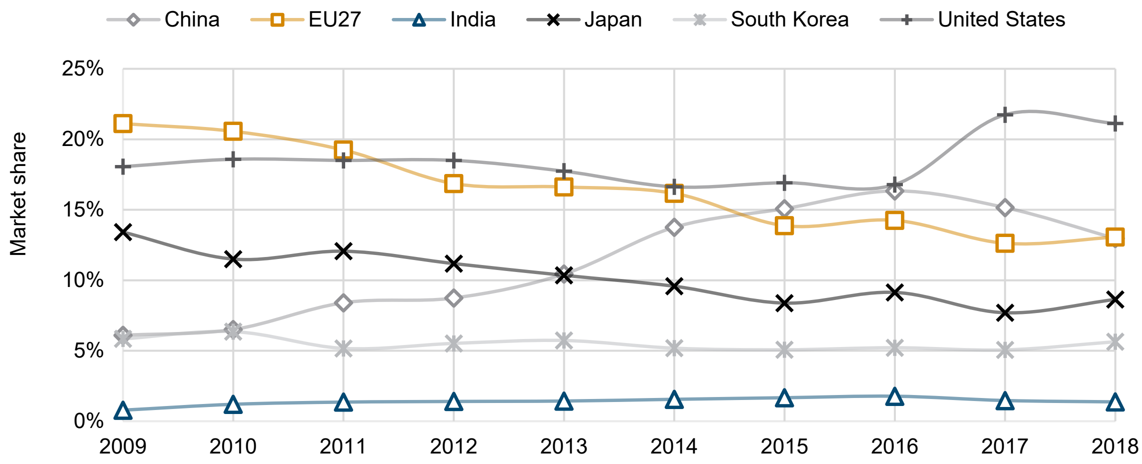


Sources: Orbis; Eurostat; OECD; authors' own elaboration.

[18] If values are missing even at aggregate levels of sectors, we elaborate using the GDP deflator (or its growth rate) sourced from the same source we use as deflators for each country.

The significant lead of US firms is also evident in Figure 23, where the aggregate market share (in terms of turnover in US dollars) of all firms located in each region is illustrated. Clearly, the US has been the market leader over past few years. However, Chinese firms have also managed to increase their global market share in the past decade, which was also evident in the aggregate data on ICT discussed in earlier chapters. The global market share of Chinese firms has increased significantly, from 6% in 2009 to 16% in 2016. However, the global market share of firms located in the EU27 has dropped significantly, from 21% in 2009 to only 13% in 2018. This may indicate a loss of competitiveness among ICT firms in the EU compared with those in China.

Figure 23 / Aggregate market share of ICT firms in six major countries over 2009-2018



Sources: Orbis; authors' own elaboration.

4.4. INNOVATIVE PERFORMANCE OF FIRMS IN ICT SECTORS

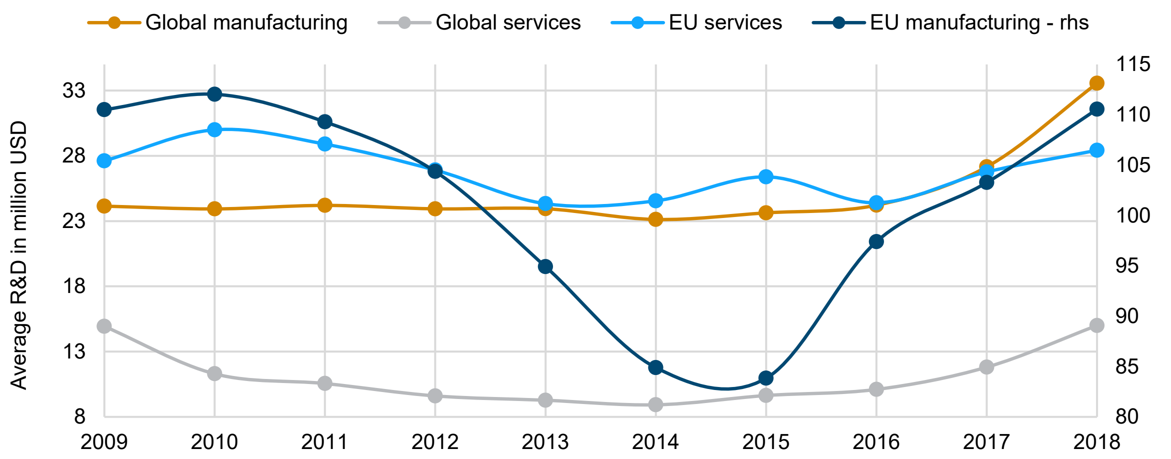
In this section we focus on the innovative performance of ICT producers. R&D encompasses all innovative activities to introduce new products, procedures or services. The costs associated with R&D activities within firms are represented as R&D expenditure in companies' financial accounting.

Figure 24 presents the average R&D expenditure for the period 2009-2018. We consider expenditure separately in ICT manufacturing and services as defined in panel (b) of Table 5 in section 3. We also compare global R&D expenditure with R&D expenditure performed. Interestingly, the average firm's R&D expenditure is higher in the EU27 countries.

Looking at R&D expenditure globally, we observe that the average firm's R&D expenditure is larger for the ICT manufacturing sector than for the services sector. Since R&D in ICT requires hardware and advanced new technologies, the average R&D expenditure in ICT is much larger in manufacturing firms than in ICT services firms. At the same time, as far as R&D in the services industries is concerned, it is possibly preferable to give more importance to complementary resources, such as managerial procedures or software, since the output is more related to intangible goods. The mean levels of R&D expenditure in both sectors are slightly below USD 35m. Overall, we observe that over the years firms tend to engage more in innovative activities.

Interestingly, the comparison between the EU27 and the global sample shows that average R&D expenditure is larger for the EU27 (Figure 24, right-hand scale). R&D expenditure is possibly concentrated among a few superstars in non-EU countries, whereas R&D expenditure in the EU is more equally dispersed among ICT firms. Furthermore, investment in R&D, which contracted until 2015, subsequently rose again, and by 2018 R&D expenditure had returned to the same high levels as those observed in the first years of our analysis.

Figure 24 / Mean R&D expenditure per year (million USD, 2015)



Sources: Orbis; authors' own elaboration.

4.5. LABOUR PRODUCTIVITY ACROSS SECTORS

In this section we analyse briefly the labour productivity of ICT firms across five large ICT-producing regions. Table 12 presents the average level of labour productivity by sector and country. Labour productivity is defined as the ratio of a firm's turnover in 2015 constant US dollars over its number of employees. We calculate the mean level for the period 2009-2018.

On average, the telecommunications sector is the most productive in the EU27, US, Japan and South Korea. The manufacturing sector performs relatively well compared with the rest of the sectors in all regions with the exception of China, which achieves high levels of labour productivity in the Software publishing and Data processing sectors. The most important reason could be the extensive economy of scale in telecommunications services, which can supply services to millions of users with ample capital and infrastructure while employing very few people, so that the capital to labour ratio for such a service sector is relatively high. Repair of computers has the lowest levels of labour productivity in the EU and China, as this service is considered to be very labour-intensive. Repairs and debugging of ICT goods and services should usually be based on labour rather than capital, although such a service may require large soft and hard ICT assets, which should be used by technicians and skilful labour on repair and maintenance. It rarely happens that debugging and repair are done automatically by an AI asset. Therefore, such a service always needs labour for maintenance, which makes it a labour-intensive sector and leads to lower labour productivity.

Table 12 / Average labour productivity across sectors (in thousand USD), 2009-2018

Sector	EU27	US	China	Japan	South Korea	India
ICT manufacturing	281.78 (65,045)	383.49 (2,537)	193.67 (30,585)	319.39 (9,799)	343.66 (19,269)	176.43 (81)
Software publishing	398.04 (31,223)	288.43 (1,119)	408.68 (2,341)	142.95 (33,098)	168.86 (22,966)	60.29 (6)
Telecommunications	501.54 (63,321)	581.42 (528)	338.04 (1,099)	411.61 (1,676)	522.45 (1,487)	98.62 (7)
Computer programming, consultancy and related activities	171.51 (488,402)	384.08 (986)	141.91 (2,875)	291.64 (2,461)	258.73 (5,013)	127.53 (91)
Data processing, hosting and related activities; web portals	114.69 (137,147)	320.76 (260)	1327.58 (154)	180.76 (1,544)	232.24 (1,692)	870.21 (2)
Repair of computers and communication equipment	94.28 (39,789)	- (0)	128.53 (19)	215.07 (327)	201.29 (348)	97.73 (1)

Note: Number of observations in parentheses. Source: Orbis, Eurostat, OECD; authors' own elaboration.

4.6. TOTAL FACTOR PRODUCTIVITY OF MANUFACTURING FIRMS

The ICT manufacturing sector is typically a capital-intensive sector. Therefore, measuring a firm's efficiency through labour productivity may be misleading. TFP is an index which takes capital stock, labour and intermediate inputs into account as inputs of a production process that yields a composite product (goods or service). Hence TFP is often considered to be a more accurate way to measure productivity and efficiency of firms to convert inputs of production into outputs (Hulten, 2001; Katayama et al., 2009; Van Beveren, 2012). To this end, we estimate TFP using the framework developed by Ackerberg et al. (2015). The appendix at the end of this report provides more information on the estimation of TFP. We estimate a 'gross output'-based production function, using turnover as the dependent variable.

Table 13 presents the mean and standard deviation of TFP (in logarithmic terms) of all ICT firms within selected countries for the period 2009-2018 separately. In that way, we select years after the financial crisis.

Within the EU27, the countries of Central and Northern Europe are the leaders (Luxembourg, Ireland, Austria, Belgium and Germany) with the highest average TFP, which indicates the efficiency of the ICT manufacturing firms located in these countries, while the least productive countries are located in the eastern and southern parts of Europe (Latvia, Croatia, Lithuania, Malta and Greece). This indicates a possible regional pattern, suggesting that Western Europe is typically more efficient than the Southeast.

On average, the US appears to be the most productive region in the sample, followed by the EU27 and India. In the latter case, however, one should consider the small number of observations, which may affect the interpretation of our results. The lowest level of TFP is recorded in China. The very large average TFP for Indian firms may be because our sample consists of a selection of the largest and most productive firms, whose financial data are fully reported to the Indian authorities and are also available in Orbis.

