Are Intangibles More Productive in ICT-Intensive Industries? Evidence from EU Countries

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Abstract

Using sectoral intangible investment data we confirm that intangible capital is a significant determinant of labour productivity growth. The sectoral setting further allows us to identify the differential impacts of intangible capital across industries with varying degrees of ICT intensity. Intangible capital appears to be significantly more productive in ICT-intensive sectors than in those that use little ICT. This finding remains robust across various alternative industry ICT intensity measures and aligns with the prior firm-level studies that place emphasis on the complementary role of intangible assets in ICT investment.

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1. Introduction

Since the influential work of Corrado, Hulten and Sichel (2005, 2009; hereafter CHS), which standardised and popularised the approach of measuring business investments in intangible assets, the role of intangibles in determining productivity and economic growth has gained momentum among scholars and policymakers. By including intangibles both as an input and an output, the growth accounting exercise, with assumed returns based on the user cost of capital, shows that the rate of labour productivity growth in the U.S. is about 10-20 percent higher relative to the conventional framework that ignores intangibles. In many cases, capital deepening becomes the dominant source of growth in labour productivity (CHS, 2009).[1] Consistent results also emerge in studies that rely on econometric estimation. For a sample of E.U. countries, Roth and Thum (2013) find intangible capital to be an important source of growth that is able to explain a significant portion of cross-country variances in labour productivity growth.

These recent findings have not only reduced, in Abramovitz's (1956) words, the "measure of our ignorance", as multifactor productivity (MFP) is no longer the prime source of growth, but they also suggest potential new research. This potential arises from the fact that we now know where most productivity growth comes from (i.e. capital deepening). That may lead us to better understand why productivity growth observed after 1995 tends to be much higher in industries that intensively use information and communication technologies (ICT). According to Stiroh (2002), all of the industry-specific contributions to aggregate productivity in the U.S. after 1995 originate in those industries that either produce or use ICT most intensively, while non-ICT intensive industries make no contribution on net.[2] Though having a clear impact, ICT alone could not be identified as the main driver of the large differences in cross-industry labour productivity growth. As argued by Bresnahan, Brynjolfsson and Hitt (2002) and Brynjolfsson and Hitt (2000, 2003) using firm-level financial data, investment in ICT per se is not likely to have a large impact on productivity. Productivity gains can only be fully realised when ICT capital deepening is complemented with investments in intangibles, such as organisational change. Further evidence is shown in Bloom, Sadun and Van Reenen (2012) who find that the U.S. ICT-related productivity advantage (relative to European companies) is primarily due to its tougher 'people management' practices.

In this paper we ask a similar question at the sectoral level. From previous research we know that intangible investment at the sectoral level represents a significant source of growth (Niebel, O'Mahony and Saam, 2013). This leads us to further explore whether this contribution

[1] In a recent paper by Corrado et al. (2013), capital deepening is found to account for 65.4 percent of labour productivity growth in the EU and 58.4 percent in the United States.

[2] In some cases, non-ICT intensive industries even make a negative contribution to aggregate productivity growth (Stiroh, 2002).

is higher in ICT-intensive sectors than in others. Aggregate evidence already shows that intangible assets play a role in explaining the gap in productivity between the U.S. and continental Europe (Corrado et al., 2012) and the lower growth contributions from investment in ICT in Europe is another driver of this productivity divergence (Van Ark, O'Mahony and Timmer, 2008). It seems possible that these two forces interact: The poorer productivity performance in Europe may not only be the result of its lower level of investment in ICT (relative to the U.S.), but *possibly* also due to its lower level of investment in intangibles, which leads to a less effective exploitation of ICT.[3]

The INTAN-Invest database represents the first source of estimates of intangible investment at the level of the market economy for a number of European countries and the U.S. This database harmonised work produced by the COINVEST and INNODRIVE projects as well as The Conference Board (Corrado et al., 2012; European Commission, 2013). Used in conjunction with the EUKLEMS data, it provides evidence on the macroeconomic importance of intangible assets in a national accounting framework. While the interaction between ICT-intensity and specific intangibles (such as organisational capital) has been investigated in a number of microeconomic studies, evidence at the sectoral and macroeconomic level for assets other than research and development (R&D) has been lacking until recently. Corrado, Haskel and Jona-Lasinio (2014) are the first to examine whether the contribution of intangibles to productivity growth depends on the ICT-intensity of an industry using cross-country data. Their analysis follows a difference-in-difference approach akin to Rajan and Zingales (1998) by interacting the industry ICT intensity with the level of intangible investment in the country. A major limitation of their analysis is that it does not account for differences in intangible investment across industries. Corrado et al. (2014) find an interaction between ICT intensity and intangible investment that is both statistically and economically significant. Meanwhile the overall magnitude of the output elasticity of intangibles remains implausibly large with values ranging between 0.4 and 0.7 depending on the method of estimation.

