CHAPTER
II.5

PRODUCTIVITY AND THE ROLE OF INTANGIBLES: FOCUS ON THE WORLD'S LARGEST R&D INVESTORS

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1. Introduction

The global productivity growth slowdown has raised concerns among policymakers and economists, and ignited an animated discussion on the causes. Scholars are actively debating the puzzling evidence of a slowdown in labour productivity growth, confronting theories which argue that such a slowdown is due either to mismeasurement issues of digital transformations (Syverson, 2016)[33] or to a more profound secular stagnation driven by innovation growth headwinds (Gordon, 2016)[34]. Others argue that behind the slowdown in aggregate productivity growth there has been a growing dispersion of productivity performance with some firms experiencing fast productivity gains, thanks to rapid technological progress, and others lagging behind (OECD, 2016). Andrews et al. (2016) identify the frictions in technological diffusion between frontier and non-frontier companies as one of the compositional effects determining the slowdown.

While the focus has been primarily on the contribution of the above-mentioned factors to the productivity slowdown, the role of intangible assets (other than ICT) in fostering productivity growth has been somewhat neglected. However, investment in intangible assets is rapidly growing, and in some cases this investment matches or exceeds investment in traditional physical capital (OECD, 2011). The increase in international competition, the global diffusion of ICTs and the new digital era, and the growing value-creating activities of the business services sector have magnified the importance of intangible assets in areas such as business organisation, workplace practices and human capital (Breshnahan et al., 2002). Consequently, some studies have pointed to investment in intangible assets as an additional contributing factor to productivity and economic growth (Corrado et al., 2005, 2009; Goodridge et al., 2013).

By considering a unique sample of large R&D investors[35] – which are expected to be among the most productive companies worldwide – this chapter provides an in-depth description of the potential differences in productivity growth for firms located in different world regions and sectors of activity. To obtain a measure of firm-level productivity, we take the residual of a revenue function (multi-factor productivity, MFP) estimated with an instrumental variable approach[36]. Our empirical analysis adds to the existing evidence on firms' productivity dispersion, which until now has mainly focused on general or national-specific trends. Moreover, we develop an empirical framework to better understand the contribution of intangible assets, specifi-

33 Several studies have shown that ICT investments have had a significant impact on productivity growth both in Europe and in the United States (Colecchia and Schreyer, 2002; Edquist and Henrekson, 2006; van Ark, O'Mahony and Timmer, 2008). However, while ICT investment remained an important component of productivity growth, its relative contribution began to decrease after 2000 (Jorgenson et al., 2008), while multi-factor productivity continued to increase, in the United States and in some parts of Europe. This phenomenon shattered the confidence in the ability of official productivity data to accurately capture all the factors that affect economic growth, and emphasised the complexity of the link from technology to productivity.

34 Link and Siegel (2003) review the main factors contributing to the 1970s' productivity slowdown. a fundamental issue is whether the causes of the past slowdown were cyclical (e.g. due to changes in the composition of demand or to the utilisation of resources), or secular, due to technology-related investment. Some authors claim that it is more than a cyclical phenomenon and that structural factors, such as the inclusion in the labour market of economies with comparatively low productivity, are at the root of the impaired current European productivity growth (Gros & Mortensen, 2004; Colijn and van Ark, 2012).

35 A complete description of the data is provided in the Appendix.

36 The Appendix provides a detailed description of how we measure MFP and reports the estimated structural parameters.

cally R&D and knowledge capital (e.g. stock of patents), to firm-level productivity across different regions. Lastly, we focus on the EU-US productivity gap by comparing our results for firms located in the EU with those in the US.

The chapter is organised into five sections. Section 2 presents productivity trends for firms located in different world regions and sectors. Section 3 provides an empirical analysis that identifies the contribution of R&D and knowledge capital to productivity growth in different regions and sectors. Section 4 combines the descriptive and analytical analyses to provide a more profound understanding of the reasons for the EU-US gap, as far as R&D capital and its relation with productivity are concerned. Finally, section 5 summarises the key findings and highlights some possible avenues for further research on how to unlock the productivity growth challenge. At the end of the chapter, we include a technical annex that describes the data, the construction of variables, and the methodology for calculating firm-level productivity.

2. Productivity trends among top R&D firms

2.1 Trends across world regions

Figures II.5.1 and II.5.2 display the dynamics and levels of the estimated MFP by macro-geographical regions. In particular, Figure II.5.1 shows the MFP averages over time for firms with headquarters in Europe, the United States, China, Japan and the rest of the world. China and Japan have opposing trends. Chinese firms[37] experienced the greatest increasing time trend, while the MFP of Japanese firms in the sample gradually diminished over time. The time trends of United States and EU R&D firms' MFPs are above the average for the whole sample, and increasing slightly. However, the MFP of United States R&D firms grew slightly faster.

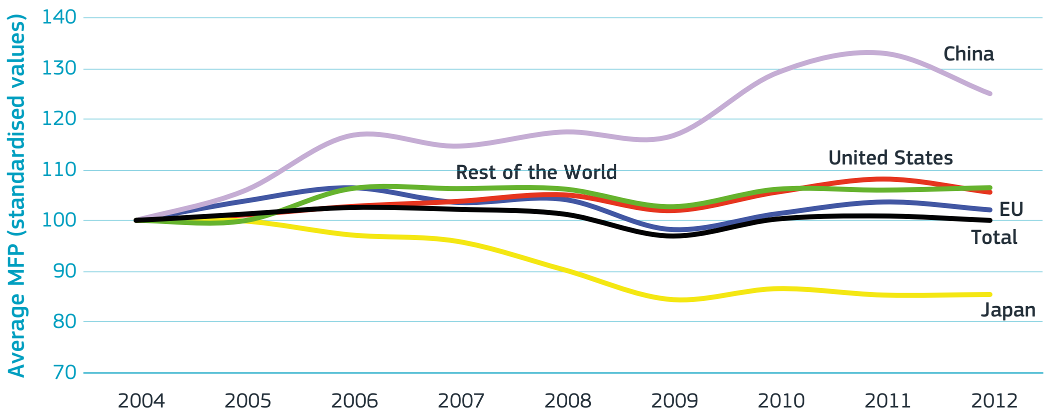
Figure II.5.2 gives a perspective of both changes over time and the relative levels of productivity. Comparing the first and the last year of the period, the average MFP of the entire sample has not changed (2.7). Despite its growth, China's MFP is smaller (in absolute terms) than all the other regions. The average MFP growth between 2004 and 2012 was 8% for EU firms and 15.5% for the United States, further increasing the gap with the latter.

Figure II.5.3 shows the productivity trends in Europe for a selected number of countries (with a sample of at least 100 firms). Apart from Denmark and UK, the MFP of firms in the other countries lies below the EU average and has had no or negative productivity growth.

Overall, the productivity trend by regions seems to reflect the general macro-economic scenario: Chinese companies are growing faster than other companies; the productivity of United States firms is consistently higher than the EU, and Japanese firms are struggling with its lagging productivity. Taking into account the inhomogeneous representativeness per sector and country of our data, among European countries, Danish firms are growing faster than the rest.

37 In the estimation sample, there are 507 observations for China, 1718 for the EU, 4766 for the United States, 2901 for Japan, and 1245 for the rest of the world.

Figure II.5.1 Multi-factor productivity (MFP) trend, 2004-2012[1]



Science, Research and Innovation performance of the EU 2018

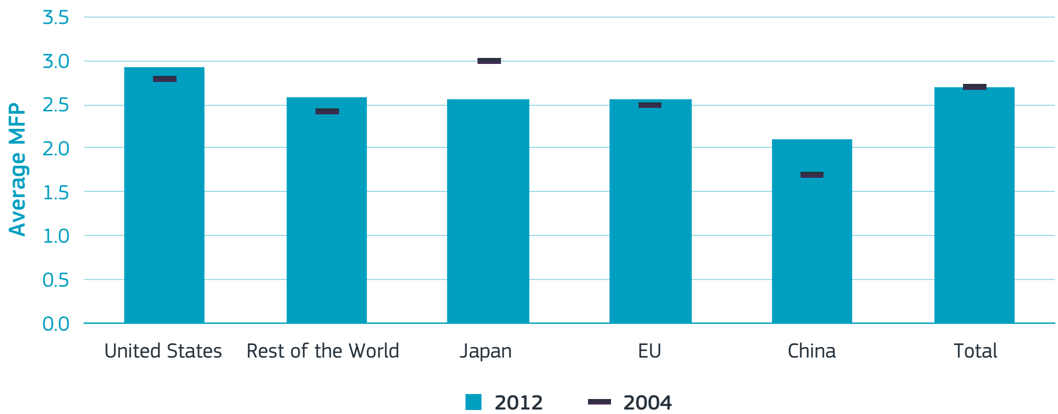
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