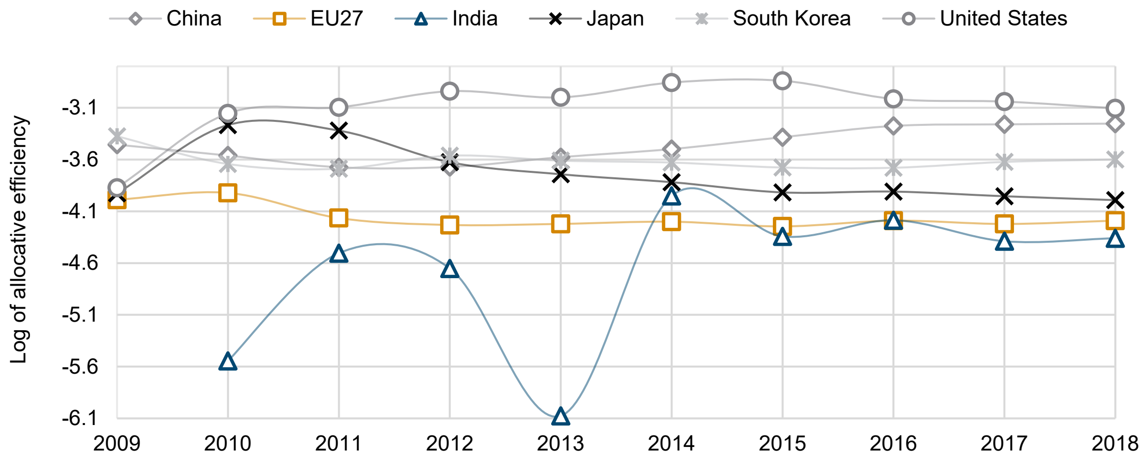
Table 13 / TFP across EU27 countries and aggregate regions, 2009-2018

Country	Mean TFP	Standard deviation TFP	Number of observations
Austria	4.939	0.81	183
Belgium	4.929	0.48	670
Bulgaria	4.366	0.97	1545
Czechia	4.194	0.57	2684
Germany	4.901	0.62	2410
Denmark	4.492	0.32	78
Spain	4.313	0.59	6512
Finland	4.693	0.80	1172
France	4.806	0.67	3739
Greece	4.106	0.49	394
Croatia	3.915	0.49	2361
Hungary	4.514	0.82	980
Ireland	4.964	0.69	442
Italy	4.835	0.84	18498
Lithuania	4.082	0.41	214
Luxembourg	5.258	0.65	20
Latvia	3.547	0.76	729
Malta	4.098	0.38	33
Netherlands	4.835	0.48	238
Poland	4.393	0.58	999
Portugal	4.379	0.61	896
Romania	4.164	0.89	2982
Sweden	4.544	0.57	2729
Slovenia	4.477	0.59	1102
Slovakia	4.322	0.58	1251
EU27	4.562	0.80	52861
US	4.667	0.50	2332
China	4.037	0.43	30029
Japan	4.277	0.46	9194
South Korea	4.200	0.40	18422
India	4.540	1.05	72

Source: Orbis, OECD, Eurostat; authors' own elaboration.

In addition to the average TFP, we can also report how productive firms evolved over time by calculating their allocative efficiency. Figure 25 presents the evolution of simple average TFP and the allocative efficiency for each region. We calculate 'capital-based' allocative efficiency following Olley and Pakes (1996) as the log difference between the capital-weighted mean of TFP and the unweighted mean of TFP of all firms in the ICT manufacturing sector. When allocative efficiency increases over time, it indicates that more capital is allocated to more productive firms (Force, 2014). In all regions, capital stock is allocated to less productive firms as the log difference between the capital-weighted TFP and the simple average TFP is negative, which indicates some inefficiency within sectors. The lowest misallocation of capital stock is observed in the US.

Figure 25 / Evolution of the of TFP (in logarithms) and allocative efficiency of ICT manufacturing firms, 2009-2018



Sources: Orbis; OECD; Eurostat; authors' own elaboration

4.7. TOP FIVE ICT PRODUCERS – GLOBAL VERSUS EU27

Based on past studies that analyse the leading companies in the digital economy (Acker et al., 2016; 2012; Friedrich et al., 2011), this section provides a brief analysis of superstar ICT firms. Table 14 illustrates the top five largest companies in each two-digit sector for the year 2016 in terms of their total turnover in US dollars. The table presents each firm's market share in terms of its turnover, capital and labour relative to market aggregates and also its profit margin. The last two columns also illustrate the sum of R&D expenditure based on previous-year prices and the number of patents owned by companies that are also granted by the official patent offices.

In the ICT manufacturing sector (manufacture of computer, electronic and optical products), superstar firms come from the US, South Korea, China and Japan. Interestingly, their labour share in the sector is comparatively low relative to their revenue and capital share. This indicates that these firms produce more because they are more capital-intensive and enjoy economies of scale. As expected, they have a large positive profit margin. Moreover, they invest heavily in R&D, which is why they own many granted patents that were published in 2016. This indicates not only that they care about producing new technologies to stay competitive in the sector, but also that they protect their technologies through intellectual property rights by investing in resources to obtain grants for their novel technologies.

Regarding the ICT services sectors, innovation activity appears to be lower than in ICT manufacturing in most cases, both in terms of R&D expenditure and in the amount of granted patents. As expected, superstar firms such as Apple, Samsung Electronics, Alphabet, AT&T and Microsoft seem to dominate each sector's market. Most of the top leading firms in each sector are located in the US, except for the sector Repair of computers and personal and household goods, as no firm-level data are available for the US in this sector, in which the top five firms are based in the Netherlands, the UK, France and Russia.

Table 14 / Top five companies in terms of turnover by sector in 2016 in global ICT manufacturing and services sectors

Company	Country	Revenue share (%)	Capital share (%)	Labour share (%)	Profit Margin (%)	R&D expenditure (billion, USD 2015)	Patents
Manufacture of computer, electronic and optical products							
Apple Inc.	United States	6.90	11.56	1.12	28.46	9.94	4309
Samsung Electronics Co.,Ltd.	South Korea	3.55	4.67	0.90	13.11	10.91	19845
Hon hai Precision Industry Co., Ltd.	Taiwan	3.27	2.08	0.07	4.76	0.95	10477
Huawei Technologies Co., Ltd.	China	2.22	0.65	1.36	6.71	-	1501
Intel Corp	United States	1.90	4.19	1.03	21.78	12.55	6099
Publishing activities							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**R&D expenditure (billion, USD 2015)**	**Patents**
Microsoft Corporation	United States	18.63	15.40	6.39	28.13	11.86	259
Oracle Corp	United States	7.57	13.70	7.62	30.89	5.73	1696
SAP S.E.	Germany	2.97	8.02	0.79	22.88	3.27	810
IBM Japan, Ltd.	Japan	1.55	0.38	0.90	9.79	-	0
VMware, Inc.	United States	1.45	1.80	1.12	21.25	1.49	55
Telecommunications							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**R&D expenditure (billion, USD 2015)**	**Patents**
AT&T Inc.	United States	9.47	10.22	5.40	12.10	1.63	399
Verizon Communications Inc.	United States	7.28	6.09	3.24	16.66	-	435
China Mobile Ltd.	China	5.91	3.76	9.93	-	-	0
Comcast Corporation	United States	4.67	4.59	3.20	17.74	-	404
Vodafone Group Public Limited Company	United Kingdom	3.68	4.36	2.25	-1.18	0	150

cond.

Table 14 / Continued

Company	Country	Revenue share (%)	Capital share (%)	Labour share (%)	Profit Margin (%)	R&D expenditure (billion, USD 2015)	Patents
Computer programming, consultancy and related activities							
Alphabet Inc.	United States	8.89	8.30	1.73	26.75	13.80	7896
International Business Machines Corp.	United States	7.87	9.84	9.15	15.43	5.67	685
Google Ireland Limited	Ireland	2.73	0.14	0.07	5.12	-	0
Facebook, Inc.	United States	2.72	4.09	0.41	45.29	5.86	51
Cognizant Technology Solutions Corp.	United States	1.33	0.76	6.26	17.48	-	13
Information service activities							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**Total R&D expenditure (billion, USD 2015)**	**Patents**
Automatic Data Processing Inc.	United States	9.04	3.78	9.22	19.15	0.60	0
First Data Corporation	United States	8.97	20.76	3.88	4.15	-	8
Booking.com B.V.	Netherlands	5.82	1.90	0.26	40.33	-	0
Alliance Data Systems Corp	United States	5.53	5.38	2.75	11.73	-	2
Fiserv Inc	United States	4.26	7.27	3.72	23.16	-	43
Repair of computers and personal and household goods							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin**	**Total R&D expenditure (billion, USD 2015)**	**Patents**
Oranjewoud N.V.	Netherlands	12.91	11.12	4.98	0.93	0.00	2
Fujitsu Services Limited	United Kingdom	12.15	31.40	5.34	5.27	0.01	0
Computacenter (UK) Limited	United Kingdom	8.80	3.38	2.27	4.19	-	0
Hewlett-Packard Centre de Competences France	France	4.21	1.63	0.60	1.88	-	0
Huawei Technologies Co.Ltd	Russia	3.16	1.06	23.66	-8.59	-	0

Source: Orbis, OECD, Eurostat, World Bank, National Statistics Rep. of China; authors' own elaboration.

Table 15 illustrates the top five firms by sector within the EU27, while the shares presented in the columns are the global shares in turnover, capital and employment. Excluded from this table are EU27 firms that are already included in the global top five firms presented in Table 14. Irish-based firms dominate the manufacturing industry, followed by firms based in the Netherlands. In the sectors of Publishing activities, Computer programming and Information services the list of countries in which the respective firms are based is more varied, since all top five firms are located in five different countries. Two of the five firms in the telecommunications sector are located in the Netherlands and another two in France, while one firm is based in Italy. France dominates the sector Repair of computers.

Comparing the top EU27 producers with global superstars, one can observe that the five largest firms in the world in terms of turnover have much larger revenue, capital and labour shares in the global market. Moreover, the innovation activity of the top five EU firms is not as intensive as that of the top five firms in the world, which suggests that the European superstars are less innovative and consequently less competitive than the non-EU top producers in a given ICT sector.

Table 15 / Top five companies in terms of turnover by sector in 2016 in ICT manufacturing and services sectors of EU27 countries.

Manufacture of computer, electronic and optical products							
Company	**Country**	**Revenue share (%)**	**Capital share(%)**	**Labour share(%)**	**Profit Margin (%)**	**R&D expenditure (billion, USD 2015)**	**Patents**
Microsoft Ireland Operations Limited	Ireland	0.687	0.093	0.008	5.100	-	2
Seagate Technology Public Limited Company	Ireland	0.357	0.254	0.441	2.460	1.225	13
Oracle Emea Limited	Ireland	0.313	0.087	0.014	-0.120	-	0
NXP Semiconductors N.V.	Netherlands	0.304	1.103	0.392	-1.755	1.060	20
ASML Holding N.V.	Netherlands	0.235	0.580	0.161	28.795	0.693	66
Publishing activities							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**R&D expenditure (billion, USD 2015)**	**Patents**
Wolters Kluwer N.V.	Netherlands	0.926	1.919	1.060	15.260	0.398	0
Tieto Oyj	Finland	0.325	0.183	0.778	9.065	0.082	0
NCR Global Solutions Limited	Ireland	0.277	0.000	0.002	5.090	-	0
Oracle France	France	0.232	0.006	0.105	2.400	-	0
Logwin A.G.	Luxembourg	0.214	0.037	0.233	3.385	0.000	0
Telecommunications							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**R&D expenditure (billion, USD 2015)**	**Patents**
Huawei Technologies Cooperatief U.A.	Netherlands	1.788	0.054	0.001	2.280	-	667
Orange	France	1.609	2.343	1.537	8.635	0.000	150
Altice Europe N.V.	Netherlands	1.265	2.143	1.001	-9.825	0.000	2
Telecom Italia S.P.A.	Italy	0.876	1.563	0.868	14.563	1.862	80
Societe Francaise du Radiotelephone - SFR	France	0.607	0.425	0.136	6.520	-	7

contd.