With a breakdown of the INTAN-Invest data to the industry level developed by Niebel, O'Mahony and Saam (2013) in the INDICSER project[4], we re-examine the productivity of intangible assets in ICT-intensive industries and add to the literature by shedding light on the magnitude of the output elasticities. Following Stiroh (2002) and Corrado, Haskel and Jona-Lasinio (2014), we define an industry characteristic that ranks the industries by the extent to which they rely on the use of ICT (i.e. industry ICT intensity). We then interact this intensity indicator with the growth of intangible capital, ICT capital, and non-ICT capital. These three

[3] According to Corrado et al., (2013), the U.S. has a much higher propensity to invest in intangibles than the EU. Between 1995 and 2009 (the period during which the productivity gap widens,) intangible investment as a share of GDP is averaged around 10.6 percent for the U.S.; while for the EU the share is only about 6.6 percent.

[4] This project is funded by the 7th Framework Programme of the European Commission.

interaction terms allow us to directly test if the productive potential of a certain capital input is dependent on how intensively an industry employs ICT. Among the three interactions, only the first interaction coefficient turns out to be significantly positive in a robust way, suggesting that only intangible capital is significantly more productive in ICT-intensive industries. This finding remains consistent across a wide range of alternative ICT-intensity measures and aligns well with the prior firm-level studies on the interaction between IT investment and investment in intangible assets (see Basu, Oulton, and Srinivasan (2004) for a discussion and references). In our preferred specification, we find a mean output elasticity of intangible assets of 12.6 percent. Taking into account the interaction with ICT intensities, this elasticity varies between 2 percent at the lowest quartile of ICT intensities and 15 percent at the highest quartile.

The remainder of this paper is organised as follows. Section 2 briefly reviews the capitalisation of intangible capital and how it changes the traditional growth accounting framework. Our econometric approach to investigate the impact of intangible capital accumulation on labour productivity growth is outlined in Section 3. Section 4 provides some basic descriptive statistics on the sectoral intangible investment data we use, and elaborates on the proxy of industry ICT intensity measures. Empirical analyses and robustness checks are presented in Section 5. Section 6 discusses the main limitations of the paper and ends with concluding remarks.

2. Capitalisation of Intangibles

Prior studies of economic growth have traditionally focused on the contribution of tangible capital, such as plants, equipment, vehicles, and buildings. While the importance of these assets as sources of growth is well acknowledged, they explain merely a small fraction of growth using the conventional growth accounting framework. According to the estimates of CHS (2005), traditional tangible capital (excluding ICT) can explain only about 10 percent of the U.S. productivity growth for the period 1995-2003. Over the last fifteen years, studies have increasingly focused on information and communication technologies (hardware and software). As shown in CHS (2009, p.679), ICT capital deepening alone accounts for about 25 percent of the U.S. productivity growth between 1995 and 2003. Though making a large contribution, over 51 percent of the growth still remains unexplained and is attributed to the growth of multifactor productivity (MFP). To better understand the factors hidden behind MFP, interest in recent years has increasingly turned towards identifying intangible capital as a source of growth. For instance, in 2011 the Organisation for Economic Co-operation and Development began a project on "new sources of growth", focusing in particular on knowledge-based assets (OECD, 2012). The point of departure for capitalising these knowledge-based assets, which we refer to as intangible assets, is the idea that whenever resources are used to provide for *future* rather than *present* consumption and production, they qualify as capital investment. As rigorously argued in CHS (2005) and in Corrado and Hulten (2010), much of the spending on intangibles, such as R&D, product design, marketing, and spending on organisational structures, satisfy this criterion and deserve to be capitalised as business investments. The need to incorporate these intangible assets into national income accounting is also discussed in Nakamura (2010).

CHS (2005) identified most of the items commonly thought to represent private business spending on intangible assets and classified them into three broad categories: (a) computerised information, (b) innovative properties, and (c) economic competencies.[5] Denoting intangible capital by the letter R, the output of the intangibles by the letter N, and assuming that each input is paid the value of its marginal product, the GDP identity is then expanded to include the flow of these new intangibles on the product side (i.e. $N(t)$) and the flow of services provided by the intangible capital stock on the income side (i.e. $R(t)$):

$$P^Q(t)Q(t) = \overbrace{P^C(t)C(t) + P^I(t)I(t) + \underbrace{P^N(t)N(t)}_{added}}^{Product\ side} = \overbrace{P^L(t)L(t) + P^K(t)K(t) + \underbrace{P^R(t)R(t)}_{added}}^{Income\ side} \quad (1)$$