Note: [1]Base year considered is 2004 = 100.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5-1_.xlsx

Figure II.5.2 Multi-factor productivity (MFP) levels, 2004 and 2012



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

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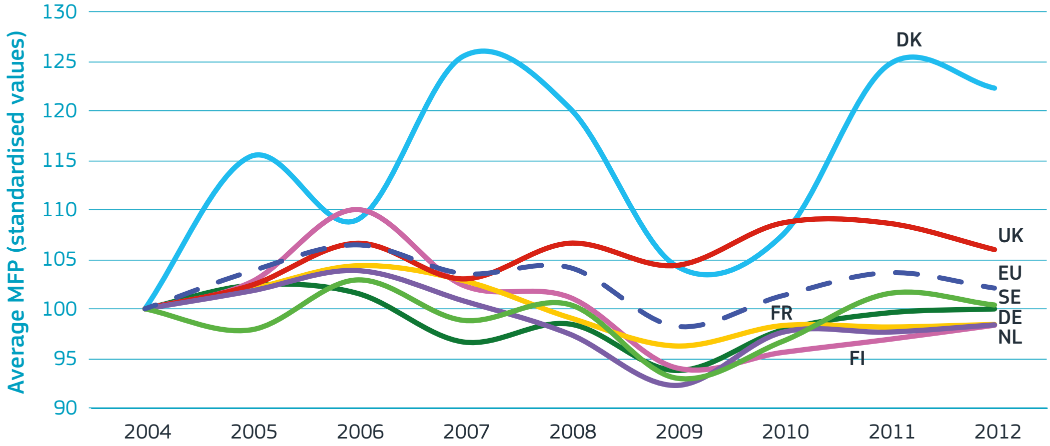
Figure II.5.3 Multi-factor productivity (MFP) trend for selected EU Member States[1], 2004-2012[2]



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: European Commission - DG JRC B.3
Notes: [1]Only Member States with more than 100 observations were considered, representing 80% of the entire EU sample.
[2]Base year considered is 2004 = 100.
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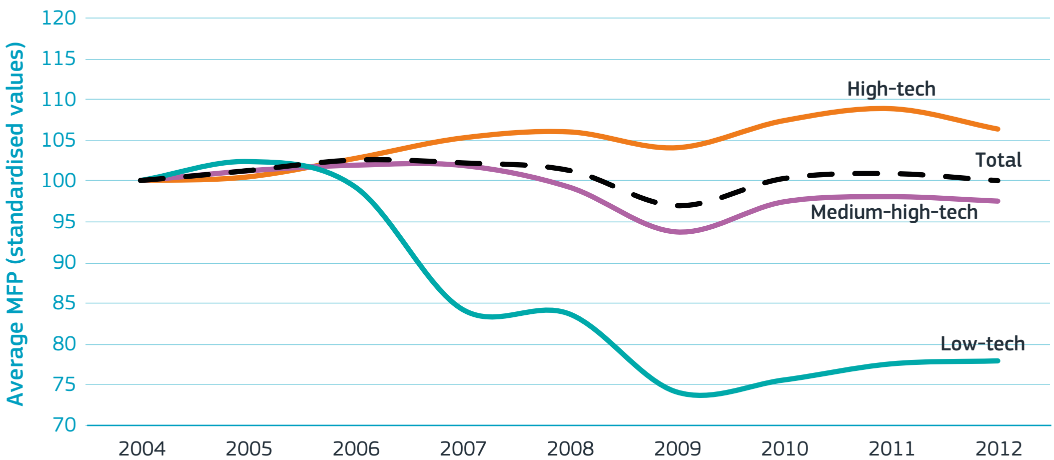
2.2 Trends across sectors

Figures II.5.4 and II.5.5 show the relative time trend and the absolute levels and changes of MFP by sector groups, namely high-tech, medium/high-tech and low-tech sectors[38]. R&D firms in high-tech sectors exhibit an increasing trend in MFP (Figure II.5.4). Conversely, the MFP of firms in medium/high- and low-tech sectors is declining over time, especially for low-tech firms. Figure II.5.5 shows that, in 2004, while firms in high- and medium/high-tech sectors had very similar levels of MFP, by 2012, high-tech firms were able to ramp up their productivity level by 18 %, while medium/high- and low-tech firms' productivity fell by 7 % and 39 %, respectively.

Lowering the level of sectoral aggregation, Figures II.5.6 and II.5.7 show that the productivity of ICT and industrials companies does not grow over time, while firms in the health sector have experienced a rapid increase in their level of MFP. As Figure II.5.6 shows, on average, firms in the health, ICT, and industrials have higher levels of MFP.

These trends suggest that companies in the high-tech sector are the only ones enjoying rapid MFP growth, the main contributors to this being the health and ICT sectors.

Figure II.5.4 Multi-factor productivity (MFP) by R&D intensity sector, 2004-2012[1]



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

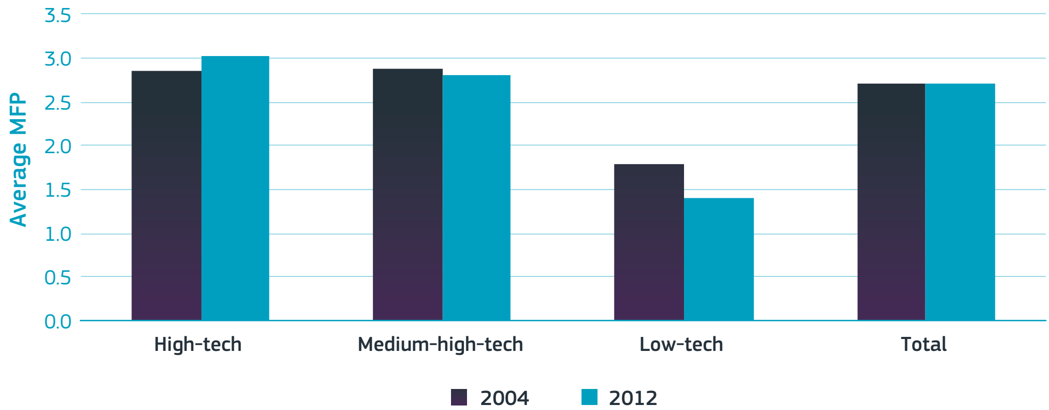
Data: European Commission - DG JRC B.3

Note: [1]Base year considered is 2004 = 100.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_4.xlsx

38 In Appendix, Table A.2 lists the business sectors by group. The choice of gathering firms in medium/low-tech and low-tech sectors is driven by the limited number of observations in these two sub-sector groups alone.

Figure II.5.5 Multi-factor productivity (MFP) levels, by R&D intensity sector, 2004 and 2012



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

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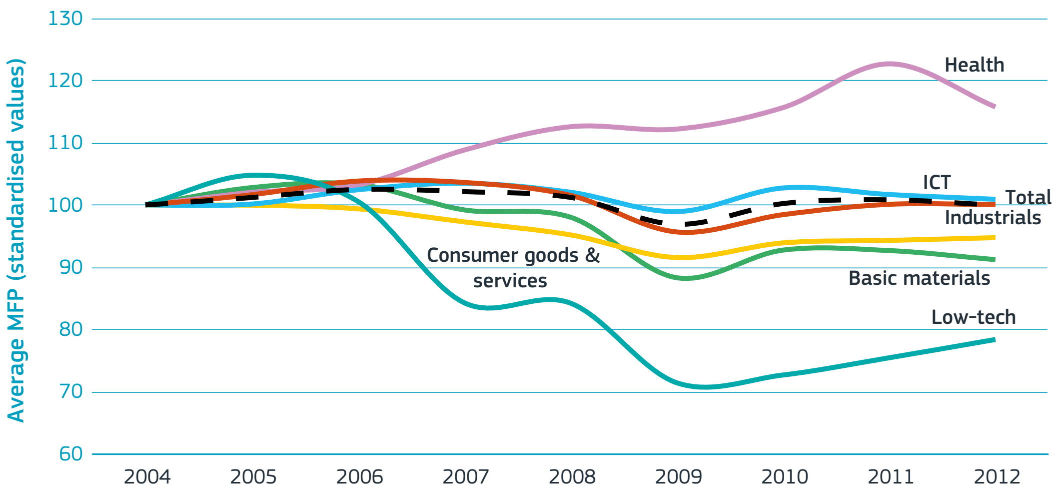
Figure II.5.6 Multi-factor productivity (MFP), by disaggregated sector[1], 2004-2012[2]