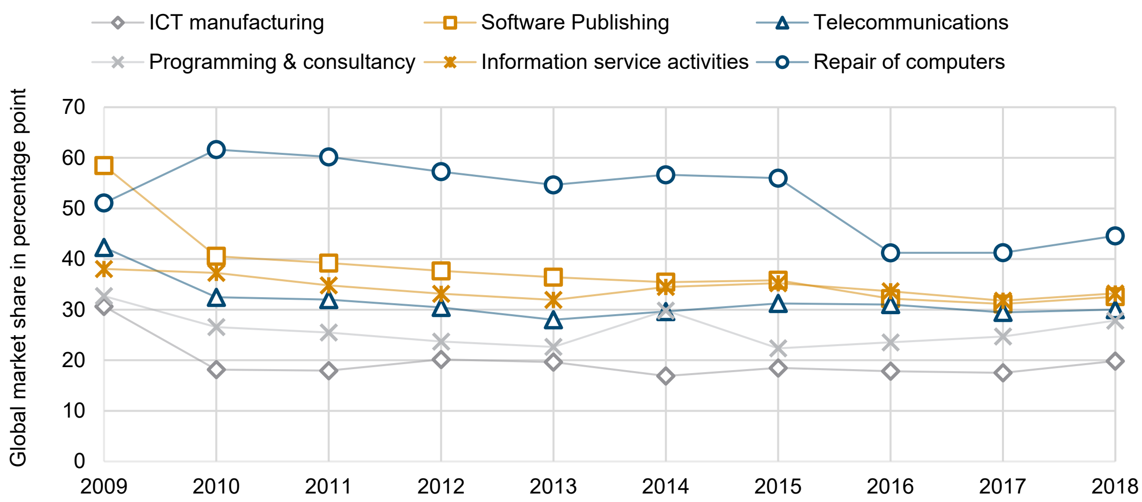
Table 15 / Continued

Company	Country	Revenue share (%)	Capital share (%)	Labour share (%)	Profit Margin (%)	R&D expenditure (billion, USD 2015)	Patents
Computer programming, consultancy and related activities							
Facebook Ireland Limited	Ireland	1.308	0.028	0.018	1.380	-	0
Ericsson AB	Sweden	1.191	0.451	0.413	-4.130	3.891	30
Amadeus IT Group, S.A.	Spain	0.412	0.656	0.020	25.570	0.317	65
Intel Deutschland GMBH	Germany	0.325	0.064	0.077	1.870	-	6
Gemalto N.V.	Netherlands	0.324	0.378	-	9.390	0.197	124
Information service activities							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**R&D expenditure (billion, USD 2015)**	**Patents**
Spotify AB	Sweden	2.113	0.710	0.146	-2.660	-	25
Snaitech S.P.A.	Italy	0.722	0.571	0.121	-3.953	0.000	0
Sgarik SAS	France	0.671	0.030	0.011	2.040	-	0
Geoquest Systems B.V.	Netherlands	0.663	4.296	0.002	0.340	-	28
International Business Machines of Belgium	Belgium	0.468	0.265	0.226	-8.930	-	0
Repair of computers and personal and household goods							
Company	**Country**	**Revenue share (%)**	**Capital share (%)**	**Labour share (%)**	**Profit Margin (%)**	**Total R&D expenditure (billion, USD 2015)**	**Total patents**
Xerox	France	2.68	9.04	0.35	6.72	-	0
Konica Minolta Business Solutions France	France	2.32	3.81	0.66	1.18	-	0
Fujitsu Technology Solutions	France	1.16	0.49	0.24	-0.91	-	0
Diebold Nixdorf	France	1.02	0.39	0.17	3.17	-	0
NCR France	France	0.85	0.19	0.22	2.49	-	0

Sources: Orbis; OECD; Eurostat; authors' own elaboration.

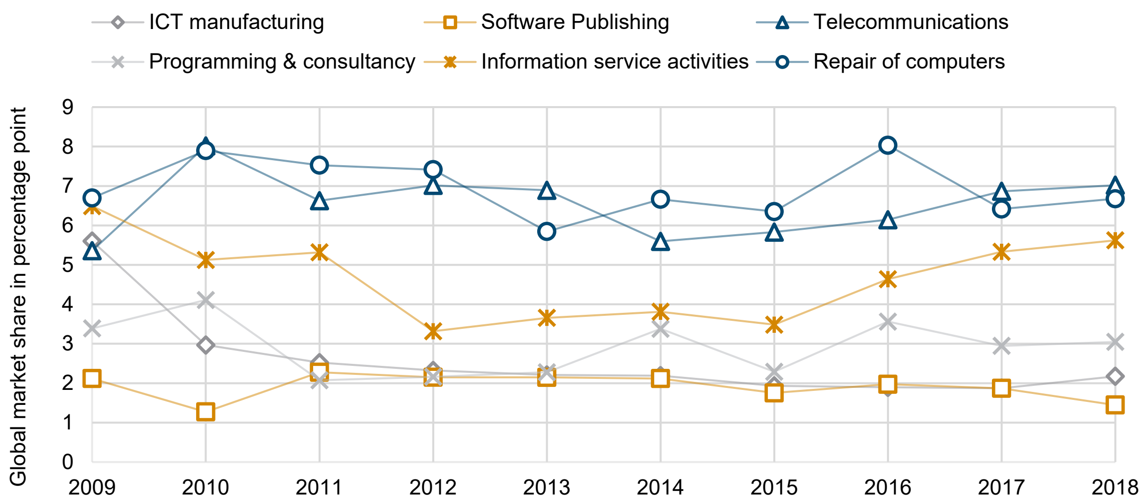
Figure 26 depicts the percentage of aggregate market shares in terms of turnover of the top five global ICT producers by sector and year over the period 2009-2018. A lower market share of the top five at the end of the period for all these sectors compared with the beginning of the period is evident. This is mostly due to the rise of newly established firms in each global sector. The largest decline in market share is visible for the top five firms in Software publishing services, where their market share declined from 58% in 2009 to 33% in 2018.

Figure 26 / Aggregate market share of top five ICT firms in each sector, during 2009-2018



Sources: Orbis; OECD; Eurostat; National Statistics Rep. of China; authors' own elaboration.

Figure 27 / Aggregate market share of top five ICT producers by sector, EU27



Sources: Orbis; OECD; Eurostat; authors' own elaboration.

For a comparison between the top five producers in the world and those in the EU27, see Figure 27, where results for the top five firms in the EU27 are illustrated. Again, we exclude any EU27 firm that is classified as a top five firm globally. As expected, aggregate market shares of these firms are much smaller than the market share of the top five global producers of ICT. However, the market share of the top five producers in the EU27 is more stable over the period. The top five EU27 manufacturers have suffered the steepest loss in their market share with a decline from 5.6% in 2009 to 2.2% in 2018.

5. Trade in ICT goods

5.1. INTRODUCTION

While it seems that only a few advanced economies are producers of ICT goods, other countries in the world are major users demanding and importing ICT goods. By analysing the bilateral trade flows of ICT goods, the supply (or producer) side of ICT goods is linked to the demand (or user) side. Furthermore, trade policy measures play an important role in the development of bilateral trade flows. In this section we provide a descriptive analysis of tariffs and various types of non-tariff measures (NTMs) imposed on the global bilateral trade flows of ICT goods. Technical barriers to trade (TBTs) from two sources – the WTO and UNCTAD – are used to provide a comprehensive analysis of the trade policies targeting ICT goods. We will focus on how the EU27 differs from other countries in the world in terms of imports, exports and trade policy measures.

Global production structures in the ICT industry have implications for the trade in ICT products too. The liberalisation of trade and the globalisation process have led to the fragmentation of production across the world. US producers of ICT have established their manufacturing lines in countries with lower costs of production factors, such as the South and East Asian economies. This has led to rapid employment growth among technicians and low-skilled workers and gross output growth in China, South and East Asia, and some East European countries. In the meantime, since the conclusion of the Information Technology Agreement by the members of the WTO in December 1996, tariffs levied on the import of ICT goods have been reduced substantially. However, the use of regulatory NTMs, which adjust the standards and regulations in the importing product market, has been on the rise. These developments mean that the global value chains for the production of ICT goods are more closely intertwined than ever before. The production process of an ICT product is spread over numerous countries, and values are added in several stages of production while crossing several borders via trade. For instance, semiconductors are major intermediate inputs that are used not only in the production of final ICT goods but also of many other products, such as automobiles and machinery, for example. As these semiconductors are produced in only a few countries hosting superstar ICT firms, the border closures caused by the COVID-19 pandemic have resulted in the recent shortage of semiconductors, illustrating the importance of smooth and frictionless trade in ICT goods.

While middle-income trap countries are feeling the slowdown in economic growth, the US superstars have been gaining in value by utilising their productive capacities, thus pushing the technology even further. As also discussed in the previous chapter, the major value added in the sector is still produced in the company headquarters in the US, where R&D expenditures are spent on facilitating the innovation process by high-skilled scientists stimulating the technological advancements in the sector. This is often reflected in the registration of new patents, which may be sold or transferred as intangible assets to the subsidiaries to maintain the level of competitive innovation and produce new products with new procedures.

In this chapter we provide a comprehensive descriptive analysis of the development of trade in ICT goods and the trade policy measures imposed at a detailed product level. In doing so, careful distinctions are made between trade in intermediate goods (e.g. Electronic components or semiconductors), capital goods (e.g. computers) and final consumption goods (e.g. consumer electronics). UNCTAD has recently classified ICT goods in its Harmonised System (HS) revision 2012.[19] These goods are classified in five broad categories: Computers and peripheral equipment, Communication equipment, Consumer electronic equipment, Electronic components, and Miscellaneous. To ensure accuracy regarding the exports of ICT goods using this UNCTAD classification, one can use the trade data starting from 2012, as concordance tables from HS 2012 to earlier HS revisions (e.g. HS 1996) do not give a one-to-one product for these ICT goods.

