CHAPTER
11.3

R&D, ICT AND PRODUCTIVITY

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15 The views expressed in this paper are those of the authors and do not necessarily reflect the views of Statistics Netherlands.

1. Introduction

It is now largely confirmed that progress in information and communication technologies (ICT) has increased labour productivity (Jorgenson, Ho and Stiroh (2008), Syverson (2011)), in particular the revolutionary digital technology, which is recognised as a general purpose technology with a widespread application in many industries. ICT can affect productivity through various channels. First, productivity may increase as firms invest more into ICT capital goods, following a price reduction in these goods, possibly accompanied by changes in quality. Second, by increasing transparency and the information available to economic agents, it may render markets more efficient and thereby improve the allocation of resources. Third, it may bring people closer together and create network effects, for instance through social media. And finally, by increasing knowledge diffusion it may create accelerate the R&D spillover effects, making knowledge produced in one sector available more quickly in another sector, which could use it to produce new knowledge.

But there is another indirect way by which ICT may increase TFP growth, namely by boosting the productivity of research and development. There are good reasons to believe that this is so. First, ICT has reduced communication costs and concomitantly increased the speed of communication and thereby the linkages between researchers, enabling collaboration between researchers located far apart. In this way, they may bring their expertise together more easily and work in larger teams with a more specialised division of tasks. Secondly, ICT allows for the storage and easy retrieval of huge amounts of data, improved search capabilities, the constitution of large databanks and access to a much larger scale of information. Third, electronic technologies have made it possible to apply data-mining techniques, to perform complex calculations and to reach a degree of precision that would have been impossible a century ago. Although there are good reasons to believe that investment in ICT could increase the return to R&D, evidence supporting the complementarity between R&D and ICT is mixed. Exploring this complementarity is the prime objective of this paper.

While innovation and its main R&D input are considered as the main drivers of long-term economic growth, Europe is lagging behind the United States in terms of R&D intensity. In order to create a stimulating environment for innovation, the European Union conceived the Europe 2020 flagship initiative known as the Innovation Union. To facilitate innovation you need basic skills, in particular e-skills, easy access to finance, protection of intellectual property rights, mobility of researchers, inter-regional and international collaboration, procurement and standards. The Innovation Union includes 34 commitments which it wants to be developed to improve the EU's innovation performance. ICT plays a particular role not only by providing the latest hardware, software and internet infrastructure, but also by changing the way researchers operate, replacing the closed mode of doing research by a more open innovation system, which relies on external as much as internal sources of knowledge.

Literature

By and large, there is agreement on three empirical regularities: that R&D earns a positive rate of return and contributes to TFP growth (Hall, Mairesse and Mohnen, 2013); that computers and the adoption of ICT show up in productivity statistics (Jorgenson, Ho and Stiroh, 2008; Biagi, 2013); and that investments in ICT affect productivity growth if they are accompanied by changes in work organisation (Brynjolfsson and Hitt, 2000; Bloom, Sadun and Van Reenen, 2012). Evidence of complementarity between R&D and ICT is more mixed. In fact, very few studies have directly examined this issue.

The study by Hall, Lotti and Mairesse (2012), based on Italian firm data, finds no conclusive evidence in favour of either a complementarity or a substitution between R&D and ICT on Italian firm data. R&D and ICT increase total factor productivity (TFP) individually but their joint investment does not give an additional boost to productivity. Cerquera and Klein (2008) point to a complementarity in the adoption of R&D and ICT but do not examine the complementarity at the outcome stage. They find on German firm data that ICT explains an increase in heterogeneity in productivity and that this process of creative destruction gives firms incentives to invest in R&D.

Some work has examined a possible complementarity not between ICT and R&D but between ICT and innovation output. Spiezia (2011) concludes from the OECD-lead international comparison study, based on company data, that ICT enables the adoption of innovation but does not increase the probability of coming up with a new innovation developed in-house. In contrast, Kleis, Chwelos, Ramirez and Cockburn (2012) find that investments in information technology increase innovation output when measured by patents. Van Leeuwen and Farooqui (2008), in the Eurostat report on ICT impacts, show that e-sales and broadband use affect productivity significantly via their effect on innovation output. Forman and van Zeebroeck (2012) found that internet connections increased collaborative research, but not the productivity of lone researchers or of researchers located close to each other. By facilitating access to outside R&D and allowing it to be conducted on an international basis, ICT makes it possible to follow the open innovation model proposed by Chesbrough (2003), evidence of which has been provided by Laursen and Salter (2006).

Some studies have been conducted at the industry level. Using data from 26 industries and 10 European countries, Corrado, Haskel and Jona-Lasinio (2017) find that the returns on intangibles in a particular industry increase with the average ICT intensity across countries in that industry. Their intangibles contain innovative property (including R&D), and economic competencies (including organisational structure). They have not investigated the complementarity of ICT with individual components of intangible capital, in particular R&D. Chen, Niebel and Saam (2014) measure the intangible capital stock at a one-digit level in 10 European countries and examine whether the intensity of ICT (computing equipment, communications equipment and software) increases the return on intangibles. They find that the output elasticity of intangible capital increases with ICT intensity whatever measure is used for the latter. When intangibles are broken down into different components, complementarity with ICT shows up only for organisational capital and R&D. However, in a similar exercise on data for 33 Dutch industries, Polder (2015) fails to replicate these results for the Netherlands, suggesting that there might be cross-country differences.