Science, Research and Innovation performance of the EU 2018

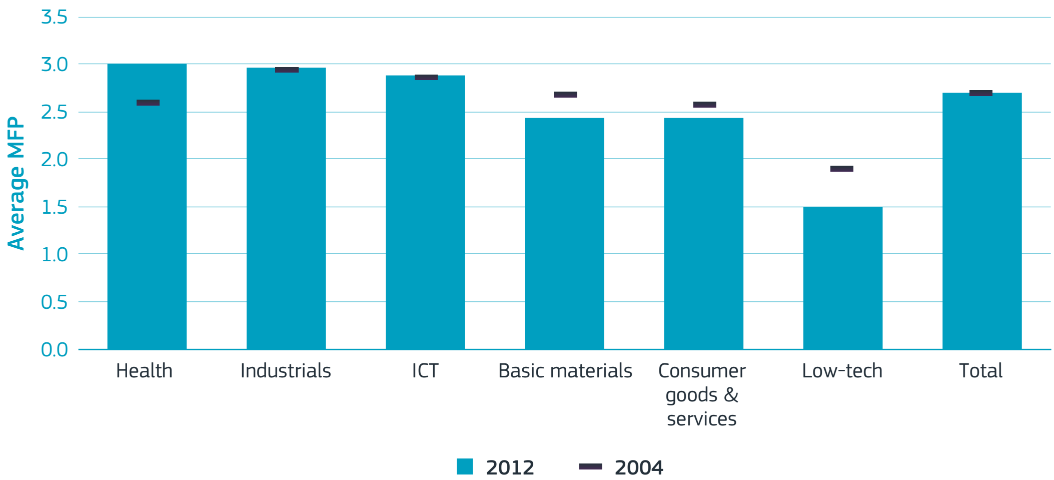
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

Notes: [1]Derived from data for ICB sectors at 3 digit level. [2]Base year considered is 2004 = 100.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_6.xlsx

Figure II.5.7 Multi-factor productivity (MFP) levels, by disaggregated sector[1], 2004 and 2012



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: European Commission - DG JRC B.3
Note: [1]Derived from data for ICB sectors at 3 digit level.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_7.xlsx

3. Intangible assets and firm productivity growth

In this section, we report the estimates from the least squares regressions of equation (3) in the Appendix, which relates MFP to intangible capital by sector and geographical area, and to a time trend (trend=0,1,2,…; where 2004 is codified as 0). The range of intangible assets is broad and can be roughly classified into four types: computer-based assets (software, databases), human and social assets, economic competencies (brand equity, advertising and marketing), and innovative assets (such as R&D, trademarks and patents). This chapter is only concerned with the last type of intangible assets. More specifically, due to data availability, we focus on the role of R&D capital and patent capital as measures of innovative capital.

The effect of R&D on MFP is expected to be different from that of patents. Indeed, although the two measures of innovative assets are generally strongly correlated and interchangeably used as a proxy for knowledge capital, the intensity of patents is sector-specific[39] and their economic impact varies significantly from patent to patent (Griliches, 1980). While this latter issue is mitigated by taking transnational patents[40], the sectoral impact of patent stock on productivity may differ from that of R&D.

Figure II.5.8 shows the results for R&D capital by sector and region. The first column (1) reports the average output elasticity of R&D for all sectors and regions. Overall, the partial elasticity of R&D is 0.078, meaning that

39 Patenting is negligible for innovations in most service industries (see Patel and Pavitt, 1995; Archibugi and Pianta, 1992).
40 See Appendix.

a 10 % increase in R&D capital stock leads to a 7.8 % increase in MFP[41]. The second column reports the results by sector. The returns to R&D are positive and statistically significant only in high- and medium/high-tech sectors. Finally, the third column shows the estimated coefficients by macro-economic region. The responsiveness of MFP to changes in the R&D capital stock is largest in the United States and especially in the rest of the world (China is the main contributor to this effect). Also, firms' MFP exhibits a declining time trend.

Figure II.5.8 Returns to R&D capital, by sector and by region, 2004-2012[1 2]

Dependent variable: MFP	(1)	(2)	(3)
R&D capital	0.078*** (0.01)		
R&D high-tech		0.084*** (0.02)	
R&D medium-high-tech		0.072*** (0.02)	
R&D low-tech		0.065 (0.04)	
R&D EU			0.071** (0.03)
R&D Japan			-0.008 (0.02)
R&D Rest of the World			0.206*** (0.04)
R&D United States			0.091*** (0.02)
Trend	-0.015*** (0.00)	-0.015*** (0.00)	-0.017*** (0.00)
Constants	2.074*** (0.17)	1.996*** (0.23)	2.177*** (0.37)
R2	0.221	0.221	0.231
N	10270	10270	10270

Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: European Commission - DG JRC B.3
Notes: [1]Sector and country dummies included but not reported. Firm clustered errors. [2]*** = p<0.01; ** = p<0.05; standard errors are given in parentheses.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_8.xlsx

41 Using a different sample of the same dataset, Cincera and Veugelers (2014) find very similar results.

Figure II.5.9 shows the same results for the stock of patents as a measure of intangible capital. In general, the average effect for all firms in the sample is statistically significant and positive (2.9% increase in MFP for a 10% increase in patent stock), but smaller than the effect of R&D capital. Column 2 reports the estimated output elasticities to patents stock by sector. As with R&D capital, the patent stock matters only for high- and especially for medium/high-tech sectors. The last column displays the results by different regions. Unlike the elasticity of R&D, the elasticity of patents is larger, on average, for EU firms and firms in the rest of the world (5.2% and 10.1%, respectively), while for the average United States firm the elasticity of the stock of patents is 3.3%.

Figure II.5.9 Returns to patents stock[1], by sector and by region, 2004-2012[2,3]

Dependent variable: MFP	(1)	(2)	(3)
PAT capital	0.029*** (0.01)		
PAT high-tech		0.027* (0.01)	
PAT medium-high-tech		0.030** (0.01)	
PAT low-tech		0.036 (0.02)	
PAT EU			0.052*** (0.02)
PAT Japan			-0.017 (0.02)
PAT Rest of the World			0.101*** (0.04)
PAT United States			0.033** (0.02)
Trend	-0.015*** (0.00)	-0.015*** (0.00)	-0.015*** (0.00)
Constants	2.914*** (0.07)	2.925*** (0.08)	2.810*** (0.11)
R2	0.207	0.207	0.212
N	8767	8767	8767

Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

Notes: [1]Transnational patents (see appendix). [2]Sector and country dummies included but not reported. Firm clustered errors. [3]*** = p<0.01; ** = p<0.05; * = p<0.1; standard errors are given in parentheses.

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4. Focus on the EU-US productivity gap

In this section, we focus on the comparison between EU- and US-based firms, with the aim of shedding light on some of the characteristics that may be responsible, at least in part, for the gap in both productivity levels and productivity growth. The section is organised into three parts. The first part reports general trends of R&D and patent capital. The second part shows the differences in productivity between the top 10% and the bottom 90% of EU and United States firms. The third part compares sectoral productivity trends and breaks down differences in the relationship between productivity and innovation capital between United States and EU firms by sector group.

4.1 Differences in intangible intensity

Results from section 3 point to the central role played by innovation capital. To give some perspective on the trends in R&D and patents, Figures II.5.10 and II.5.11 compare the median values of R&D capital and the stock of patents per employee.

Figure II.5.10 shows how the US-EU gap in R&D capital per employee has been widening over the period considered, due to a more rapid growth in R&D capital accumulation by United States firms. Figure II.5.11 shows that both EU and United States firms exhibit a falling trend in patent accumulation intensity; however, EU firms have decreased their accumulation of patents at a lower rate, resulting in a smaller EU-US gap in 2012 than in 2004.

Taking everything into account, R&D investment seems to be the contributing factor which sets the productivity of United States firms apart from that of EU firms. Indeed, not only is the gap in patent stock per employee decreasing over time (Figure II.5.10), but also EU firms are better than United States firms at appropriating from the returns to patents stock (see Figure II.5.9). As expected, Figure II.5.12 shows that while the R&D intensity of United States firms is increasing sharply over time, that of EU firms is stagnating.