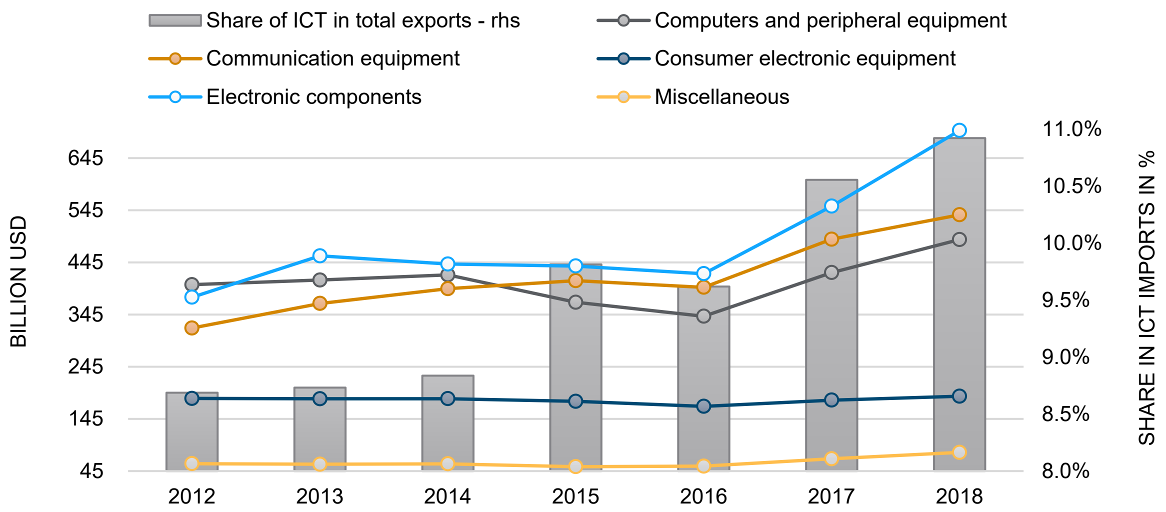
The global demand for digitalisation has been the main driver of trade in ICT goods. Figure 28 depicts the worldwide exports of ICT goods in US dollars by five product categories and the share of ICT exports in total exports over the period 2012–2018. In 2018 exports of ICT goods stood at about USD 2trn, which marks a 50% increase since 2012, whereas growth in total global exports during these seven years was only 18%. Thus, the share of ICT in total exports increased from 8.7% in 2012 to 10.9% in 2018, which is depicted in the right-hand-side (rhs) axis in Figure 28. However, corresponding the HS codes of these ICT goods from revision 2012 to revision 2000, UNCTAD shows that the share of exports of ICT in total exports at the time of the dot-com boom in 2000 was at its highest level of 16.1%.[20]

As illustrated in Figure 28, the largest category of exports in ICT are Electronic components, whose share in total ICT exports rose from 28% in 2012 to 35% in 2018. Electronic components are intermediate inputs, such as technologically advanced semiconductors, which are used in many other ICT goods and sectors. The second major category in ICT exports is Communication equipment, which accounted for around 27% of ICT exports in 2018. Sensitive and political issues surrounding the production of this communication equipment, and the need to maintain privacy and security despite the surveillance of these products by giant Chinese tech firms such as Huawei and ZTE and US tech producers such as Apple or Google, have become a challenging obstacle on the path of China-US diplomacy (Segal, 2018). The third major category of exports relates to Computers and peripheral equipment. Total exports of this important ICT capital grew from USD 402bn in 2012 to USD 489bn in 2018. However, its share in total ICT exports declined from 30% to 24% over the same period. This decline could be the result of the digitalisation era, which started at the beginning of this century with a large initial investment in these goods by households and businesses and has gradually become a steady investment in US dollar terms. Consumer electronic equipment is the next important category of ICT exports and covers various electric appliances, such as headphones, radio, video cameras and monitors. Total exports of these products almost stagnated during the period of analysis, whereas its share in total ICT exports dropped from 14% in 2012 to only 9% in 2018. The smallest category of ICT exports is Miscellaneous, whose share in total ICT exports has been hovering around 4% during the period of analysis. For instance, solid-state, non-volatile data storage, which is usually referred to as the read-only memory (ROM) of a computer, is one of the few products in this category. Lasers, aerials and media for sound recording are other products in this category.

19 https://unctadstat.unctad.org/EN/Classifications/DimHS2012Products_Ict_Hierarchy.pdf

20 https://unctad.org/en/pages/newsdetails.aspx?OriginalVersionID=2007&Sitemap_x0020_Taxonomy=UNCTAD%20Home

Figure 28 / Worldwide exports of ICT goods, billion USD by product category; share in total exports, 2012–2018



Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

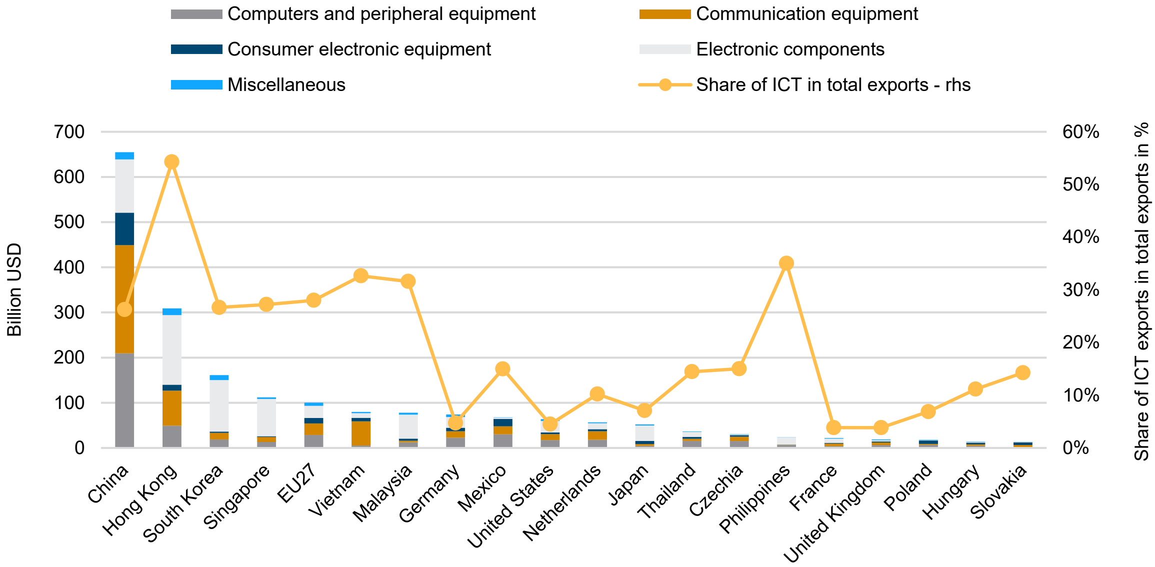
5.2. GEOGRAPHICAL PATTERNS

5.2.1. Main exporters

In the next section we investigate the geographical distribution of the 20 top exporters of ICT goods. In Figure 29 we see that Asian countries are indeed the major exporters of these products. As mentioned above, the large inflows of FDI into Southeast Asia led to the establishment of large producers of high-tech ICT products. China was the top exporter with ICT goods worth USD 655bn in 2018, which was around 26% of its total goods exports. As Figure 30 illustrates, 37% of these Chinese ICT exports consisted of Communication equipment, 32% of Computers and peripheral equipment, 18% of Electronic components, 11% of Consumer electronic equipment and 2% of Miscellaneous. This highlights just how diversified China is in the production of these goods.

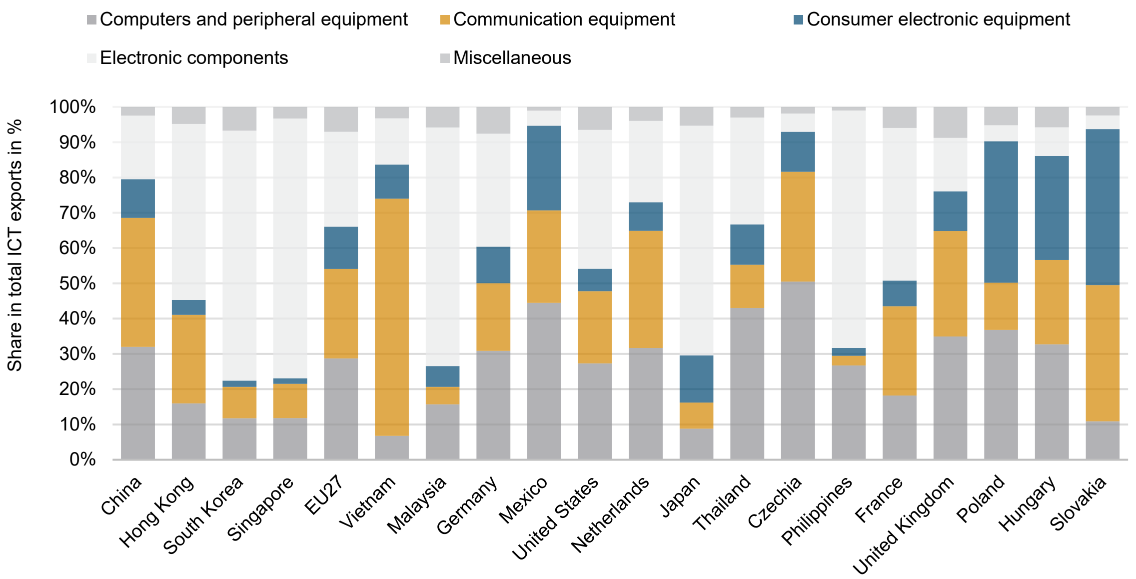
The EU27 as a whole exported ICT goods worth about USD 100bn in 2018, ranking it only fifth among the largest exporter of these goods after China, Hong Kong, South Korea and Singapore. It is important to note that this figure excludes intra-EU trade; if intra-EU trade is included, the EU27 is ranked third after Hong Kong. Only about 28% of the EU's total goods exports consist of ICT exports, which reveals a much weaker comparative advantage with respect to other Asian top exporters, namely Hong Kong with a 54% share of ICT exports in total exports, Vietnam with 33% and Malaysia with 32%. However, as Figure 30 shows, exports of ICT goods from the EU27 are also more diversified across the four main categories. By looking at the distribution of export categories among the member states, Figure 30 indicates that exports of ICT are quite diversified among the EU economies, whereas Asian countries specialise mostly in exports of Electronic components. Exports of Electronic components account for 74% and 71% of total ICT exports from Singapore and South Korea, respectively. This shows that Southeast Asian countries have a comparative advantage in supplying these technologically advanced intermediate inputs to the global factory of ICT goods. As these countries are geographically distant from the EU and the US, the COVID-19 pandemic has caused severe disruptions to the supply of these crucial components.

Figure 29 / Top 20 exporters of ICT goods, billion USD by product category; share of ICT exports in total exports, 2018



Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

Figure 30 / Diversification of exports of ICT goods by categories of 20 top exporters in 2018



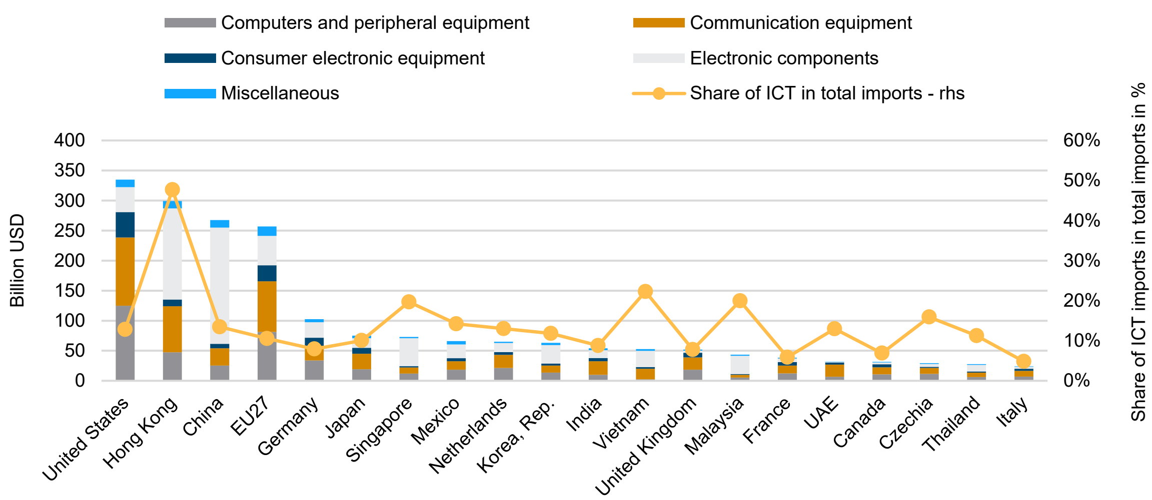
Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

5.2.2. Main importers

While the data on the top exporters tell us where the ICT goods are produced, data on the top importers indicate the utilisation of ICT goods on the demand side. The Top 20 importers of ICT goods according to their imports in each product category and the share of ICT imports in their total imports are presented in Figure 31. The US as the top importer accounted for ICT goods worth USD 335bn in 2018, which equates to about 13% of total US goods imports. Figure 32 shows that 37% of these imports consisted of Computers and peripheral equipment, followed by Communication equipment with 34%. Assembly lines of Apple products such as iPhones, iPads and MacBooks in China and East Asia are prime examples of the type of products that reflect the large imports of ICT goods into the US, especially from the leading category of Computers and peripheral equipment.