Two kinds of data and two types of approach

We will conduct the analysis at two levels of aggregation: at the micro-level, using firm panel data from the Netherlands, and at the meso-level, using sector panel data from nine EU countries. Micro-data are characterised by a lot of heterogeneity, which will allow us to examine non-linearities. At the firm level, we can also distinguish between firms investing in R&D or ICT and those that do not. At a more aggregate level, some of the individual heterogeneity gets washed away, but in exchange there is the institutional heterogeneity across countries. Aggregate data may pick up the presence of spillovers without having to make specific assumptions about the way they occur when constructing externality variables. Given that we want a sufficient degree of freedom, we have decided to work at the meso- rather than the macro-level.

First, we take a descriptive look at the link between investments in ICT/R&D and the growth rate of TFP, primarily for both kinds of investment separately and then for their interaction. We will conduct the analysis at the extensive margin – that is to say, we will compare firms that invest and those that do not invest in R&D/ICT, and at the intensive margin – that is to say looking at the link between the distribution of R&D/ICT and TFP growth. This first approach delivers an in-depth insight into the correlation between firm performance and investment in ICT and R&D and a possible complementarity between both investments. Finally, we will conduct an econometric analysis where we regress TFP growth on investments in R&D and ICT, controlling for industry-specific effects, and formally test for the presence of complementarity between both investments.

It is difficult to establish a causal link between investment and performance. Besides the obvious simultaneity problem, various issues complicate the analysis. First, it should be acknowledged that the distribution of investment is not smooth. Because investment is subject to adjustment costs, it is not a continuous process, and thus firms do not necessarily invest in each period. Secondly, there may be non-linearities in the sense that effects on performance are only visible for specific ranges of intensity. In addition, the effect on performance could depend on other characteristics, which means that there could be substantial heterogeneity across firms or industries. The complementarity between R&D and ICT of interest can once again show up at two stages: at the extensive or intensive margin. There is complementarity at the extensive margin when firms or industries tend to invest either in both R&D and ICT at the same time or in neither of them, more formally when investing in both yields a higher return than the sum of the returns from each investment in isolation. There is complementarity at the intensive margin when the marginal return of investing in R&D increases with the amount invested in ICT or vice versa. The return can be measured in different ways. We will concentrate on TFP growth.

A micro-level perspective

The firm-level data used is sourced from Statistics Netherlands. Three surveys have been combined for our purposes: the Production Statistics (PS), the Investment survey (INV), and the Community Innovation Survey (CIS). All results presented here pertain to the sample whereby firms are covered in each survey. The years 2000-2012 are used, where odd years have been removed because of the biannual nature of the CIS. This yields 257 763 observations covering a total of 144 949 individual firms. Productivity is calculated using the PS data from a regression of labour productivity on capital intensity, controlling for industry effects, and assuming constant returns to scale. Output is measured as value added and capital is proxied by the depreciation costs. Firms are classified in industries (economic activities) according to the publication level of the National Accounts based on NACE Rev. 1. In total, 36 industries are differentiated, covering various economic activities[16].

Firms in the research and development sector (NACE code 73) have been dropped from the sample. Appropriate deflators at this level of aggregation have been used to convert nominal into real figures. The residual of this regression is our measure of TFP. By taking into account industry averages, TFP figures are comparable across firms from different industries. The bottom and top percentiles of TFP levels have been discarded to avoid sensitivity to outliers in TFP distribution. Productivity growth is then computed as the differences in log-transformed productivity TFP levels. Investment in ICT is taken from the Investment Survey. R&D and innovation variables are sourced from the biannual Community Innovation Survey. ICT investment is restricted to hardware, as software data have only been included in the Investment Survey since 2012.

The intensities of ICT and R&D investment are calculated by taking ratios of investment to labour input (in full-time equivalents), and are divided by the pertinent industry average. This makes it convenient to compare above- and below-average firms, and across industries. For the analysis, the distributions of the relevant variables are broken down into quintiles or deciles. For each sub-sample, these breakdowns are calculated separately. Moreover, these groups are defined by industry-year combinations separately, so that each industry and year is represented in each bin according to its share in the total number of observations, mitigating any issues of selectivity which are typical when looking at such a granular level of detail.

We start by examining whether firms' productivity performance varies with investments in ICT and R&D. Therefore, a comparison is carried out between firms that invest and those that do not (i.e. the extensive margin), as well as between firms in different parts of the investment distributions (i.e. the intensive margin)[17]. Panel (I) of Figure II.3.1 considers TFP growth rates of firms that invest in ICT and/or R&D, and those that do not invest in either.

16 The economic activities covered include (subsectors of) agriculture; mining and quarrying; manufacturing; electricity, water and gas; construction; wholesale and retail trade; accommodation and food services; transportation, storage and communication; business services; health care; and other services.

17 It is important to note that the results of this analysis do not imply or make claims about causality. The analysis is intended to illustrate the performance of firms that invest in ICT and R&D. a better performance of investing firms could mean that investment in ICT and R&D raises productivity, but also that firms invest in ICT and R&D because they are productive and, for instance, subject to fewer financial constraints. Moreover, since our analysis does not control for any additional factors, there could be other variables affecting both investment and performance.

Average TFP growth for the whole sample[18] is 1.1 %. Firms that do not invest in either ICT or R&D are substantially below that figure at 0.4 %, which is the lowest of all categories considered. Firms that invest in ICT perform only slight better, with 0.6 % TFP growth on average. The group that comprises firms that invest in R&D only has a TFP growth of more than twice the average (2.3 %); firms that invest in both ICT and R&D are slightly below that with 2.2 %. Therefore, there is no sign that ICT 'helps' R&D in realising productivity growth, or vice versa. However, it should be noted that this analysis concerns the extensive margin only, i.e. whether or not firms make an investment. Complementarities could be present in the intensive margin, which will be discussed next.