Moreover, as mentioned in the introduction to this chapter, the relevance of intangible assets is accentuated by the shift from physical to knowledge capital accumulation. In this respect, Figure II.5.13 reports the average values of the ratio between R&D capital and physical capital. An average ratio larger than one indicates that firms are more R&D capital intensive; a ratio smaller than one indicates that firms are more physical capital intensive. The figure shows how United States firms have an R&D-to-physical-capital ratio larger than one, while EU firms have a smaller than one ratio. On average, the R&D capital intensity trend is increasing for both groups of firms.

Figure II.5.10 R&D capital per employee, 2004-2012

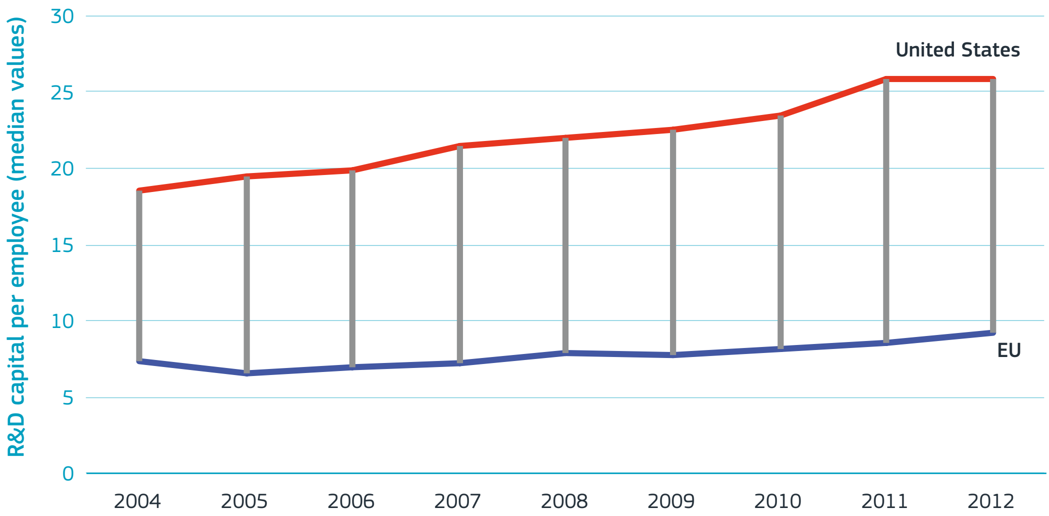

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Figure II.5.11 Patent stock per employee, 2004-2011

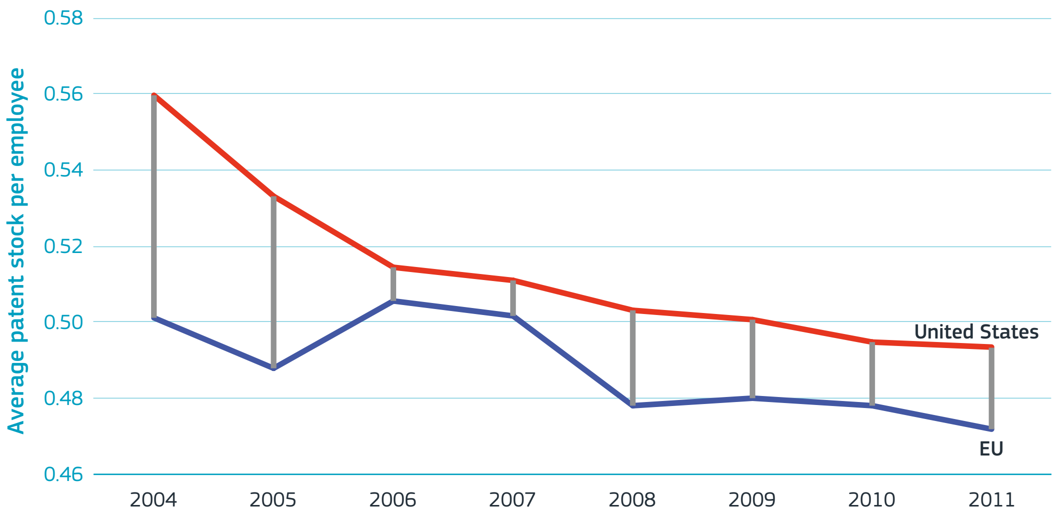

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Figure II.5.12 R&D investment per employee (2004=100), 2004-2012

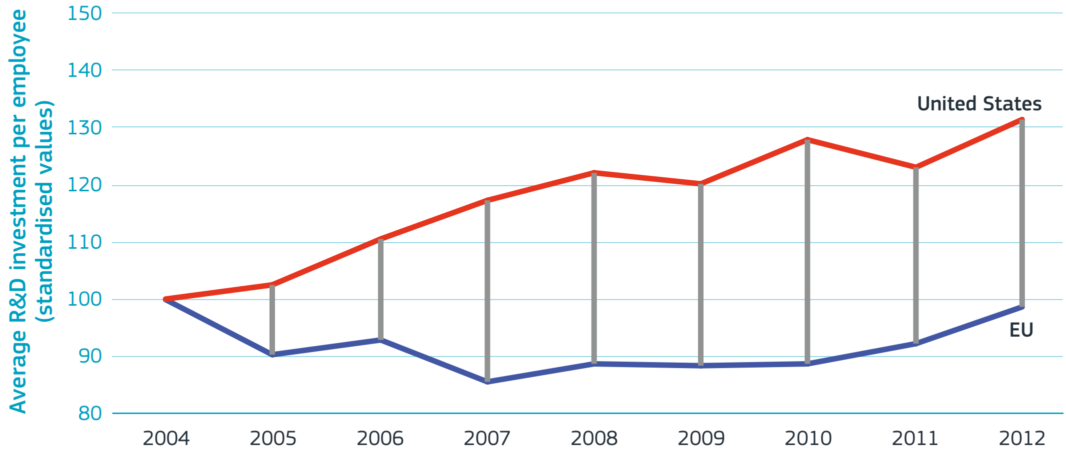

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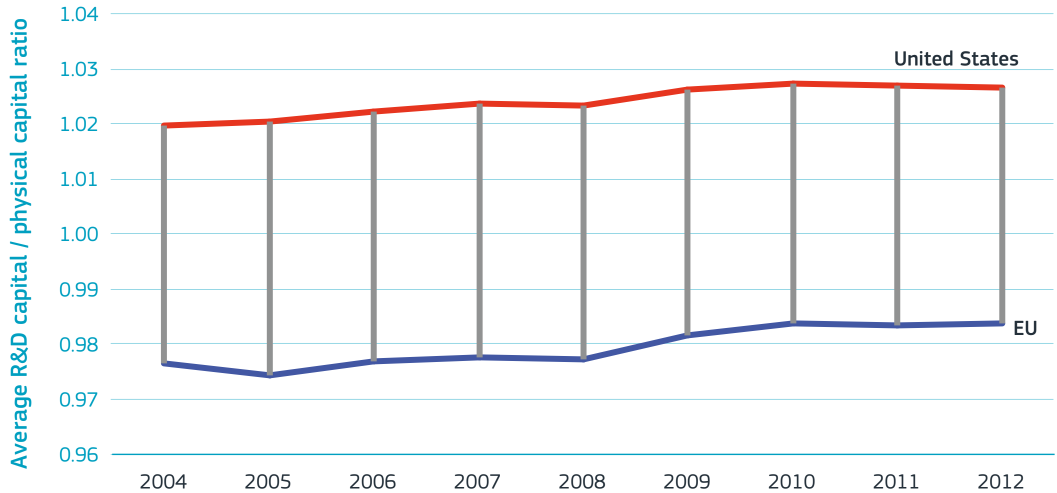
Figure II.5.13 R&D capital to physical capital ratio, 2004-2012



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

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4.2 The gap between the most productive firms and the rest

In this subsection, we define as 'top 10' those firms with an average MFP larger than the top 10th percentile by sector, and compare the top 10% of firms with the rest. Overall, we find that the productivity gap between United States and EU firms is driven by the less productive ones, and that the divergence between more and less productive firms is decreasing over time.

The top panel in Figure II.5.14 shows that, among the most productive firms (top 10), there is a significant gap between EU and United States MFPs. Unlike United States firms, EU companies experienced a growth spurt in 2006 (pre-crisis), when they had caught up with the MFP levels of the top United States R&D firms. However, the subsequent crisis had a larger impact on the MFP of EU firms, restoring the gap within three years. However, from 2009, the gap has been shrinking slowly. The bottom panel in Figure II.5.14 compares the rest of the companies across the two economies. First, unlike the top 10 firms, the MFP gap is increasing over time, as the MPF level in the bottom 90% only shows an increasing trend for United States firms.