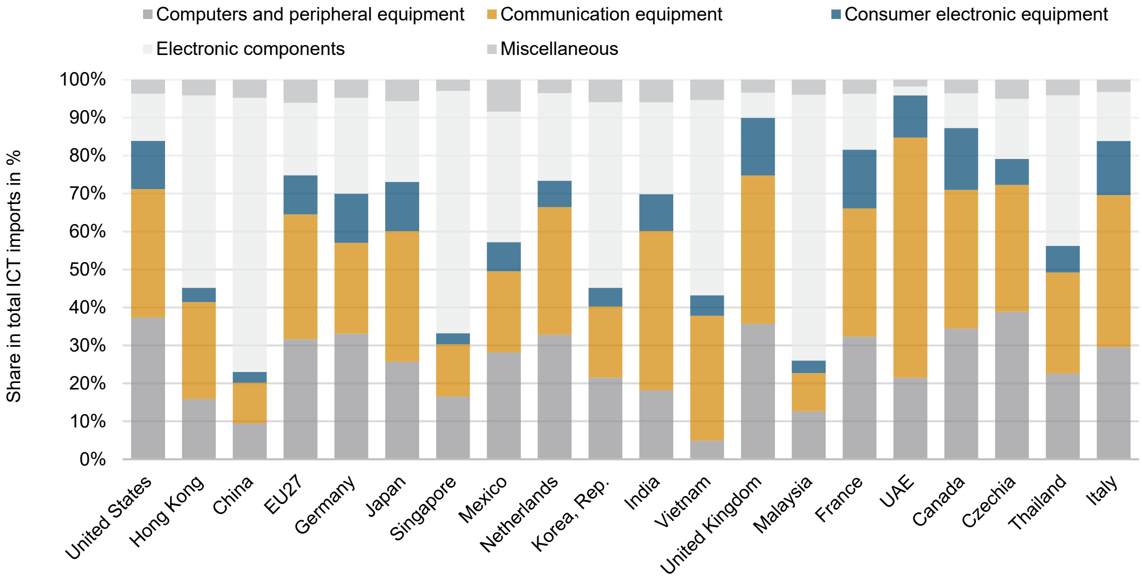
As the second-largest importer, Hong Kong's imports of ICT goods in 2018 made up about 48% of its total imports and were worth USD 299bn. It is evident that Hong Kong is a major factory of ICT goods, as half of its imports and exports consist entirely of ICT goods and its total trade in ICT goods accounted for about 170% of its GDP in 2018. China is the third-largest importer of ICT goods with USD 268bn, which corresponds to about 13% of its total imports. The most interesting fact about Chinese trade in ICT goods is that 72% of its imports consist of Electronic components, while imports of Communication equipment and Computers and peripheral equipment account for 11% and 9%, respectively. Again, this points to the importance of China as a global factory of ICT goods at the centre of global value chains. In fact, China imports major intermediate inputs in the form of Electronic components from other producers such as South Korea, Singapore and Japan in Southeast Asia and from advanced economies such as the US and the EU. These inputs are then assembled and turned into ICT final goods, which adds value to them and makes China the major exporter of ICT goods. It is worth mentioning that during the US-China trade war and after the sanctioning of ZTE by the US administration in April 2018 the Chinese company was forced to cease some of its major production operations due to the lack of supply of microchips from US producers.

Figure 31 / Top 20 importers of ICT goods, billion USD by product category; and share of ICT imports in total imports, 2018



WITS; COMTRADE; UNCTAD; authors' elaboration.

Figure 32 / Diversification of imports of ICT goods by categories, of 20 top importers in 2018



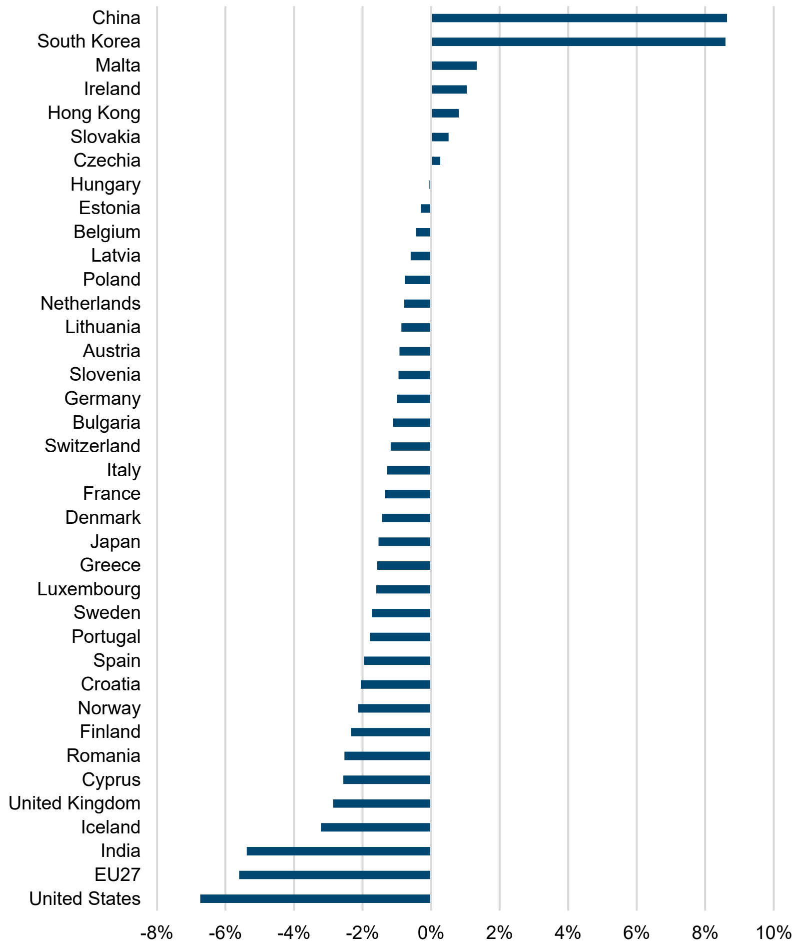
Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

The EU27 is the fourth-largest importer of ICT products from other countries around the world. In fact, when intra-EU27 trade is included, the EU27 is the largest importer in the world. While 28% of extra-EU27 exports were accounted for by ICT goods in 2018, only about 11% of total extra-EU27 imports of goods were in ICT. In 2018 the EU27 imported ICT goods worth USD 257bn but only exported ICT goods worth USD 100bn, making it one of the many countries in the world with a trade deficit in ICT goods. Only 12 countries[21] had a positive trade balance in ICT goods in 2018, four of which are members of the EU.

The trade balance in ICT goods of some selected countries is depicted in Figure 33. It shows that the US had the largest trade deficit in ICT goods in 2018 at USD 271bn, equivalent to about 6.7% of its total trade. The EU27 had the second-largest trade deficit in ICT goods at USD 156bn, which corresponds to about 5.6% of its total trade. Germany, the largest economy in the EU, had a USD 28bn trade deficit in this sector (about 1% of its total trade), while France, the next-largest economy, had a USD 16bn deficit (about 1.3% of its total trade). In fact, all EU 27 economies, with the exception of Czechia, the Slovak Republic, Ireland and Malta, recorded trade deficits in this sector, which may indicate their lack of competitiveness in the global ICT market. However, China, South Korea and Hong Kong enjoyed large trade surpluses of USD 387bn, USD 97bn and USD 10bn, respectively, in the ICT sector.

[21] These countries are China, Czechia, Ireland, Israel, Korea, Rep., Malaysia, Malta, Philippines, Singapore, Slovak Republic, Thailand, Vietnam

Figure 33 / Trade balance in ICT goods relative to total trade in selected countries, 2018



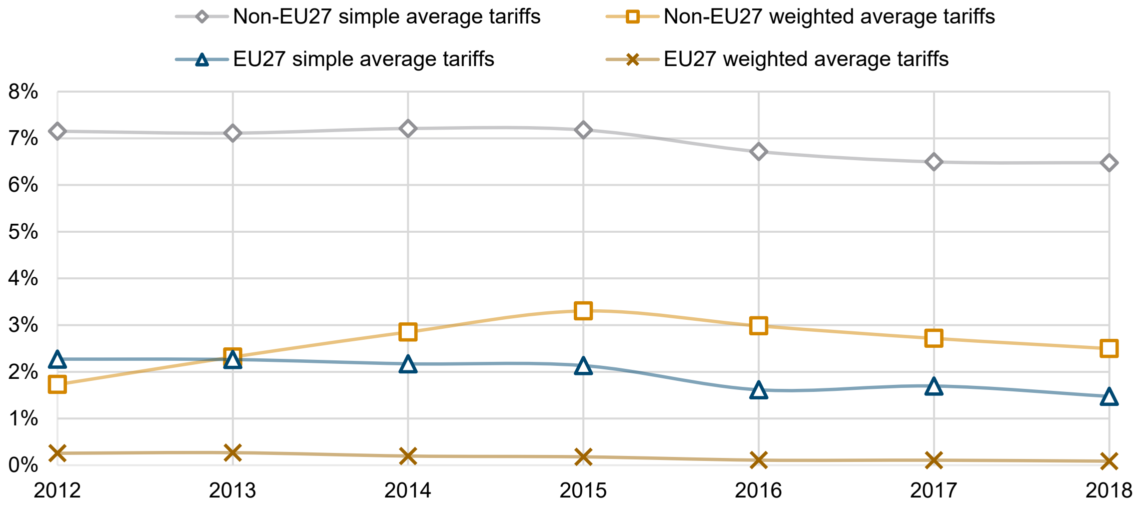
Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