Turning to panels (II) and (III), we relate the average TFP growth to positive investments in either ICT or R&D in order to assess whether TFP performance varies as the intensity of investment increases. Looking at ICT investment, in contrast to the earlier finding related to the extensive margin, firms investing *more* in ICT do seem to show higher TFP growth. Another interesting result is that firms in the lowest quintile of the ICT distribution have higher TFP growth than those in the second and third quintile of the distribution. It is those latter two groups of firms in particular that bring down the overall average.

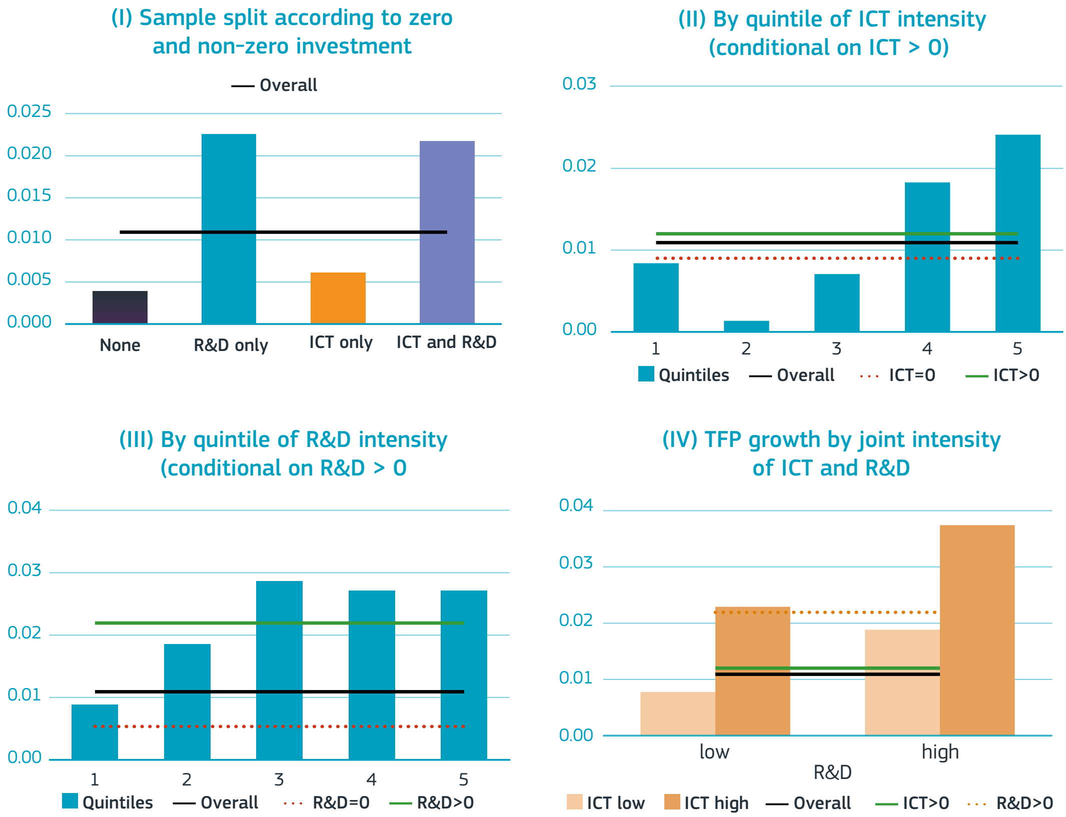
Considering R&D investment, in panel III, TFP growth is on average also higher for firms investing more in R&D. In this case, it seems that there is clear delineation between firms with lower levels of investments (first and second quintiles) and those with higher levels of investment (third to fifth quintiles). Once firms reach a level of R&D investment that corresponds to the average of the third quintile of the distribution, additional investments do not produce any proportional increase in terms of TFP growth beyond that achieved by firms in the third quintile of the distribution.

To summarise, panels I to III suggest that performance in terms of productivity seems to vary along the distribution of ICT and R&D intensity. While switching to ICT investment does not seem to be associated with higher TFP growth, higher levels of ICT intensity correlate positively with TFP growth. The positive correlation of R&D investment with TFP growth should also be attributed to firms with a higher R&D investment intensity.

Panel IV looks at the cross relation between low (below the median) and high (above the median) ICT and R&D vis-à-vis the growth of TFP. a central question in this paper is whether ICT can help R&D to increase productivity, and vice versa. If such complementarities are present, average TFP growth should increase in the intensity of one type of investment as the other type of investment increases as well. The results in panel IV offer *prima facie* evidence of complementarity between ICT and R&D. Indeed, the difference in TFP growth between high and low R&D-intensive firms is higher for high (the two right-hand columns) than for low R&D-intensive firms (the two left-hand columns). Vice versa, high R&D performers show a greater increase in TFP performance as ICT intensity shifts from low to high than low R&D performers. The highest TFP growth is achieved in the high R&D/high ICT column; the lowest TFP growth is in the low R&D/low ICT group.