Figure II.5.14 Multi-factor productivity (MFP) - top 10% of firms[1] and the rest, 2004-2012

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: European Commission - DG JRC B.3
Note: [1]Top 10% are those firms whose average multi-factor productivity (MFP) is larger than the top 10th percentile by sector.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_14.xlsx

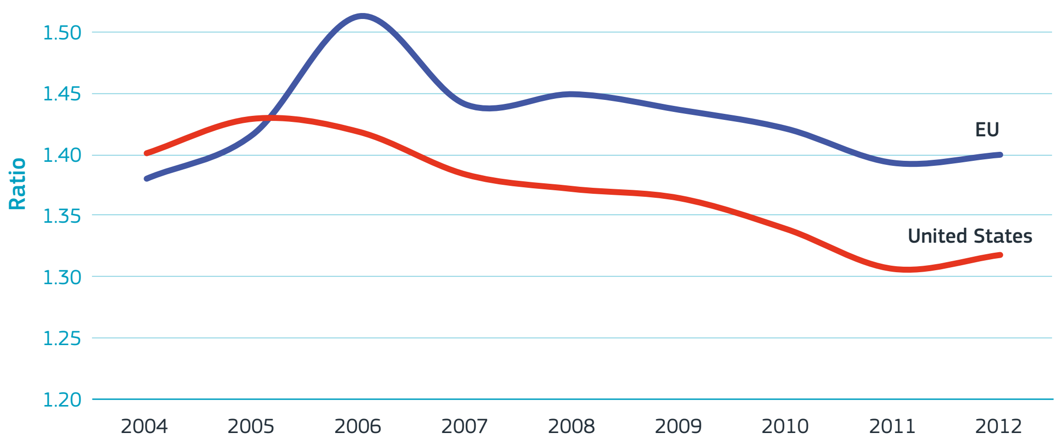
Figure II.5.15 reports the ratio between the MFP levels of the top 10 firms and the other EU and United States firms. a declining trend indicates that the difference in MFP between the most productive firms and the rest is decreasing over time. Although the difference is higher for EU than for United States firms, both sets of companies show a similar trend in the converging levels of productivity. These results differ from those of the OECD (2016) whereby they found an increasing divergence between the frontier and laggard firms. It is important to note, however, that our sample does not include small, local firms, but only considers large, international, R&D-focused firms operating in a highly competitive environment, where they need to defend their market power.

Finding a trend of convergence in productivity between the top 10% and the rest may be due to the said competition, as this has been shown to raise the productivity gains resulting from cost-reducing innovations (Willig, 1987) on the one hand, and from greater managerial efficiency, on the other (Nickell, 1996).

4.3 Sectoral differences in R&D and the impact of innovation capital on MFP

This subsection initially investigates the differences in R&D intensity and productivity across sectors, and then concludes with a quantile regression analysis of the effects of R&D and patents on MFP.

Figure II.5.15 **The ratio between multi-factor productivity (MFP) levels of the top 10 firms and the other firms, 2004-2012**



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: European Commission - DG JRC B.3
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Descriptive analysis

In general, our descriptive findings suggest that, at the sectoral level, EU firms continue to be relatively specialised in medium-tech sectors (such as the automobile industry), and are slacking in new high-technology sectors when compared to United States firms (Cincera and Veugelers, 2014).

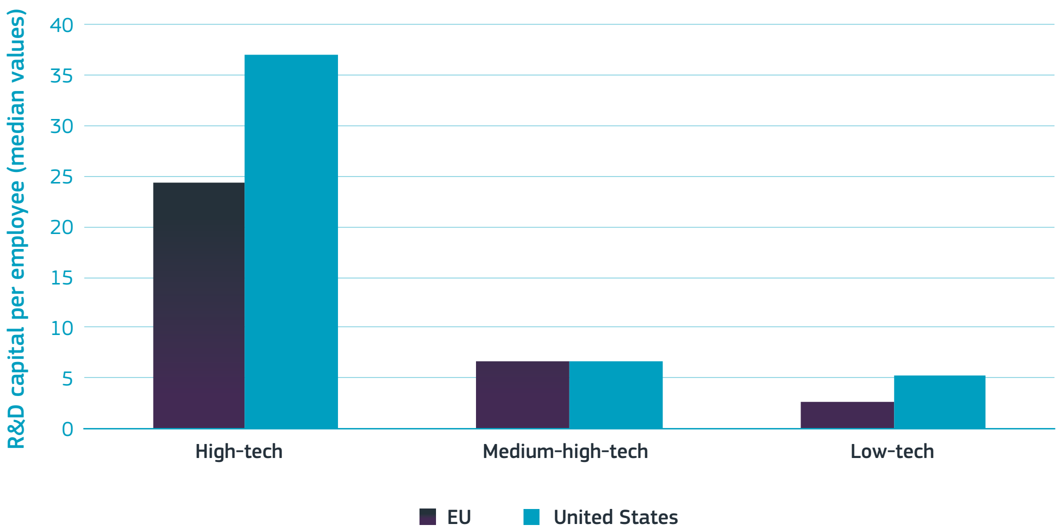
Figure II.5.16 shows the median values across firms and years of R&D capital per employee in EU and United States firms. The latter invest comparatively more in high- and low-tech sectors than EU firms.

Figure II.5.17 reports the average values of MFP for each sector, comparing United States and EU firms in both 2004 and 2012. On the horizontal axis, Figure II.5.17 gives the values of MFP by sector for EU firms, while the vertical axis shows the value of MFP for United States companies. The left panel refers to 2004, the right panel to 2012. If a coloured disk, representing the average MFP per sector, is below the diagonal, its average MFP is higher for EU firms than for US. And vice versa: if the disk is plotted above the diagonal, the average MFP is higher for United States firms.

Looking at the two panels, in all sectors except industrials, the average MFP is higher for United States firms. Also, it can be seen how the sectoral averages have evolved over time. In particular, European firms have lost ground in the health sector but gained some in the industrials. The positioning of United States versus EU firms has not changed in any of the other sectors.

Figure II.5.18 compares the average levels of MFP in 2012 and 2004 between United States and EU firms. The graph is interpreted as follows: sectors below the diagonal had a higher average MFP in 2004 than in 2012; vice versa if sectors lie above the diagonal. The left panel shows how the EU average MFP fell in three sectors, among which is the ICT sector and consumer goods and services, which is key for the EU economy as it includes the automobile sector. By comparing the left (EU) and the right (US) panels, it is evident how the average level of MFP is more heterogeneous among European firms than United States ones.

Figure II.5.16 R&D capital per employee (median values) by sector, 2004-2012



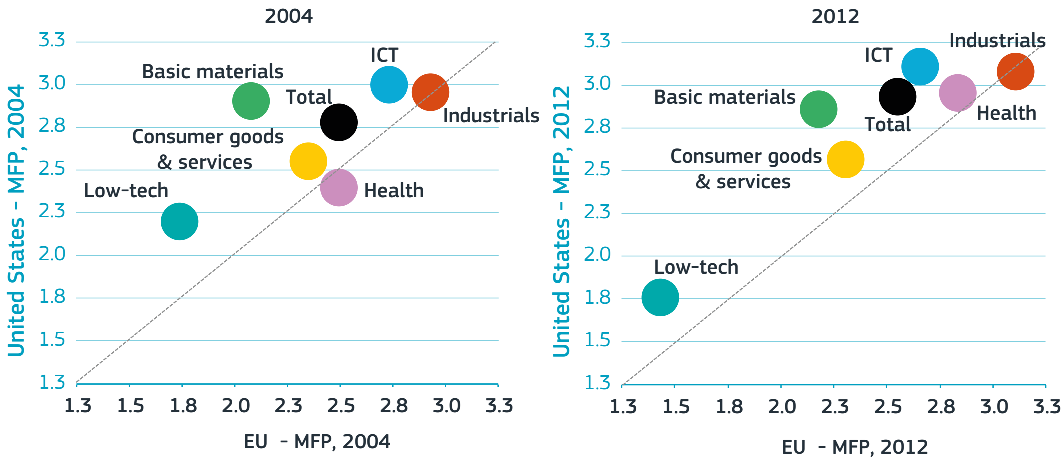
Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_16.xlsx

Figure II.5.17 Multi-factor productivity (MFP) levels by sector[1] – the EU compared to the United States, 2004 and 2012