5.3. TRADE POLICY MEASURES FOR ICT GOODS

5.3.1. Tariffs levied against ICT goods

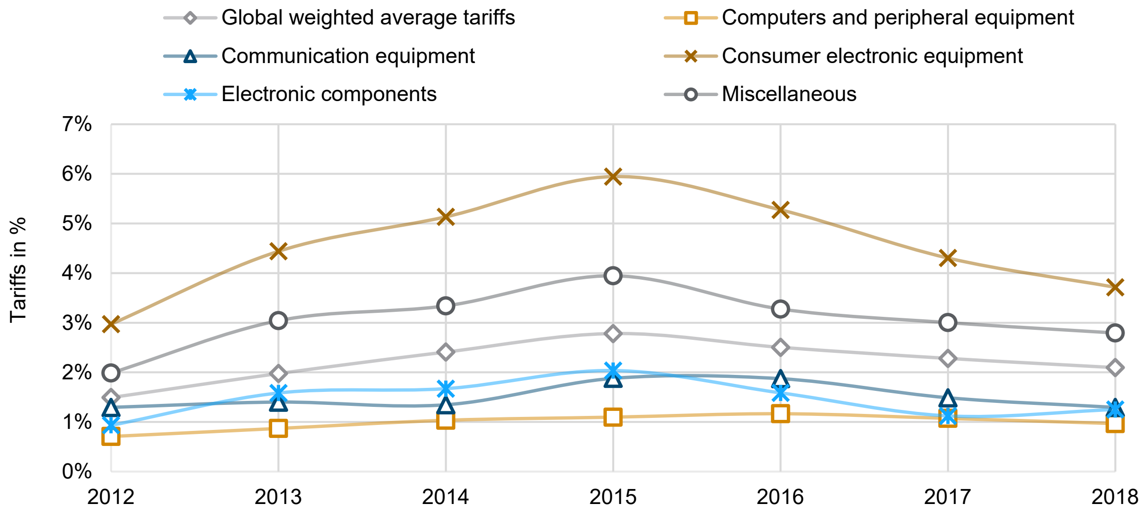
In this sub-section we give an overview of the tariffs levied against the exports of ICT goods in the world. Figure 34 presents the development of the tariffs levied on ICT goods traded bilaterally by all non-EU27 countries and the EU27 countries separately over the period 2012-2018. Simple averages are made on all bilateral flows including zero trade flows, while trade values are used as the weights in the calculation of weighted tariffs. As the figure shows, simple average tariffs imposed by non-EU27 countries on these products declined from around 7.15% in 2012 to 6.47% in 2018 on all products. However, trade-weighted tariffs imposed by non-EU27 countries increased from 1.7% in 2012 to 2.5% in 2018, with a slight peak of 3.3% in 2015. The reason why weighted tariffs show a smaller value than simple tariffs is that exporters of products direct their exports endogenously through the tariff lines with the lowest tariff costs. Furthermore, when comparing the non-EU27 tariffs with the tariffs imposed by the EU27, one can observe that the latter are much smaller than the former. In fact, import-weighted average tariffs imposed by the EU on ICT goods hovered around only 0.2% during this period, while the simple average tariff was about 1.9%. This is mostly because the EU is one of the major members of the Information Technology Agreement concluded in December 1996.

Figure 34 / Development of tariffs levied on ICT goods traded bilaterally during 2012-2018, EU27 versus non-EU27



Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

Figure 35 / Trade-weighted average tariffs levied on global bilaterally traded ICT goods, by product category, 2012-2018



Sources: WITS; COMTRADE; UNCTAD; authors' elaboration.

Figure 35 represents the weighted tariffs of each product category traded bilaterally during the period 2012-2018. It shows that tariffs levied against exports of Consumer electronic equipment are higher than tariffs imposed on other products. The simple average of tariffs levied against exports of Consumer electronic equipment during the period is around 10%, which is much higher than the simple average tariffs imposed on other ICT products, whereas the weighted tariffs against the exports of these products stand at around 4.5%, with the peak of 5.9% in 2015. While simple average tariffs on these products did not rise and experienced no peak in 2015, a peak of weighted average tariffs in 2015 against the exports of Consumer electronic equipment indicates that in 2015 trade flows were directed at countries and tariff lines with higher tariffs. Following the agreements of the WTO that is treating the most-favoured nation (MFN) tariffs imposed by the developed economies, developing countries are able to impose larger tariffs than developed countries do. Therefore, it seems that in 2015 more developing countries have been importing goods in 'Consumer electronic equipment' that has led to a peak in trade-weighted tariffs.

5.3.2. Investigation of TBTs imposed on ICT goods

Regulatory NTMs, such as TBTs embedding technical regulations and standards concerning health, safety, environmental quality etc., could be the most important trade policy measures with a quality impact on ICT products traded globally. Therefore, a detailed study of quality NTMs imposed on ICT goods would indicate their policy implications. Two sources of NTM data from the WTO and UNCTAD will be used here to provide a comprehensive analysis of these measures. UNCTAD collects NTM data with the help of national statistics that gather NTMs from official gazettes and regulative updates. While these domestic NTMs may be available in each country's customs and trade offices, they may not be easily accessible to exporters, causing trade frictions. Therefore, the efforts made by UNCTAD to collect such databases have improved transparency significantly. The NTM database[22] published by the WTO Secretariat is based on the notifications received from its members. Thus, these notifications represent the official announcement by member countries of the NTMs they have imposed. WTO agreements such as the TBT agreement oblige members to notify their NTMs to the WTO Secretariat to increase transparency in the imposition of trade policy measures and to improve smooth and frictionless trade across the globe.

Figure 36 presents the development of TBTs collected by UNCTAD that are imposed against the imports of ICT goods by non-EU27 countries and the EU27 over the period 2012–2018. The average stock number of TBTs imposed on each 6-digit product traded bilaterally since 2012, including zero trade flows, averaged over the sample of countries is shown on the rhs axis. As can be seen, the average stock number of TBTs imposed by non-EU27 countries increased from 0.008 TBTs per product in 2012 to 0.4 per product in 2018. The major increases happened in 2015 and 2016. However, the average stock number of TBTs imposed by the EU27 increased from 0.47 in 2012 to 5 in 2018. This is mainly due to the frequent imposition by the EU27 of regulatory NTMs to regulate the single market.

In addition to the average number of TBTs, two other measures of TBTs are also used and depicted in this graph. The frequency index (FI) of each country i in year t is calculated as the number of its tariff lines affected by TBTs divided by the total number of import tariff lines, including zero trade flows, as follows:

$$FI_{it} = \frac{\sum_j \sum_h TBT_{ijht}^{D} V_{ijht}^{DX}}{\sum_j \sum_h V_{ijht}^{DX}} \qquad (1)$$

[22] This database can be found here: http://i-tip.wto.org/goods/default.aspx?language=en. The data have been improved by Ghodsi et al. (2017), who found the missing HS codes for many of the NTMs through fuzzy text matching algorithms.

where TBT_{ijht}^{D} is a dummy variable taking the value of 1 if there is a TBT imposed by importer i against the exports of product h from exporting country j in year t; where V_{ijht}^{DX} is a dummy variable equal to 1 for a tariff line of exporting product h from exporting country j to importer i in year t. Thus, Figure 36 depicts the average of the FI of all importers of ICT goods.

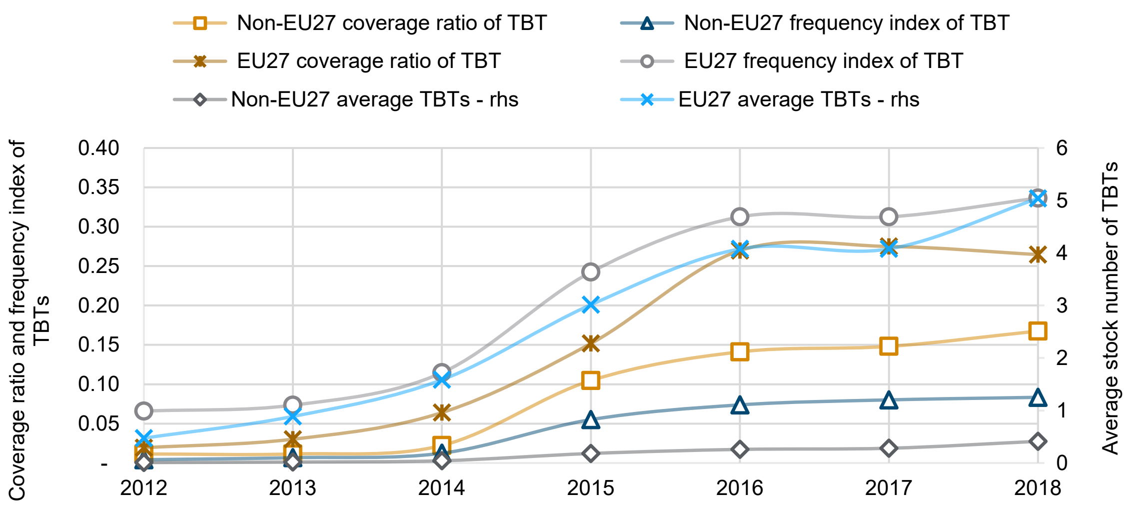
The coverage ratio is calculated similar to the frequency index, with an additional trade weight for each tariff line. Thus, the coverage ratio (CR) of each country i in year t is calculated as follows:

$$CR_{it} = \frac{\sum_j \sum_h TBT_{ijht}^{D} V_{ijht}^{X}}{\sum_j \sum_h V_{ijht}^{X}} \tag{2}$$

where V_{ijht}^{X} represents the export value of product h from exporting country j to importer i in year t. Figure 36 also depicts the average CR of all importers of ICT goods.

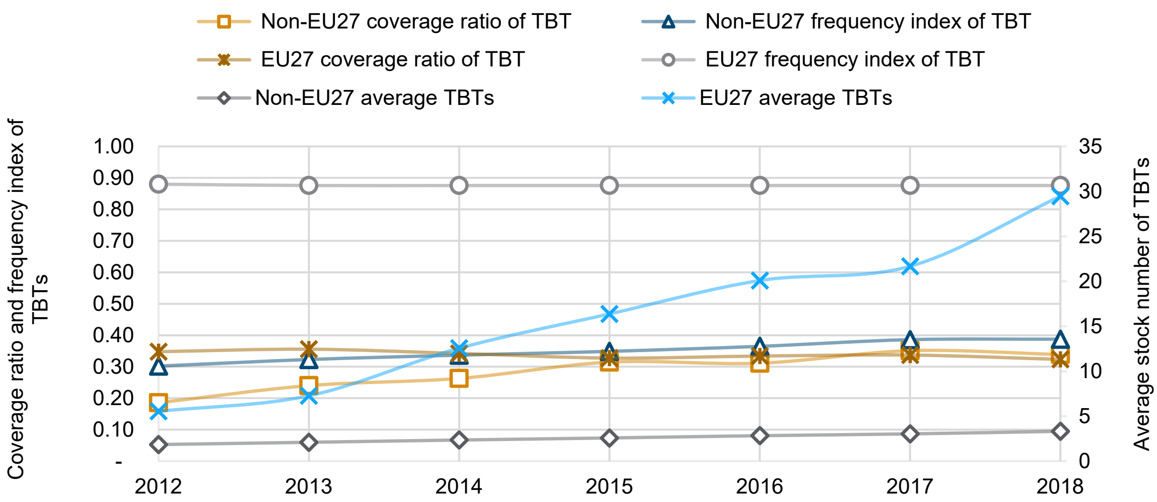
As depicted in Figure 36, both the average FI and the average CR of TBTs in ICT goods follow a similar pattern over time as average numbers of TBTs. In 2015 and 2016 the FI of TBTs increases at a faster rate than the CR of TBTs or the average number of TBTs. This suggests that in 2015 more tariff lines (or products) in ICT goods are affected by TBTs. However, although the CR (and FI) of TBTs imposed by non-EU27 countries is still smaller than the CR (and FI) of TBTs imposed by the EU27, the magnitudes are much closer for the CR (FI) than for simple averages. This indicates that larger import values are linked to the TBTs imposed by the non-EU27, which may hint at the trade promotion of TBTs imposed globally.