18 The sample comprises firms present in all three surveys combined.

Figure II.3.1 TFP growth by ICT and R&D intensity, 2000-2012 (even years)



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: Statistics Netherlands: Production Statistics, Investment Survey, Community Innovation Survey (authors' own calculations)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii-3_1_i.xlsx, https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii-3_1_ii.xlsx, https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii-3_1_iii.xlsx, https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii-3_1_iv.xlsx

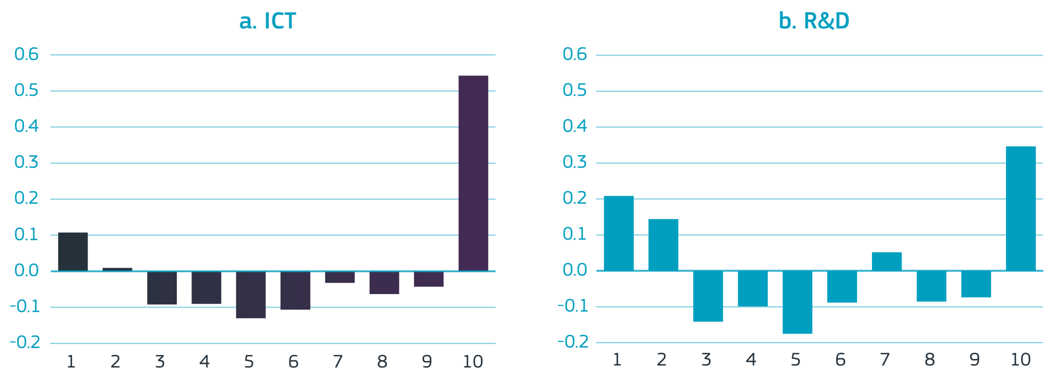
Next, we consider the investment behaviour of firms along the distribution of productivity. With the availability of firm-level panel data, the heterogeneity in firms' performance has become well documented (Bartelsman and Doms, 2000). Recently, Andrews, Criscuolo and Gal (2016) have attributed the dismal macroeconomic productivity performance since the beginning of the new century to a growing gap between 'leaders' and 'laggards'. That is, although a clear slowdown in productivity growth can be seen in the aggregate numbers, nonetheless, frontier firms seem to have experienced significant productivity growth while a larger proportion of firms is falling behind with marginal growth numbers. An important question for policy is to identify the characteristics of firms in different parts of the productivity distribution. Who are the top performers, and who are the firms lagging behind? Andrews et al. (2016) show that frontier firms are typically larger, more profitable, younger and more likely to patent and be part of a multinational group than other firms.

Figure II.3.2 shows ICT and R&D expenditures by growth of TFP. We consider the entire distribution of TFP growth, not only the leaders versus laggards. Frontier firms can be thought of as those in the top decile. ICT and R&D expenditures are expressed relative to the number of workers (in full-time equivalent (fte)), and the ratios are divided by the relevant industry averages. Figure II.3.2 shows deviations from the industry averages (e.g. 0 means on par with the firm's industry)[19].

Panel I of Figure II.3.2 shows that ICT investments seem to be strongly concentrated among those firms that are in the top 10% of the TFP growth distribution. On average, firms in the highest TFP growth decile have ICT investments of 54% above the industry average. By contrast, they are below average in the rest of the TFP growth distribution, except in the two bottom deciles. In the bottom decile, ICT investments appear to be 10% above average. The pattern for R&D is roughly similar (panel II). However, the TFP growth distribution suggests that R&D expenditure is relatively more concentrated not only in the top decile, but also in the bottom deciles. Firms with the strongest TFP growth spend 35% more on R&D compared to the industry average, while expenditure on R&D is relatively high in the bottom two deciles as well, with 21% and 14% above average, respectively.

In conclusion, it can be noted that there is a U-shaped distribution of R&D and ICT per fte as productivity growth increases. The high intensities at the two extremes of the TFP growth distributions could be explained as follows. At the top end, the explanation is quite straightforward. Firms that are close to the frontier, in terms of technology adoption or best practice, invest relatively more in R&D and ICT to stay at or push out the frontier, and they also probably have the means to finance those investments. Those at the bottom of the distribution could be small firms, maybe

Figure II.3.2 **ICT and R&D intensity relative to the industry average, by deciles of the distribution of TFP growth, 2000-2012 (even years)**



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Statistics Netherlands: Production Statistics, Investment Survey, Community Innovation Survey (authors' own calculations)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_2.xlsx

19 ICT and R&D distributions have been cleaned to exclude the most extreme observations. The TFP distribution was not cleaned for this analysis. Commonly, outliers are dealt with by setting them at a value in line with the bottom or top deciles. Therefore, assigning any potential outliers to the bottom or top decile does not make a difference to any of our results.

start-ups, that have to invest in ICT and R&D because they are newcomers, investing in the latest technology, or in order to grow. However, these firms may not have the capacity yet to be very productive because of adjustment costs, lack of experience, and their size does not allow them to benefit from returns to scale. As they grow, if they survive, they become more productive, moving up the learning curve, and they need to invest relatively less compared to the number of workers they have in ICT equipment and R&D.

Finally, we present the results of a simple regression analysis relating firms' TFP growth performance to ICT and R&D investment. The descriptive analysis above shows that there may be relevant non-linearities in the relation between productivity and investment in ICT and R&D. In particular, there may be differences in the correlations depending on whether the investment intensity is high or low. In addition, there could be complementarities between ICT and R&D, meaning correlations are stronger for firms that conduct joint investment.