Science, Research and Innovation performance of the EU 2018

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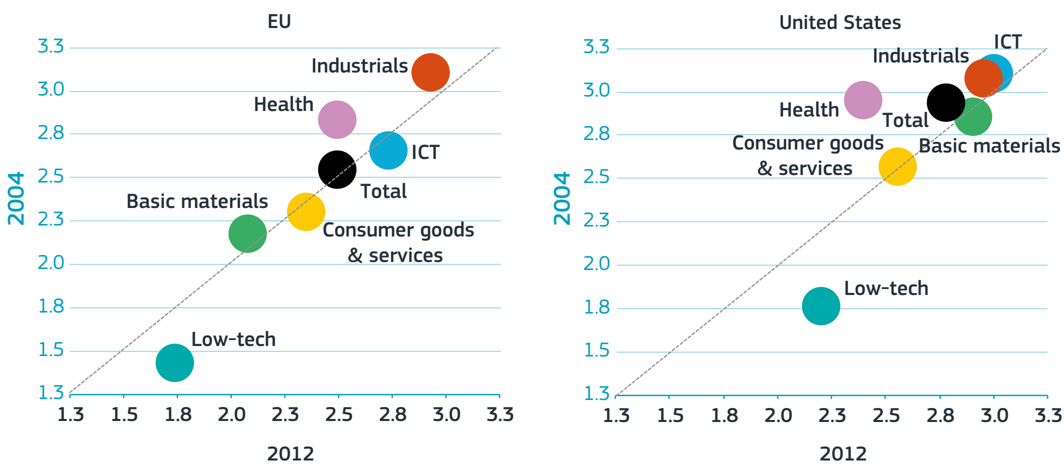
Data: European Commission - DG JRC B.3

Note: [1]Derived from data for ICB sectors at 3 digit level.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_17.xlsx

Figure II.5.18 Multi-factor productivity (MFP) levels by sector[1] in the EU and the United States, 2012 compared to 2004



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Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_18.xlsx

R&D, patents and productivity: a quantile regression analysis

The empirical results suggest that an increase in R&D capital results in a proportionate increase in the productivity of United States high-tech firms and in a less-than-proportionate increase in the productivity of EU firms. In other words, while R&D capital for United States high-tech firms is a capital good with an increasing marginal productivity 'à la Arrow'[42], it has a diminishing marginal productivity for EU high-tech firms and other sectors, where its characteristics are similar to physical capital. Patent capital, on the other hand, exhibits diminishing marginal productivity in all sectors except low-tech, where the most productive firm (US and EU) have positive elasticity to patents stock that increases with a firm's productivity.

Figures II.5.19 and II.5.20 report the results from a quantile regression analysis. Each figure has six panels which display the elasticity of both R&D capital (Figure II.5.19) and patent stock (Figure II.5.20) on MFP for United States (left) and EU firms (right), by R&D intensity sector.

The estimated elasticities of R&D capital for different sectors (Figure II.5.19) generally decrease as the productivity level increases. In other words, assuming that the level of R&D intensity is constant among firms per sector, the declining slope stems from the decreasing marginal productivity of R&D capital[43]. However, while in the medium/high-tech sector both EU and United States firms have similar ranges and declining patterns of R&D elasticity, firms in the high- and low-tech sectors present different dynamics. In the high-tech sector, the R&D capital of EU firms behaves just like a physical asset which exhibits diminishing marginal returns. On the other hand, the R&D capital accumulated by United States firms seems to have a constant marginal productivity of R&D above a certain level of MFP (roughly the 25th percentile).

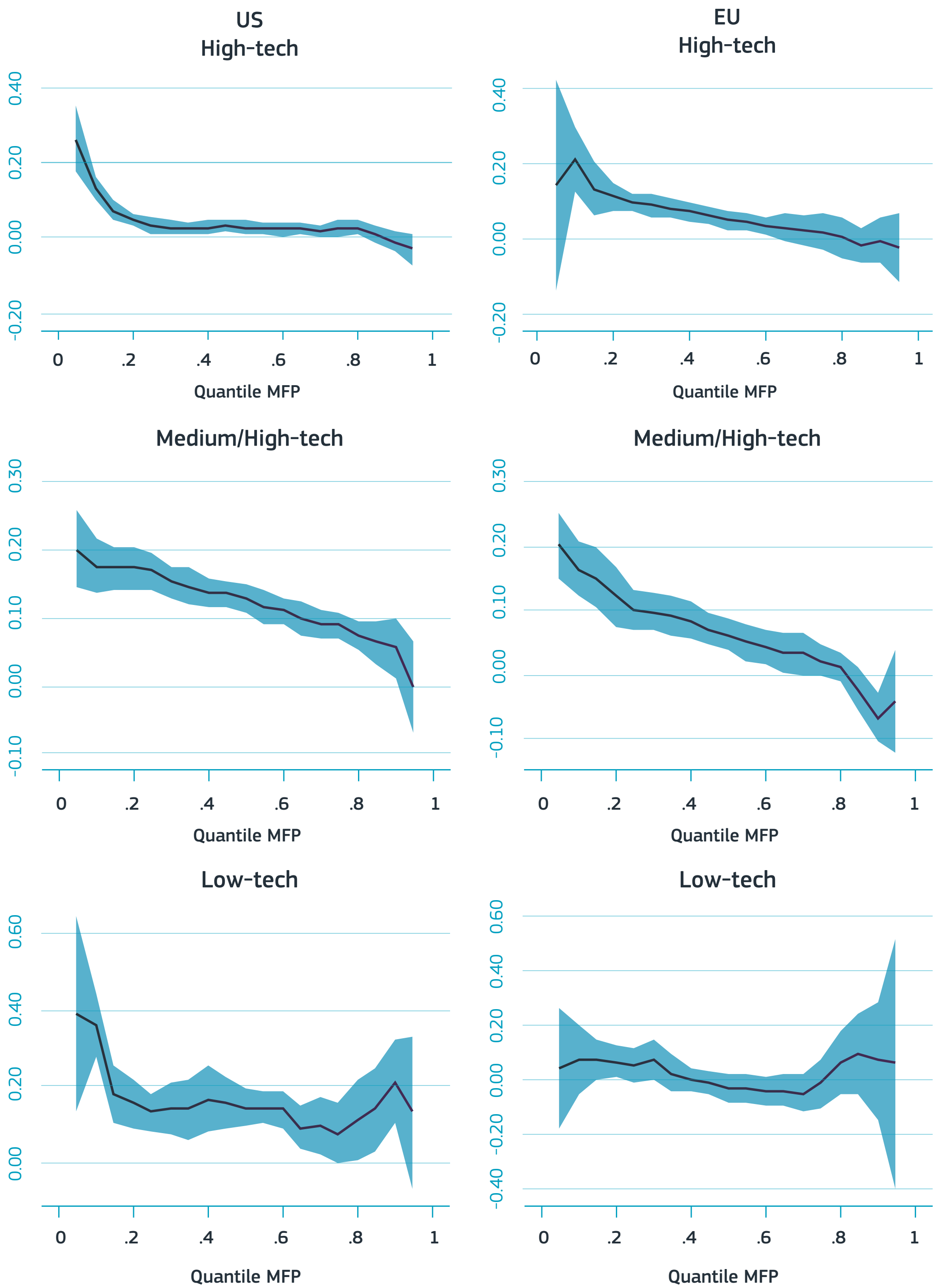
Lastly, the productivity of R&D among low-tech EU firms is zero, while that of United States firms is positive and exhibits constant marginal productivity for some levels of MFP (roughly between the 20th and 60th percentile).

Figure II.5.20 shows the estimated elasticity of patent capital. Similar to R&D capital, EU and United States firms in the medium/high-tech sector have similar diminishing elasticities to patents stock. In the high-tech sector, however, United States firms' marginal productivity of patents stock is totally unconditional on the volume of patents stock (from the 15th percentile onwards). In the low-tech sector, the most productive firms – United States and EU – have increasing patent capital elasticity, although low-tech United States firms start to reap the benefits of their knowledge investment from a relatively lower level of productivity compared to that of EU firms.

42 Arrow argued that increasing marginal returns on R&D arise because new knowledge is discovered as investment and production take place.