Figure 36 / Development of TBTs collected by UNCTAD imposed on ICT goods traded bilaterally during 2012–2018



Sources: UNCTAD (2017); COMTRADE; authors' elaboration.

Figure 37 / Development of TBTs notified to the WTO imposed on ICT goods traded bilaterally during 2012–2018



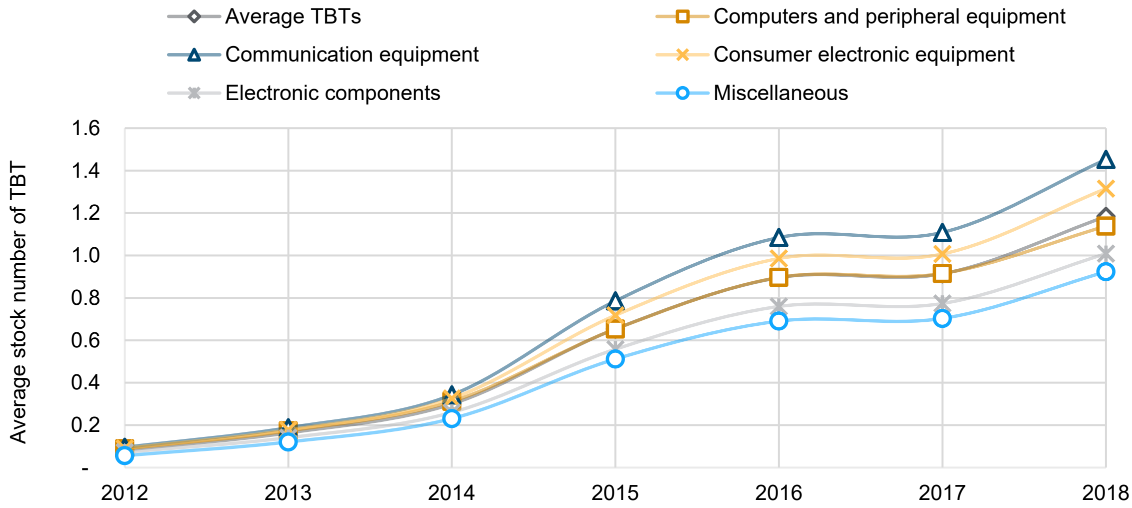
Sources: WTO I-TIP; COMTRAD; authors' elaboration.

Figure 37 shows the development of TBTs notified to the WTO imposed by non-EU27 countries and the EU27 on ICT goods traded bilaterally during the period 2012-2018. As can be observed on the rhs axis, the average stock number of TBTs notified since 1995 to the WTO that are imposed on ICT goods at the beginning of the period is 1.8 per tariff line for non-EU countries and equal to 5.5 for EU27 countries. That is much higher than the average stock number of TBTs collected by UNCTAD, which is explained by the fact that WTO members have been notifying their NTMs to the WTO since 1995 and there were some more TBTs in existence prior to 2012. Such information is missing in the data collected by UNCTAD. Due to the lower initial value of NTMs collected by UNCTAD, the average number of TBTs listed in the UNCTAD database in 2018 is 13 time larger than in 2012, compared with the number of WTO notifications, which is only twice as large. In other words, we can observe from the WTO notifications that the average stock number of TBTs imposed by non-EU countries per ICT tariff line increased from 1.8 in 2012 to only 3.3 in 2018. However, since the EU has been implementing NTMs more regularly, the average stock number of TBTs imposed by the EU27 increased from 5.5 in 2012 to 29.5 in 2018.

Moreover, the average number of TBTs notified to the WTO per ICT tariff line increased more than the CR and FI of these TBTs between 2012 and 2018. This suggests that the TBTs notified to the WTO increased the stringency of the regulations on the existing affected tariff lines. However, we observe that the FI and CR of these TBTs also increased, which suggests that new tariff lines and tariff lines with larger export values are affected by these TBTs over time.

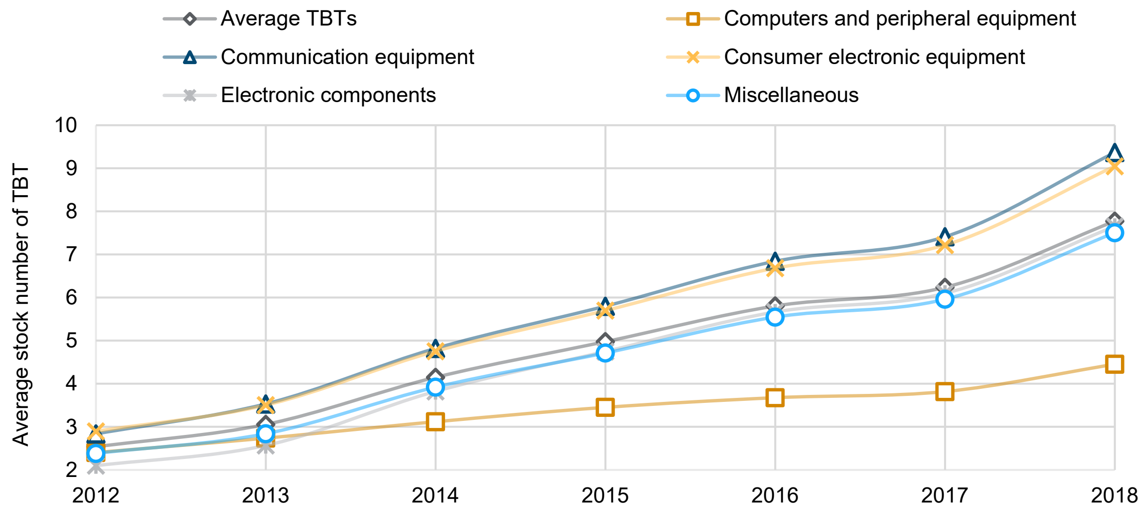
Figure 38 presents the average number of TBTs imposed on ICT goods traded bilaterally by product category over the period 2012-2018 as reported by UNCTAD. It shows that goods in the Communication equipment category were targeted by TBTs more than any other product category. Figure 39 presents the average number of TBTs notified to the WTO. These TBTs, too, were targeted at goods in the Communication equipment category more than at any other ICT category. Both graphs show that the second most targeted category was Consumer electronic equipment. While Computers and peripheral equipment was the next category most affected by TBTs according to UNCTAD, it is the last category affected by TBTs as reported by the WTO.

Figure 38 / Average stock number of TBTs collected by UNCTAD imposed on ICT goods traded bilaterally, by product category, 2012–2018



Sources: UNCTAD (2017); COMTRADE; authors' elaboration.

Figure 39 / Average number of TBTs notified to the WTO imposed on ICT goods traded bilaterally, by product category, 2012-2018



Sources: WTO I-TIP; COMTRADE; authors' elaboration.

6. Summary and conclusions

The main findings of the report can be summarised as follows. Section 2 provides some descriptive information about the relative importance of the accumulation of ICT capital and software and database capital asset types on the relative growth performance. From a growth accounting perspective, the contributions to growth of these assets are relatively small, contributing around 5-10% to overall growth. This analysis has also highlighted, first, the relatively lower importance of these assets to growth in European countries compared with Japan and the US, and second, that the contribution has become smaller in the post-crisis period (2010-2016) compared with the years before the global financial crisis. Nonetheless, in the econometric analysis growth of ICT assets (together with intangible economic competencies assets) has been identified as a significant driver of growth. However, such an analysis does not account for where the respective ICT assets are produced or from where these are imported. This has been studied in more detail in the next sections.

Section 3 shows that the ICT sector qualifies as a lead sector characterised as a sector that is (i) expanding in terms of (real) value added, and (ii) generates an increasing number of jobs, while (iii) displaying above-average productivity levels and high R&D rates. These attributes provide a good description of the ICT sector – including its two main sub-components, ICT manufacturing and ICT services – at the global level. When looking at the ICT sectors in the main producing countries, this general characterisation has to be qualified in the EU and the other countries of the economic triad (US and Japan) because their ICT sectors were unable to create significant amounts of additional employment over the period 2000-2016. Apart from the high productivity levels observable in the ICT sector, this lack of significant employment creation can also be attributed to the functional division of labour in the global economy (resulting from the emergence of global value chains).

What is troubling from an EU perspective is the fact that it lags behind other advanced main ICT producing countries, notably the US, in terms of the sector's share in the economy, labour productivity and R&D intensity. Particularly pronounced is the productivity differential vis-à-vis the US, where the data suggest a 40% gap. Staying at the technological frontier and reducing the productivity advantage of the US is an issue that has, rightly or wrongly, plagued European policy makers since the 1980s at the latest. According to the PREDICT data, the realm of ICT is definitely an area where such concerns are justified.

Zooming inside the EU economy and looking at individual member states has revealed that the comparatively weak position of the European ICT sector is partly attributable to the fact that none of the three largest EU economies (Germany, France, Italy) and the UK show a strong specialisation in the ICT sector. Moreover, there are very large productivity differentials within the EU, which poses a particular challenge for the bloc's cohesion objective. On the upside, these productivity differentials also imply that the productivity and R&D gap of the leading EU member states is smaller than for the EU as a whole, which is advantageous in the context of international competitiveness.

Similar to the aggregate analysis at the sector level, it is again evident at the firm level that ICT firms in the US are the major leaders in global ICT sectors in both manufacturing and services, which is highlighted in Section 4. Apple, Microsoft, AT&T, Alphabet (Google) and Automatic Data Processing are all superstars in the US, enjoying the largest global market share in terms of turnover in their two-digit NACE sectors. Some market leaders, such as Samsung Electronics in South Korea, Hon Hai Precision Industry in Taiwan and Huawei Technologies in China are among the five largest firms in the manufacture of ICT. However, the largest firms in the EU are lagging far behind in terms of market share compared with these global giants. It is also evident that a major share of capital and labour employed in the ICT two-digit sectors is allocated to the global giants. Therefore, as they are abundant in resources, they manage to allocate more resources to R&D activities, which enables them to push the frontiers of technology by introducing new products and novel production technologies. While the former helps them to gain market share and increase their revenues, the latter makes them more productive, efficient and more competitive in the global market.