This leads us to adopt the following specification for TFP growth:

$$\begin{aligned} tfpg = {} & \beta_1 ICT + \beta_2 R\&D + \beta_3 I\,[\text{ICT high}] + \beta_4 I\,[\text{R\&D high}] \\ & + \beta_5\, I\,[\text{ICT high}] \times ICT + \beta_6 I\,[\text{R\&D high}] \times R\&D \\ & + \beta_7 ICT \times R\&D + \beta_8 I\,[\text{ICT high}] \times I\,[\text{R\&D high}] \\ & + \beta_9 (\text{ICTxR\&D}) \times I\,[\text{ICT high}] \times I\,[\text{R\&D high}] \end{aligned}$$

where tfpg denotes TFP growth, ICT and R&D are investment intensities (i.e. investment per fte), in deviation from the industry averages, and *I [ ]* is an indicator of whether ICT or R&D are higher than the corresponding medians. That is *I* [ ] = 1 indicates that the firm is research-or ICT-intensive. All variables are in logs. The interpretation of the coefficients is as follows: first, β_1 and β_2 measure the linear effect of the investment intensity of ICT and R&D on TFP (growth), whereas β_3 and β_4 measure whether firms that have a relatively high intensity of investment display a higher-than-average TFP growth. Then, β_5 and β_6 measure whether the linear effect in the high-intensity groups deviates from the overall linear effect. In a similar vein, β_7 assesses whether there is complementarity between ICT and R&D, and β_8 and β_9 whether such a complementarity is stronger in the high-intensity groups. We prefer to estimate a TFP growth equation rather than a TFP level equation, because our data refer to investments. What matters for TFP are the stocks of R&D (a proxy for the stock of knowledge) and ICT, while the corresponding investments matter more for the explanations of TFP growth. It should be noted that these coefficients should be seen as estimates of the excess effects of ICT and R&D on value-added growth – i.e. the effect over and above the 'normal returns' which equal the respective cost shares and are already included in the TFP measure. Thus, an insignificant coefficient implies that the contribution of ICT and R&D to the growth of output (or labour productivity) is in line with its cost share.

Figure II.3.3 reports the results. We have experimented with two measures of TFP: one where factor weights sum up to 1, i.e. constant returns to scale are imposed, and one that allows for non-constant returns to scale. As the results are basically the same for both measures, we report only those obtained with constant returns to scale imposed. The results point to ICT having a significant positive correlation with TFP growth, but only in the high-intensity group. The intensity of R&D investment has a significant positive correlation that is similar for both the low- and high-intensity groups. There is no evidence of complementarity between R&D and ICT.

In a separate estimation, we simplified the above specification and only examined the excess effect by the interaction between R&D and ICT – i.e. we ignored all the terms that involve the intensity dummy *I* [ ] and made β_3, β_4, β_5, β_6, β_8, and β_9 equal to zero. We used a less-flexible model, but in return the estimation was performed for each 2-digit industry separately. We only found a significant positive interaction term (i.e. for coefficient β_7) pointing to complementarity between ICT and R&D for rubber and plastics, basic metal, wholesale, transport services, environmental services and other manufacturing, and a significant negative coefficient pointing to substitutability for transport on land.

Figure II.3.3 Regression of TFP growth on ICT and R&D, Dutch firm data, 2000-2012

	Coef.	Std. Err.	p-value
ICT	-0.007	0.008	0.370
High ICT (dummy)	0.018	0.014	0.185
ICT*High ICT[1]	0.029	0.012	0.016*
R&D[1]	0.008	0.005	0.087*
High R&D (dummy)	0.000	0.012	0.997
R&D*High R&D	-0.001	0.010	0.933
ICT*R&D	0.001	0.002	0.795
High ICT*High R&D (dummy)	-0.019	0.013	0.136
(ICT*R&D)*(High ICT*High R&D)	0.001	0.001	0.362
Constant	0.005	0.014	0.737

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: Statistics Netherlands: Production Statistics, Investment Survey, Community Innovation Survey (authors' own calculations)
Note: [1]p-value: * = significant at 5%
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_3.xlsx

A meso-level perspective

At the meso-level, we used data from the 2016 release of the EU-KLEMS data (Jäger, 2016) to cover nine countries (Austria, Germany, Spain, Finland, France, Italy, the Netherlands, Sweden and the UK), and 32 manufacturing and service industries at the NACE 2 2-digit level, over the period 1995 to 2014. ICT comprises computing and communication equipment, software and databases. For labour, we used hours worked, and the non-ICT capital stock comprises non-residential buildings, transportation equipment and other machinery. Output is measured as value added. Following the European System of National Accounts ESA2010, R&D is considered as a separate investment rather than an intermediate input. Value added has been corrected for this capitalisation of R&D. As in the micro-analysis, TFP growth is determined by first estimating a Cobb-Douglas production function with constant returns to scale, retrieving the residual (all in logarithms) and then taking the differences in the residual measure of TFP growth. Swedish and UK data have been converted into euros. The nominal investment and value-added data have been deflated by appropriate deflators (base year = 2010). The capital stock data by industry and asset type are taken directly from Eurostat and constructed by the national statistical offices using the perpetual inventory method.

At the industry level, it is impossible of course to analyse the extensive margin as in every industry there is at least one firm that carries out ICT and/or R&D. Therefore, we have concentrated on the intensive margin. In Figure II.3.4, we compare the figures of TFP growth along the quintiles of the distributions of ICT intensity (in panel a) and R&D intensity (in panel b). The distribution quintiles are computed separately for each industry. Because of differences in institutions, policies and industrial specialisations, it makes little sense to assume the same distribution across sectors per country. There is probably more homogeneity in the distribution of R&D and ICT intensity (in millions of euro per hour worked) per industry than per country. For every industry, we have included observations on ICT and R&D that vary across countries and over time. We have plotted the average TFP growth corresponding to each quintile of the distribution of ICT or R&D for the 32 industries.