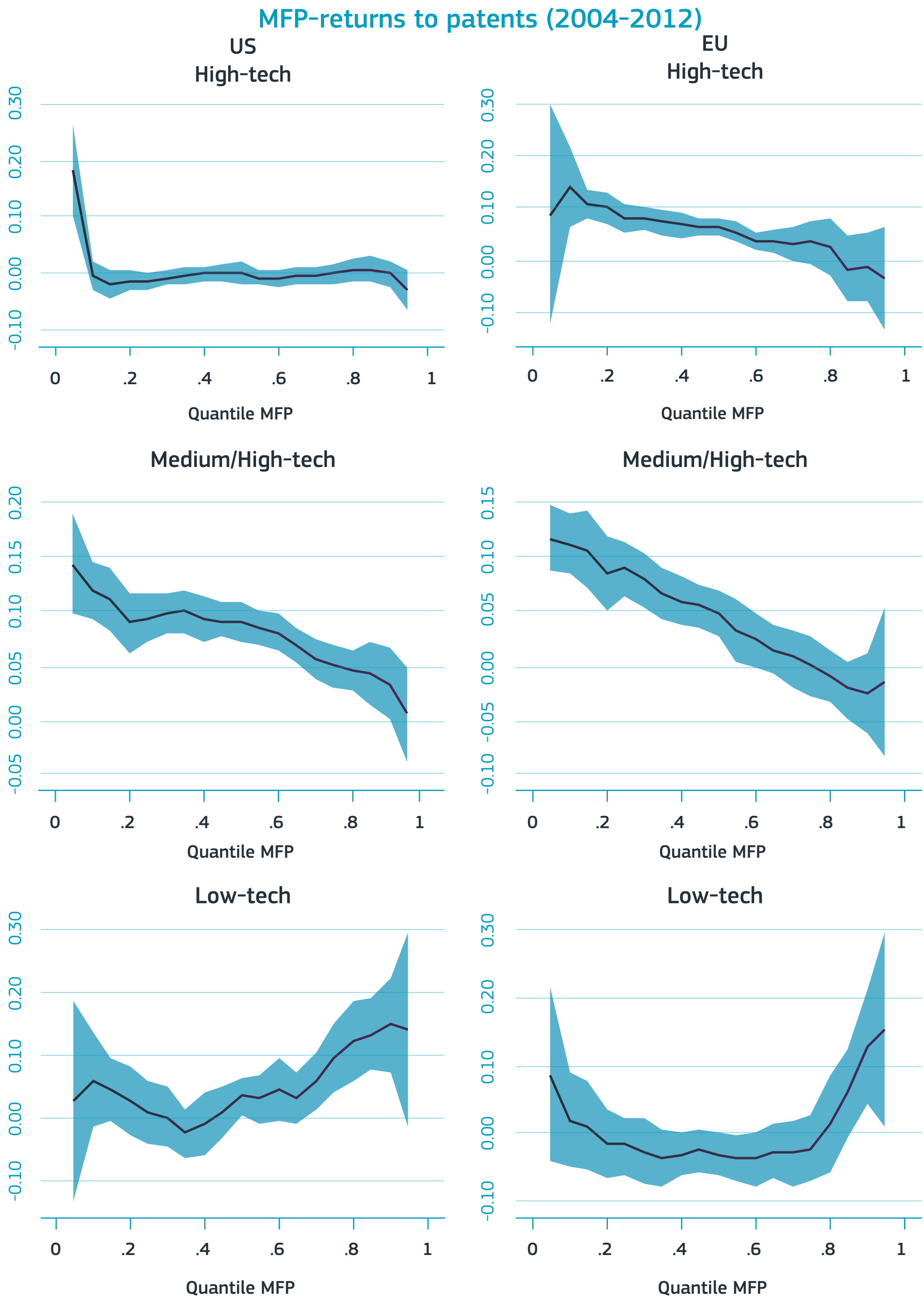
43 By definition, the elasticity of R&D capital is $\theta_{R\&D} = MP_{R\&D}(R\&D/Y)$, where $MP_{R\&D}$ is the marginal productivity of R&D capital and *R&D/Y* is the R&D intensity.

Figure II.5.19 The relationship between R&D and MFP, by sector and region
MFP-returns to R&D capital (2004-2012)



Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_ii_5_19.png

Figure II.5.20 The relationship between patents and MFP, by sector and region



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5 Conclusions and avenues for further research

This chapter contributes to the discussion on the global productivity slowdown by providing a more nuanced analysis about regional and sectoral differences in productivity growth patterns and by investigating the role of intangibles. It also provides a detailed comparison between the characteristics of EU and United States firms, with the aim of identifying potential reasons behind the increasing productivity gap between the two economies. Unlike previous studies, the analysis focuses on a unique sample of top international R&D investors, as they are key players in globalised economies. Although these firms may not be classified as the global frontier of productivity (Andrews et al., 2017), they are more than companies selling products. These top R&D multinational corporations are well-established giants which are a vehicle for global investment, market developments, and the mobilisation of knowledge generated across their worldwide corporate networks.

In the descriptive part of this chapter, we compare our estimated multi-factor productivity (MFP) across regions and sectors, using EU Industrial R&D Investment Scoreboard data for the top world 2000 R&D investors between 2004 and 2012. Overall, the productivity of the whole sample of firms did not budge over time. More specifically, the increase in productivity experienced by US, Chinese and EU firms has been balanced by the decrease in productivity by Japanese R&D investors. At the sectoral level, companies in the high-tech sector are the only ones enjoying a fast productivity growth, and the main contributors to this growth are the health and ICT sectors.

Scholars have attributed the recent United States productivity growth to the rapid expansion and application of technological knowledge (Corrado et al., 2005) and to investments in intangible capital. Results from the empirical analysis in Section 3 on the contribution of innovation capital (R&D and patents) to productivity confirm the importance of intangible assets, such as R&D and patents, as drivers of productivity growth. For example, a 10 % increase in R&D capital stock (or in patents stock) leads to a 7.8 % (2.9 %) increase in MFP. However, the productivity gains from R&D and patents derive exclusively from high- and medium/high-tech sectors. At the regional level, United States and Chinese firms have the largest R&D elasticities, while Chinese and EU firms have the largest patents stock elasticities. Moreover, our results confirm the findings from previous studies that the output elasticity of R&D exceeds its factor share (8 % versus 6 %, respectively), that is to say the marginal productivity of R&D exceeds its cost.

Lastly, we focus on the comparison between EU and United States firms with the intent of shedding light on some of the characteristics that may be partly responsible for the productivity gap. EU firms are less productive than United States firms in almost all sectors and have lost ground in some sectors where they used to outperform the United States (i.e. health and industrials). Moreover, by defining as ‘top 10’ those firms with an average MFP larger than the top 10th percentile by sector, we can compare the top 10 % of firms with the rest. Overall, we find that the productivity gap between United States and EU firms is driven by the less productive ones, and that the divergence between more and less productive firms is decreasing over time.

Also, we find that the gap in R&D capital intensity has been increasing over the period considered, due to a more rapid growth in United States firms’ R&D capital accumulation, while the gap in patents stock has narrowed in the last three years of the period considered. This suggests that R&D investment may be one of the contributing factors that sets the productivity of United States firms apart from that of EU firms. Indeed, not only is the gap in patent stock closing, but EU firms also have a higher patents marginal productivity than United States companies.

Our empirical results from a quantile regression analysis suggest that an increase in R&D capital results in a proportionate increase in the productivity of United States high-tech firms and in a less-than-proportionate increase in the productivity of EU firms. In other words, the R&D capital of EU firms relies more on embodied knowledge and technologies, which are exploited by investing in new equipment, and exhibits characteristics that are more similar to physical capital, including the marginal productivity. On the other hand, patent capital exhibits diminishing marginal productivity in all sectors except the low-tech one, where the most productive firm (US and EU) have positive elasticity to patents stock that is growing with firms' productivity levels.

To sum up, our analyses indicate that some of the reasons behind EU firms' lagging productivity may be due to the structural anchoring of EU high-tech firms to capital-intensive manufacturing sectors. Indeed, most of the new high-tech firms have shifted their focus from the traditional production paradigm, where R&D and innovation are used to reduce production costs, to network efficiency, where technology is used to expand their network and meet new demands. New tech firms, such as Google, Amazon and Apple, are platforms that enable their users to connect, exchange and express their demands, which immediately translate into business opportunities.

This chapter's analysis and results give rise to a number of related open questions that we leave as avenues for future research, such as how the global decline in business dynamism affects the allocation of capital and labour across firms and consequently impacts productivity growth. Apart from global factors, there may be a number of additional Europe-specific factors, such as structural rigidities and framework conditions, which may help explain the US-EU productivity gap.

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Appendix

Data

To analyse the productivity trends across regions and sectors, and to investigate the role of intangible investments on productivity growth, this chapter considers a unique sample of companies. The EU Industrial R&D Investment Scoreboard[44] is a Scoreboard analysis of top corporate R&D investors worldwide, which the European Commission's Joint Research has conducted annually since 2004. The dataset contains economic and financial data of the top 2000 world R&D investors and covers the period 2004-2012. In particular, starting from the top-ranked companies for 2012, historical financial data are collected to analyse their trajectories along the time period considered. Data are collected from the companies' published accounts and refer to the ultimate parent company in the case of consolidated groups. The key variable of the EU R&D Scoreboard is a type of intangible investment, that is, the cash investment in R&D (as from international accounting standards) that the companies funded themselves, excluding those undertaken under contract for customers such as government or other companies.