The price $P^R(t)$ is the user cost of the services provided by intangible capital, a source of income that is absent prior to capitalising the expenditures on intangibles. Intangible capital is now both a productive input and a part of the adjusted output. Hence, the concept of GDP is more comprehensive and larger in magnitude than conventionally defined. The traditional sources-of-growth model that allocates the growth rate of output to the share-weighted growth rates of the inputs plus a residual is accordingly modified as:

$$\begin{aligned} g_Q(t) &= \overbrace{s_c(t)g_c(t) + s_I(t)g_I(t) + \underbrace{s_N(t)g_N(t)}_{added}}^{Output} \\ &= \overbrace{s_L(t)g_L(t) + s_K(t)g_K(t) + \underbrace{s_R(t)g_R(t)}_{added} + g_A(t)}^{Input} \end{aligned} \quad (2)$$

where the output growth rate $g_Q(t)$ now includes growth of intangible assets. It equals the share-weighted contributions from the growth in labour $g_L(t)$, tangible capital $g_K(t)$, the newly added intangible capital $g_R(t)$, plus multifactor productivity $g_A(t)$.

[5] For more detailed discussions on measurement issues, such as the deprecation rate for certain specific intangible asset or price deflators needed to calculate the real investment in intangibles, see CHS (2005).

3. Econometric Approach

The main model of interest builds upon the following general production function:

$$V_{c,i,t} = A_{c,i,t}F(L_{c,i,t}, \boldsymbol{K}_{c,i,t}) \tag{3}$$

where V denotes value added adjusted to include intangible capital: $VA_{adj} = VA + \sum_{k \in INT} I_k$. This is our preferred measure of output at the sectoral level, since labour productivity based on value added is measured more accurately in the presence of outsourcing, a feature commonly observed at the industry level.[6] A is the Hicks-neutral technology parameter that allows for changes in productivity with which labour (L) and capital (K) are transformed into output. The subscripts c, i, t indicate country, industry, and year. Suppose total capital input $\boldsymbol{K}$ is composed of three types: non-ICT (NICT), ICT, and intangible capital (INT) and assume a Cobb-Douglas functional form for the production function. Then equation (3) can be written as:

$$V_{c,i,t} = A_{c,i,t} \cdot L^{\alpha}_{c,i,t} \left(K^{NICT}_{c,i,t}\right)^{\beta_1} \left(K^{ICT}_{c,i,t}\right)^{\beta_2} \left(K^{INT}_{c,i,t}\right)^{\beta_3} \tag{4}$$

where L denotes labour input measured by labour services and $\boldsymbol{K}$ is the capital services provided by non-ICT, ICT, and intangible capital. Their output elasticities are labelled by the superscripts α and β_x, $x = (1, 2, 3)$. After taking logs and first differences and assuming constant returns to scale, we can rewrite equation (4) as follows:

$$\Delta(v - l)_{c,i,t} = \beta_1 \Delta(k^{NICT} - l)_{c,i,t} + \beta_2 \Delta(k^{ICT} - l)_{c,i,t} + \beta_3 \Delta(k^{INT} - l)_{c,i,t} + \mu_{c,i,t} \tag{5}$$

where lower-case denotes variables in natural logarithms. The efficiency term A is modelled as part of the error term $\mu_{c,i,t}$. For reasons explained below, the error term is decomposed into a country-industry specific fixed effect $\omega_{c,i}$, a full set of time dummies τ_t, and an idiosyncratic component $\epsilon_{c,i,t}$. In order to examine whether the productive potential of the capital inputs differs across industries with varying degrees of ICT intensity, we interact each capital input with the ICT intensity indicator denoted by $D^{ICT}_{c,i}$:

$$\Delta(v - l)_{c,i,t} = \gamma_1 \Delta(k^{NICT} - l)_{c,i,t} * D^{ICT}_{c,i} + \gamma_2 \Delta(k^{ICT} - l)_{c,i,t} * D^{ICT}_{c,i} + \gamma_3 \Delta(k^{INT} - l)_{c,i,t} * D^{ICT}_{c,i}$$
$$+ \beta \boldsymbol{X}' + \omega_{c,i} + \tau_t + \epsilon_{c,i,t} \tag{6}$$

[6] See Schreyer and Pilat (2001) for a discussion on output measures between *value-added* and *gross output.*

This practice has its antecedents in literature that analyses the impact of financial development on industry growth (Rajan and Zingales, 1998)[7] and has been used in the previous work on productivity in ICT-intensive sectors (Corrado, Haskel and Jona-Lasinio, 2014). This specification allows us to directly examine whether capital inputs are more productive in more ICT-intensive industries. If our hypothesis holds true, we would expect to find $\gamma_3 > 0$ with conventional statistical significance, while γ_1 and γ_2 should not differ from zero. That is to say, among the three capital types only intangible capital would generate a *higher* productivity growth in *more* ICT-intensive industries because of the complementarity hypothesis proposed in prior firm-level studies. $\boldsymbol{X}'$ indicates a vector of the main variables including the growth of three capital inputs: k^{NICT}, k^{ICT}, and k^{INT}. To ensure a meaningful interpretation of the coefficients of the main variables, we estimate the interacted regression in a demeaned form, following the suggestion of Balli and Sørensen (2013):