While the average size of firms in the US is much larger than in other parts of the world, the size of large firms with at least 250 employees is relatively similar in the EU27, Japan and India in terms of turnover. However, after the US the largest turnover is achieved by large firms in South Korea and other Southeast Asian countries, while Chinese ICT firms are by comparison much smaller than in the rest of these regions. This indicates that firms in the EU may need to improve their competitiveness to catch up with other major ICT producers. As experienced by the global superstars, the way to achieve such a target could be by allocating more financial resources and expanding the productive and innovative capacities at the firm level. It is evident that while global superstars have much larger R&D expenditures than the EU27 superstars, in the EU27 this R&D expenditure is more equally distributed across ICT producers. The problem is that not every R&D activity leads to a positive and innovative outcome, which suggests that R&D activities in the EU are not efficiently allocated to the most pioneering and productive firms.

Publishing patents is considered to be the main indicator of successful innovative efforts through R&D activities (Van Hove, 2010). Moreover, inventors of novel technologies usually invest larger resources to get their patents granted after publishing (Davies et al., 2020), which ensures better protection for their intellectual property rights in courts. A recent paper by Exadaktylos et al. (2021) analyses the impact of patenting on the performance of firms in the ICT sector, using the same dataset as the one used in this report. The results suggest that there is a strong correlation between the number of granted patents that are owned by the ICT firm and its subsidiaries and the market share of the firm and its labour productivity. However, using the diff-in-diff technique to analyse the causation from patent to these performance indicators, the results indicate a direct significant impact of patenting only on the market share of firms that were patenting for the first time during the period 2009-2017. This means that all superstar firms which had innovated earlier and published patents earlier are excluded from the analysis, which is much more relevant for small and newly established ICT firms that are starting up in the EU. When the innovative activity of a firm leads to its first successful patent (and continues with more patents in the future), the firm gains a significant market share, while its productivity is not necessarily affected in a significant manner that is in line with past empirical studies (Balasubramanian and Sivadasan, 2011; Andrews et al., 2014). This may be related to the fact that knowledge secrecy is more important in the process than product innovation (Levin et al., 1987). Therefore, a firm aiming to improve its production process through innovation would not commercialise these new techniques by publishing a patent to prevent competitors from receiving information that could lead to more efficient production. However, introducing new products through patenting leads to higher revenues (Balasubramanian & Sivadasan, 2011) and hence a larger market share. In that case, the optimal strategy for a firm is to secure its knowledge through patenting. Therefore, the results indicate a product innovation rather than a process innovation in the ICT sector. For example, the introduction of the simplified application of a software that can work in one or several operating systems may potentially lead to new subscribers. When the software is novel and it can receive a grant from the official patent offices, then the firm should expect a significant rise in subscribers, demand and operating turnover.

Overall, global superstars, which are mostly located in the US, are pushing the frontiers of technology, and for that they enjoy large financial dividends thanks to their large global market shares. These superstars also ensure the strategic autonomy of their home countries over the production of the digital sector, the beating heart of the global economy, whose shortages have been felt deeply in many sectors and countries during the COVID-19 pandemic and the consequent border closures. Therefore, to improve the competitiveness of firms, start-ups and emerging rising stars in this sector, the policy makers at the EU may need to direct resources to more efficient and more innovative ICT firms. This could help them to introduce new products and services and consequently enable them to invest in efforts to successfully receive grants for their patents. The latter could also be supported by introducing patent boxes and giving tax credits after a successful patent application (Davies et al., 2022). As the empirical evidence also shows, such a policy will increase the global market share of EU-based firms, so that they can catch up with the global superstars and consequently improve their strategic autonomy over this vital sector.

Finally, the resulting trade patterns have been studied in Section 5. Overall, we can observe that Southeast Asian economies are the major exporters of ICT goods, with some of them also enjoying a trade surplus in this sector. The US and the EU27 are the major importers of ICT goods. Moreover, since the conclusion of the Information Technology Agreement by the members of the WTO in December 1996, tariffs imposed on the imports of ICT goods have been reduced to their lowest level by many member states. However, the use of regulatory NTMs, and in particular TBTs, has been on the rise.

From a trade policy perspective, using a longer time series of imports of ICT goods, Ghodsi (2021) finds that tariffs have no statistically significant impact on imports of ICT goods during the period 1996-2018. However, TBTs have a positive impact on imports of ICT goods in a statistically significant manner. The trade-stimulative impact of TBTs is more significant on the imports of goods in the Communication equipment category. This suggests that TBTs targeting these goods generate positive externalities, which may arise from the convergence of the regulatory frameworks across countries that improves the conformity of technical standards on communications equipment across various countries. Furthermore, keywords cited in TBT notifications may indicate the objectives of these regulatory NTMs. The empirical evidence suggests that the impact of TBTs on imports of ICT goods is very heterogenous based on their objectives. For instance, TBTs citing keywords on ‘conformity assessment’ or ‘harmonisation’ stimulate import values of ICT goods across product categories, while TBTs citing keywords such as ‘food standards’ or ‘nutrition information’ that target a universal set of products and also ICT goods hamper imports. It could be argued that some TBTs may act as a barrier to trade, while some others may stimulate trade.

The econometric results presented by Adarov and Ghodsi (2021) show that stringent regulatory TBTs imposed by a country increase the amount of cross-border investment by global MNEs active in the ICT sector, which indicates a regulatory barrier-jumping motive of FDI. This impact is much smaller for the cross-border investment by all global MNEs in all manufacturing sectors. However, trade-restrictive TBTs and sanitary and phytosanitary (SPS) measures imposed by the home of the MNE that is active in the ICT sector reduces the amount of cross-border investment in the host economy. This points to a barrier against the vertical integration of the production process by the MNE. Therefore, instead of imposing trade restrictive NTMs to foster both trade and cross-border investment, which usually leads to retaliation by trading partners, policy makers should aim at designing frameworks to reduce unnecessary obstacles on trade and improve the mechanisms through which the harmonisation of standards and regulatory NTMs could facilitate the use of ICT goods produced in any country. Such mechanisms could best be designed in multilateral agreements under the auspices of the WTO or through bilateral agreements that can improve the minimum set of standards and regulatory frameworks in other countries. As noted above, goods in the Electrical equipment category, such as semiconductors, are the most important intermediate inputs in the modern digitalised factory of the world. A harmonised set of standards and regulatory framework on the production side of these goods may eliminate unnecessary mismatches in product specifications and will lead to the diffusion of positive externalities, not only in the ICT sector but also in many other sectors in the global economy, which will have a substantial impact on fostering export-oriented growth.

These cross-country analyses of the ICT sector clearly indicate that the EU must step up its efforts to (i) accelerate the shift towards digital production methods and (ii) strengthen the ICT sector that produces the required technologies and services. That is at the heart of the challenge, and it will require moving from the policy formulation stage, where the EU scores highly, to the actual implementation of these policies. Defining an appropriate industrial mission (Mazzucato, 2018) that tackles the societal challenge of the digital transformation would be a first important step in this direction, the agreement on a series of Important Projects of Common European Interest (IPCEI) in the digital domain would be a second.

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Appendix

APPENDIX A

Appendix Table A.1 / List of countries in the PREDICT dataset

Country ISO2	Country	Country group
EU	European Union	EU
AT	Austria	EU member state
BE	Belgium	EU member state
BG	Bulgaria	EU member state
CZ	Czechia	EU member state
DE	Germany	EU member state
DK	Denmark	EU member state
EL	Greece	EU member state
ES	Spain	EU member state
FI	Finland	EU member state
FR	France	EU member state
HR	Croatia	EU member state
HU	Hungary	EU member state
IE	Ireland	EU member state
IT	Italy	EU member state
LT	Lithuania	EU member state
LU	Luxembourg	EU member state
LV	Latvia	EU member state
MT	Malta	EU member state
NL	Netherlands	EU member state
PL	Poland	EU member state
PT	Portugal	EU member state
RO	Romania	EU member state
SE	Sweden	EU member state
SI	Slovenia	EU member state
SK	Slovakia	EU member state
BR	Brazil	other countries
CA	Canada	other countries
CH	Switzerland	other countries
CN	China	China
IL	Israel	Other countries
IN	India	India
JP	Japan	Japan
KR	Korea	Korea
NO	Norway	other countries
RU	Russia	other countries
TR	Turkey	other countries
TW	Taiwan	other countries
UK	United Kingdom	other countries
US	United States	United States

APPENDIX B - TFP ESTIMATION

For the calculation of firm-level total factory productivity (TFP) in the literature, it is common to assume that production in firm i in industry j located in country c at time t takes the following form of a Cobb-Douglas production function:

$$Y_{ijct} = A_{ijct}\, K_{ijct}{}^{\alpha_k} L_{ijct}{}^{\alpha_l} M_{ijct}{}^{\alpha_m} \tag{1}$$

where Y denotes real revenue; K, L, and M are respectively inputs of capital, labour and materials; and A is the traditional TFP measure. Assuming a homogeneous production function in each industry j across all countries, in order to be able to estimate (1), we consider the log transformation:

$$y_{ijct} = \alpha_{j0} + \alpha_k k_{ijct} + \alpha_l l_{ijct} + \alpha_m m_{ijct} + \varepsilon_{ijct} \tag{2}$$

where lower-case letters indicate natural logarithms and α_f $(f = k, l, m)$ parameters refer to the share of the contribution of traditional inputs to output; and ε_{ijct} is the usual error term. TFP is then defined as:

$$\ln(A_{ijct}) = \alpha_{j0} + \varepsilon_{ijct} \tag{3}$$

Equation (2) is usually estimated for each industry (firms across one country), where α_{j0} indicates the mean level of efficiency across firms within industry j over time, and ε_{ijct} is the deviation of time-producer specific efficiency from that mean in the country. The latter has an unobservable component μ_{ijct} that can be corrected by semi-parametric production function estimations in the literature (Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Wooldridge, 2009; De Loecker, 2011; Ackerberg et al., 2015) and a predictable observable component ϑ_{ijct}. The former thus becomes an i.i.d. component including unobserved characteristics that can be correlated with the benchmark level efficiency at the industry level. Estimating equation (2) by industry, the measure of TFP then becomes:

$$\ln(A_{ijct}) = \alpha_{j0} + \varepsilon_{ijct} = \alpha_{j0} + \mu_{ijct} + \vartheta_{ijct} \tag{4}$$

hence, $\varphi_{icjt} = \alpha_{j0} + \mu_{ijct}$ represents the firm's efficiency. Therefore, after controlling for characteristics of the unobserved effects μ_{ijct} in regressions which show the deviation from the mean, the TFP measure at the firm-level will be calculated by the fitted parameters of the following equation:

$$\varphi_{ijct} = y_{ijct} - \left(\hat{\alpha}_k k_{ijct} + \hat{\alpha}_l l_{ijct} + \hat{\alpha}_m m_{icrt}\right) \tag{5}$$

Equation (2) will provide for the fitted values of the estimates at the industry level across all countries. In this study we use φ_{ijct} as the semi-parametric production function proposed by Ackerberg et al. (2015). In order to estimate TFP, we calculate factor elasticities for each industry on a global scale to be able to assess the competitiveness of firms horizontally across national borders. The intuition behind this is that the competitive pressure has a diverse impact on productivity, as it is referred to in the literature of economic geography (Beaudry and Schiffauerova, 2009). Therefore, it is assumed that the functional form of the production is uniform across the industry globally and the differences are due to the differences in TFP, which is the efficiency in choosing the best sets of inputs to produce the most of output in the industry.

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