The highest rate of annual TFP growth occurs around the middle of the distribution of ICT intensity. But higher rates of TFP growth are found at both extremes of the distribution of ICT investment per hour worked than at the second and fourth quintile. At the lower tail of the distribution of ICT intensity, TFP growth declines as more is spent on ICT per hour worked, but at the high end of the distribution, TFP growth is positively related to ICT intensity. In contrast, there seems to be a more or less monotonically increasing link between R&D intensity and TFP growth. Interestingly, however, the returns to R&D seem to jump between the fourth and fifth quintile, indicating an excess return for the most research-intensive countries or in the periods where R&D intensity was highest.

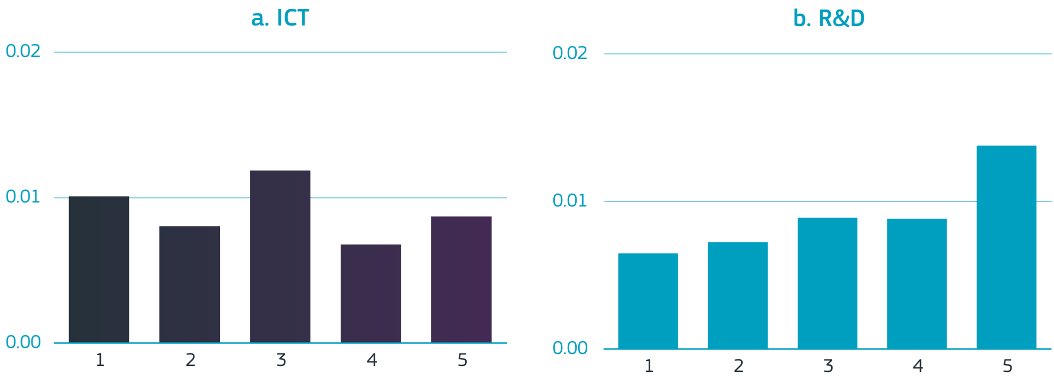
In Figure II.3.5, we compare the intensities of ICT (in panel a) and R&D (in panel b) across the deciles of the distribution of TFP growth where the intensities are compared to the mean intensities in the respective industries over the nine countries and 20 years[20]. There is no clear pattern for ICT, except that industry observations that correspond to above median TFP growth figures show above-average ICT investments per hour worked. On the R&D front, however, we observe once again markedly higher-than-average R&D intensities when TFP growth is high, and a slightly higher R&D intensity in the first decile compared to the next five deciles. This phenomenon could be explained by the presence of adjustment costs or lags between the time the R&D investments are made and when the benefits of those investments are earned. Or it could be, although this hypothesis seems less plausible, that R&D has a low rate of return in a particular country.

In Figure II.3.6, we examine any evidence of complementarity between R&D and ICT at the meso-level. We compare TFP growth when ICT intensity is both below and above the median, conditional on R&D intensity being below or above the median value of its distribution per industry. We have noticed that, when R&D per hour worked is low, TFP growth is higher when more than the median is invested in ICT. However, when R&D is high, TFP growth is lower when more than the median is invested in R&D. Therefore, on the data from the whole sample, it cannot be concluded that R&D and ICT are complements. If that was the case, we would have observed an even higher increase in TFP growth when R&D and ICT are high than when ICT is high and R&D is low. One explanation could be that both contribute to productivity growth but do not complement each other, ICT being devoted more to production, logistics and marketing than to R&D activities. It could also be that the complementarity would show up in more direct measures of research output, such as innovations, patents or publications and only appear much later in the productivity figures.

Nevertheless, there seems to be heterogeneity across industries in this respect. If we do the same computation of double differences for each of the 32 sectors individually, we see apparent signs of complementarity for 17 of them, as shown in Figure II.3.7. Of course, this kind of descriptive analysis does not indicate whether these differences in TFP growth are significantly different from zero.

20 Observations with missing values for TFP growth or R&D and ICT investment are deleted.

Figure II.3.4 TFP growth by quintiles of ICT and R&D intensity - EU KLEMS data, 32 industries, 9 countries, 1995-2014



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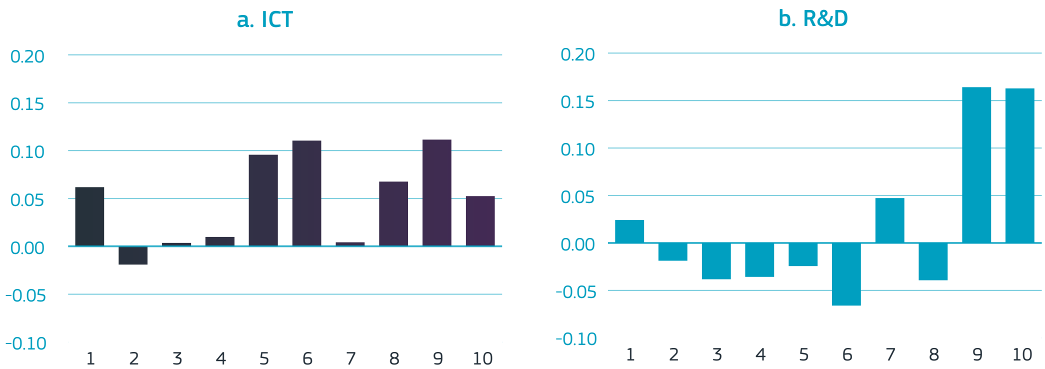
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: EU KLEMS Growth and Productivity Accounts 2017 Release, see Jäger (2017).