In addition to R&D, data on net sales, operating profit, capital expenditure, number of employees and market capitalisation are reported. The EU R&D Scoreboard economic data are nominal and expressed in euros with all foreign currencies converted at the exchange rate of the year-end closing date (31 December). The country attributed to a given company refers to the country where the headquarters are located. Although headquarters are concentrated in a relatively small set of countries, the subsidiaries of top corporate R&D investors are located in more than 200 economies, where the levels of risk and uncertainty may be different. However, corporate R&D performers seemingly concentrate the majority of their subsidiaries in the very same area where the headquarters are located.

In addition to R&D, as additional measures of intangible investment, we consider patents[45], and we propose a new method to estimate the contribution of intangibles to productivity. For each firm, data on financials and R&D are matched to the number of transnational patents[46] from Patstat. The indirect measure of output elasticity of an intangible is discussed in the next section.

To construct the stocks of physical and knowledge (R&D and patents) capital, we use the well-known perpetual inventory method (PIM) with depreciation rates of 6% and 15% for physical and intangible capitals, respectively. Figure A.1 reports the summary statistics of net sales, capital and labour – used to estimate the MFP – and the two measures of intangible capital, R&D and patents stock.

44 http://iri.jrc.ec.europa.eu/

45 The seminal work of Corrado et al. (2005) provides a framework on how to integrate intangible capital into growth accounts, although the implementation and development of measuring intangible capital is still an area for investigation. Indeed, Sullivan and Wurzer (2009) argue that it is not clear how the value of intangibles should be measured in principle, as value itself is not even a clearly defined concept. To capture the value from intangibles, firm-level studies have used balance sheet data on intangibles (Corrado et al., 2009; Gatchev et al., 2009; Marrocu et al., 2011), R&D expenditure (Griliches, 1981; Hall, 1993; and more recently, Chan et al., 2002; Lev, 2004; Sougiannis, 2015; Goodridge et al., 2017), patents and trademarks (Sandner et al., 2011; Crass and Peters, 2014), and indirect measures based on earnings, such as the calculated intangible value (CIV; Stewart, 1995; Lev, 2004; Larkin, 2013; Clausen and Hirth, 2016).

46 See Frietsch and Schmoch (2010) for more information on the comparability of this type of patents.

Figure A Summary statistics of main variables, 2004-2012

Variable	Mean	Median	Standard deviation	Min	Max
Net sales (thousand euro)	7,172,374	1,558,998	19,380,611	3.0	357,000,000
Employees	25,175	6,863	54,534	1.0	961,000
Capital stock (thousand euro)	3,526,263	523,982	11,595,852	5.2	194,188,960
R&D stock (thousand euro)	1,199,349	245,070	3,508,389	33.8	41,947,620
Patents stock	309	44	1,029	0.0	18,386

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Measures of MFP and intangibles

A common issue when estimating a firm's multi-factor productivity arises from the positive correlation between the observable input levels and the unobservable inputs and productivity shocks. When firms face a positive productivity shock, they demand a higher level of inputs in order to expand their production output. Conversely, when facing a negative shock, firms tend to decrease their demand for inputs and contract their production. a variety of methods have been proposed to tackle such simultaneous issues ranging from fixed effects (FE) to instrumental variables (IV) and control function (CF).

The CF approach relies on the availability of expenditure on materials. In our sample, information on this expenditure is available for less than 50% of the observations. Therefore, we adopt and compare results from FE and IV approaches.

A measure of MFP is retrieved from the following Cobb-Douglas production function:

$$(1)\ Y_{it} = I_{it}^{\theta INT} X_{it}^{\theta x} e^{\varepsilon it},$$

where Y_{it} is the revenue of firm i at time t, I_{it} is the intangible capital; θ_{INT} is the production elasticity with respect to intangible capital; X_{it} is a set of tangible and observable inputs, namely, physical capital stock, and labour (number of employees); θ_x is the production elasticity with respect to tangible inputs; finally ε_{it} is the unobservable idiosyncratic output shock.

Here, the ratio of output to classical inputs (labour and capital) is defined as multi-factor productivity (MFP). Therefore, rewriting eq. (1), we have

$$(2)\ \frac{Y_{it}}{X_{it}^{\theta x}} = MFP_{it} = I_{it}^{\theta INT} e^{\varepsilon it},$$

taking logarithms, we can write the MFP as a function of intangible input

$$(3)\ \log(MFP_{it}) = \theta_{INT} log(I_{it}) + \varepsilon_{it}.$$

To obtain an estimate of log(MFP_{it}) we use an IV estimator with clustered errors by firm, using the lags (up to two years before) of physical capital and labour inputs as instruments. Moreover, given that we use revenue rather than output, the price variation may be correlated with the input choice. To solve this additional endogeneity issue, we follow Klette and Griliches (1996) and De Loecker (2011) and control the price and demand variation to remove any potential correlation between productivity shocks and all those factors that might have an impact on prices and demand, but are not related to productivity. Specifically, we take the weighted aggregated revenues by NACE sector (at 2-digit), using the firm market shares as weights.

To investigate the role of intangible capital on MFP (equation 3), we use two direct measures of intangibles: R&D and patents. Figure B reports the estimated revenue elasticity of labour and physical capital for three groups of firms, namely those in the high-tech, medium/high-tech and low-tech sectors. The choice of sectors is based on the number of observations per sector[47].

Results show the elasticity of physical capital with respect to output is smaller in the high-tech sector than in medium/high and low-tech ones. This means that revenues in medium/high-tech and low-tech companies are more sensitive to changes in capital stock than to the number of employees.

The variable 'market demand' is the aggregated industry revenue, which is directly related to price mark-ups (De Loeker, 2011). On average, firms in low-tech industries charge a higher mark-up than in medium/high- and in high-tech. The time trend coefficient shows that only high-tech firms experienced an increasing trend in their revenues during the period 2004-2012. Finally, the estimated returns to scale θ are increasing significantly for high-tech firms[48], while remaining constant for the other two groups of firms.

47 As a robustness check, we tried grouping firms into high-, medium-, and low-tech, and there are no significant differences.

48 The returns to scale are estimated as $(1 - \hat{\sigma}_{mrkt\ dmnd}) * (\hat{\theta}_{EMP} + \hat{\theta}_{CAP})$.

Figure B Main business sectors and number of observations by technology intensity[1]

Sector	High R&D intensity	Medium-high R&D intensity	Low R&D intensity
	Aerospace & defence Biotechnology Computer hardware Computer services Electronic office equipment Health care equipment & services Internet Leisure goods Pharmaceuticals Semiconductors Software Telecommunications equipment	Automobiles & parts Chemicals Commercial vehicles & trucks Electrical components & equipment Electronic equipment General industrials Household goods & home construction Industrial machinery Other financials Personal goods Support services Travel & leisure	Alternative energy Banks Beverages Construction & materials Electricity Fixed line telecommunications Food & drug retailers Food producers Forestry & paper Gas, water & multiutilities General retailers Industrial metals & mining Industrial transportation Life insurance Media Mining Mobile telecommunications Nonlife insurance Tobacco Other
Number of observations	7731	7109	3154

Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: European Commission - DG JRC B.3

Note: [1]The technology intensity groupings were determined on the basis of R&D expenditure as % of sales.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_a_2.xlsx

Figure C Instrumental variables (IV) - estimates of production function[1,2], 2004-2012

Variable	High R&D intensity	Medium-high R&D intensity	Low R&D intensity
log(Emp)	0.760*** (0.04)	0.385*** (0.04)	0.381*** (0.07)
log(Cap)	0.274*** (0.04)	0.500*** (0.03)	0.481*** (0.05)
Market demand	0.082* (0.04)	0.124*** (0.04)	0.231*** (0.06)
Trend	0.025*** (0.01)	-0.026*** (0.00)	-0.040*** (0.01)
Constant	2.818*** (0.61)	2.989*** (0.55)	1.226 (0.77)
R2	0.827	0.858	0.865
N	3691	3366	1245
$\hat{\theta}$	1.126*** (0.05)	1.011*** (0.05)	1.121*** (0.08)

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Notes: [1]Sector and country dummies included but not reported. Firm clustered errors. [2]*** = p<0.01; ** = p<0.05; * = p<0.1; standard errors are given in parentheses.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_5/figure_a_3.xlsx