Reference: Jäger, K. (2017), EU KLEMS Growth and Productivity Accounts 2017 Release, Statistical Module, The Conference Board. http://www.euklems.net/TCB/2017/Metholology_EU%20KLEMS_2017.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_4.xlsx

Figure II.3.5 ICT and R&D intensity by decile of TFP growth - EU KLEMS data, 32 industries, 9 countries, 1995-2014



Science, Research and Innovation performance of the EU 2018

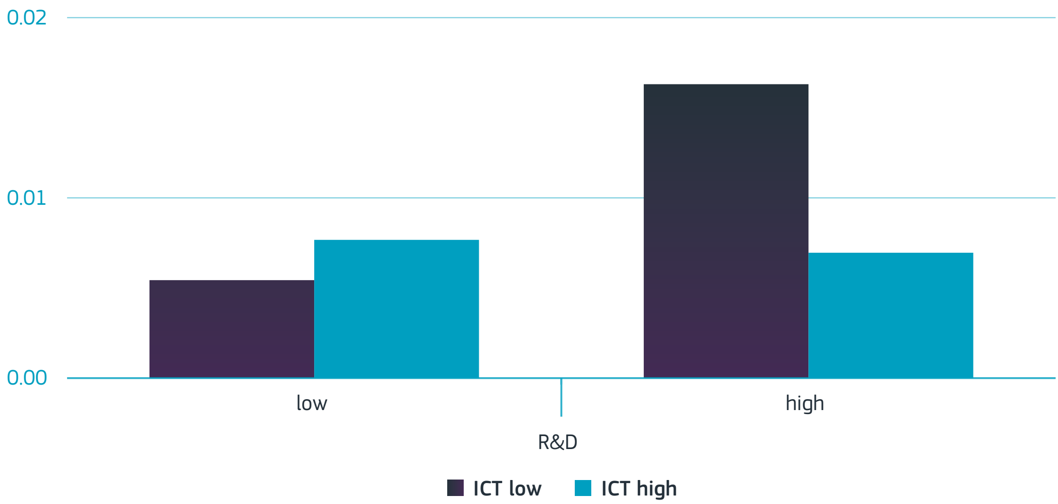
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: EU KLEMS Growth and Productivity Accounts 2017 Release, see Jäger (2017).

Reference: Jäger, K. (2017), EU KLEMS Growth and Productivity Accounts 2017 Release, Statistical Module, The Conference Board. .http://www.euklems.net/TCB/2017/Metholology_EU%20KLEMS_2017.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_5.xlsx

Figure II.3.6 Growth of TFP by joint intensity of ICT and R&D - EU KLEMS data, 32 industries, 9 countries, 1995-2014



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: EU KLEMS Growth and Productivity Accounts 2017 Release, see Jäger (2017).

Reference: Jäger, K. (2017), EU KLEMS Growth and Productivity Accounts 2017 Release, Statistical Module, The Conference Board. .http://www.euklems.net/TCB/2017/Metholology_EU%20KLEMS_2017.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_6.xlsx

Figure II.3.7 Complementarity across industry - EU KLEMS data, 31 industries, 9 countries, 1995-2014[1,2]

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: EU KLEMS Growth and Productivity Accounts 2017 Release, see Jäger (2017).
Reference: Jäger, K. (2017), EU KLEMS Growth and Productivity Accounts 2017 Release, Statistical Module, The Conference Board.
http://www.euklems.net/TCB/2017/Methodology_EU%20KLEMS_2017.pdf
Notes: [1]Each bar represents the double difference in TFP growth, between above and below median ICT intensities, for below and for above median R&D intensities (as in Figure II.3.6). [2]Coke and refined petroleum products was dropped from Figure II.3.7 as the magnitude was not comparable to other industries.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_7.xlsx

Figure II.3.8 Labour productivity, system GMM, EU KLEMS industry data, 9 countries, 1995-2014[1,2]

Dependent variable: labour productivity	coefficient	t-statistic
N = 4509		
Labour productivity (lagged)	0.911 ***	214.62
Employment	-0.016	-0.73
Capital intensity		
ICT	0.044 ***	7.03
Tangible non-ICT	0.379 ***	13.37
Software and databases	0.091 ***	6.73
R&D	-0.003	-0.46
Interactions of capital intensities		
ICT and tangible non-ICT	-0.007 ***	-3.35
ICT and software/databases	0.008 ***	4.67
ICT and R&D	-0.001	-0.92
Tangible non-ICT and software/databases	0.009 ***	6.44
Tangible non-ICT and R&D	0.000	0.10
Software databases and R&D	0.000	0.05
Trend	-0.001 ***	-4.18

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: EU KLEMS Growth and Productivity Accounts 2017 Release, see Jäger (2017).
Reference: Jäger, K. (2017), EU KLEMS Growth and Productivity Accounts 2017 Release, Statistical Module, The Conference Board. http://www.euklems.net/TCB/2017/Metholology_EU%20KLEMS_2017.pdf
Notes: [1]All variables are in logs. Labour productivity is real value added over hours worked. The capital intensities are in terms of hours worked. The instruments used are two and more lagged inputs in the first difference equation and one lagged growth rate in the level equation. Estimation includes time and country dummies. [2] *** = significant at 1% level of confidence.
Stat. link:. https://ec.europa.eu/info/sites/info/files/srip/partii/partii_3/figure_ii_3_8.xlsx

Finally, we have estimated a labour productivity equation with productivity persistence, derived from a Cobb-Douglas production function, allowing for returns to scale and letting the various capital stocks interact with each other. The estimation was performed using the generalised method of moments estimator known as the GMM system. This is a fairly unrestricted specification and an estimation method that tackles problems of endogeneity typical in this kind of model. Under pairwise complementarity, the interaction terms should have a positive and significant coefficient. Software and databases have been taken out of the composite ICT capital stock to form a separate capital stock. There is high persistence in labour productivity (shown by the positive and significant coefficient of lagged labour productivity), and constant returns to scale cannot be rejected (as the coefficient for employment, which captures the deviation of the sum of capital and labour output elasticities from one is not significant). Software and databases, tangible ICT and non-ICT capital are positively correlated to labour productivity, but in this dataset the stock of accumulated R&D does not appear to be significant, contrary to most studies on the topic. This could be due to double-counting if R&D labour and the various capital inputs devoted to R&D are not subtracted from the conventional inputs (Schankerman, 1981). Tangible ICT and non-ICT capital appear to be substitutes, whereas tangible ICT capital and software and databases are complements, as expected. Non-ICT capital as well as software and databases also appear to be complements, although between R&D and hardware or software ICT there is no sign of complementarity.

Conclusion

The aim of this chapter was to test whether there is any complementarity between investments in R&D and investments in ICT, in the sense that investing in one increases the return on investing in the other. The returns were measured by TFP growth. The analysis was conducted from various angles: using micro data from the Netherlands and industry data from nine European countries, examining the TFP growth performance across the joint distribution of the two types of investment, looking for complementarity at both the extensive and intensive margin, and estimating production functions sufficiently flexibly to capture the returns from joint investments.

There is only weak evidence of complementarity along the different approaches to the problem. It is only by looking at the differences in productivity growth for high and low intensities of R&D and ICT at the firm level that some weak signs of complementarity are evident. This evidence is not confirmed in a regression analysis either on firm or on industry data. However, there appears to be a lot of heterogeneity across industries with respect to the magnitude of complementarity, with some evidence of it for about half of our industries. Furthermore, the visual evidence should be confirmed by a more extensive multivariate analysis, which would also control for other confounders of productivity growth and would test whether statistically speaking the observed differences in TFP growth across the joint densities of R&D and ICT investments are significantly different from zero. To do this kind of analysis, more data would be needed at both the firm and industry level.

It is also possible that we would observe more complementarity between the two investments if we considered other measures of performance, such as publications, patent counts, co-publications and co-patenting, scientific discoveries and so on – i.e. innovation output measures rather than measures of economic performance. As mentioned in the introduction, various studies have found evidence of complementarity in terms of innovation output. It is hard to believe that all the progress in ICT over the last 50 years (computers, software, internet, cloud computing, skype, teleconference and so on) has had no effect on the productivity of scientific research. It has changed the way research is organised and enlarged the researchers' toolbox. All this may lead to a better research outcome and yet be hardly visible or even invisible in the productivity statistics. There are various reasons for that. First, as it opens up the realm of research opportunities, ICT may also increase the costs of doing research. Firms need to buy the appropriate equipment, continuously update their software, train their workers to use the ICT equipment and reorganise their way of operating in an ICT-dominated environment. Second, even if more knowledge is created thanks to progress in ICT, it may take time for that knowledge to be converted into new products or processes, and even more time and effort to bring the new products successfully to market. Third, the new ways of communicating, gathering and storing information may create their own hurdles in terms of learning, reorganisation of work and too much information. Finally, while the adoption of ICTs, such as PCs and the internet, may have significantly boosted the effectiveness and speed of R&D, as their usage has become ubiquitous across firms and industries, it may become more challenging to identify such a positive effect from cross-sectional information or panel data covering only a short and recent period.

However, there seems to be a positive correlation between R&D, respectively ICT, and productivity growth. Although the relationship is non-linear, firms or industries that invest more in R&D or ICT experience higher productivity growth. Normally, companies are aware of this positive correlation and invest accordingly. It may be that there are market failures which prevent firms from investing as much as they would like to. This is where policymakers can intervene to overcome these market failures and enable those investments to occur which are beneficial to individual firms and society as a whole. Examples of such market failures include lack of access to finance, too little or too much competition, and overzealous employment protection legislation.

In the absence of complementarity between R&D and ICT investments, a stimulating measure in favour of R&D, such as a grant or tax incentive, will not automatically increase the return on an investment in ICT, and vice versa. Since, as our analysis has shown and many previous studies have concluded, both R&D and ICT eventually increase TFP growth, it is still beneficial to invest in them, although from a policy perspective it is not possible, so to say, to kill two birds with one stone. Each has to be stimulated separately without relying on the possibility that they may reinforce one another.

Lacking any evidence on complementarity between ICT and R&D, a policy goal could be to stimulate such mutually reinforcing benefits. There may be various ways to achieve this. One would be to increase the research in ICT to push the limit of what can be achieved with this technology even further. a second one would be to allow this technology to reach its full potential by making science and innovation more open, and sharing the knowledge instead of hiding it in order to exploit a temporary knowledge-based monopoly.

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