$$\Delta(v-l)_{c,i,t} = \gamma_1 \Delta\left(\widetilde{k_{c,i,t}^{NICT}}\right) * \left(\widetilde{D_{c,i}^{ICT}}\right) + \gamma_2 \Delta\left(\widetilde{k_{c,i,t}^{ICT}}\right) * \left(\widetilde{D_{c,i}^{ICT}}\right) + \gamma_3 \Delta\left(\widetilde{k_{c,i,t}^{INT}}\right) * \left(\widetilde{D_{c,i}^{ICT}}\right)$$
$$+\beta \boldsymbol{X}' + \omega_{c,i} + \tau_t + \epsilon_{c,i,t} \qquad (7)$$

where the demeaned growth rates of the capital inputs are defined as: $\widetilde{k_{c,i,t}^{X}} \equiv (k^X - l)_{c,i,t} - \overline{(k^X - l)}_{c,i,t}$; $X = NICT, ICT, INT$; and the demeaned ICT intensity is defined as: $\widetilde{D_{c,i}^{ICT}} \equiv \left(D_{c,i}^{ICT} - \overline{D_{c,i}^{ICT}}\right)$.

A key issue in the estimation of equation (7) is the potential correlation between unobservable productivity shocks and the input levels, as was first noted by Marschak and Andrews (1944) and further discussed in Griliches and Mairesse (1998). This problem is commonly referred to as simultaneity bias in production function estimation. It arises from the fact that unobservable productivity shocks are known to the firms, but not to the econometrician when firms choose their input levels. Firms facing a positive productivity shock may respond by using more inputs. Negative shocks, on the other hand, may lead firms to cut back their output by decreasing input use.

To control for this simultaneity bias, a commonly used practice is to include time dummies and (the country-industry specific) fixed effects in the error term (Ackerberg et al., 2007). To the extent that the observable productivity shocks are time-invariant and country-industry specific, this specification should go a long way towards dealing with the problem of simultaneity bias. Following Michaels, Natraj and Van Reenen (2014), we additionally take into account the potential endogeneity of the ICT intensity measure at the country-industry level by instrumenting it with the industry-level U.S. values at the beginning of the period of observation.

[7] For a more extensive review on using this difference-in-difference estimation approach and its pros and cons, see Ciccone and Papaioannou (2010).

The idea behind this is that the sharp decline in quality-adjusted ICT prices disproportionately affects industries that have a greater potential for using ICT inputs. An indicator of this potential, as argued by Michaels et al. (2014), is the initial ICT intensity in the U.S., a country that is widely seen as the technological leader. Standard errors are corrected for heteroskedasticity and correlation between the country-industry pairs, an approach also applied in Stiroh's (2002) investigation of the revival of U.S. productivity growth using industry-level data.

4. Data and Methods

In this section, we provide an overview of the sectoral data we use and explain in detail how we calculate the various ICT intensity indicators that are country-industry specific.

4.1 Sectoral intangible investment data

The dataset developed by Niebel, O'Mahony and Saam (2013) provides new estimates on intangible investments at the level of 1-digit NACE industries (Rev.1.1) for ten EU countries between 1995 and 2007. It is constructed as a sectoral breakdown of the INTAN-Invest database, which harmonised the work produced by the COINVEST and INNODRIVE projects and The Conference Board (Corrado et al., 2012). We use the term "intangibles" to designate those investments not capitalized in national accounts prior to the SNA 2008 revision and thus not contained in EUKLEMS. Doing so, software is counted as "ICT" not as "intangibles" in this paper. Table 4.1 displays the country-industry coverage of the sectoral data we use and Table 4.2 reports more detailed information on each industry's share in total intangible investment.

As shown in Table 4.2, among all industries investment in intangibles is concentrated most intensively in the manufacturing industry (D), with shares of total intangible investment exceeding 50 percent in Germany and Finland. This is in line with the work of Goodridge, Haskel and Wallis (2012) which finds that the manufacturing industry has the highest ratio of intangible investment to value added. The business service industry (K) and the wholesale and retail trade industry (G) also show larger shares of intangible investment than the remaining sectors.

Table 4.1: COUNTRY-INDUSTRY COVERAGE

Countries	**Industries (NACE Rev.1.1)**	*Acronym*
Austria	Agriculture, Hunting, Forestry and Fishing	*(AtB)*
Czech Republic	Mining and Quarrying	*(C)*
Denmark	Total Manufacturing	*(D)*
Finland	Electricity, Gas and Water Supply	*(E)*
France	Construction	*(F)*
Germany	Wholesale and Retail Trade	*(G)*
Italy	Hotels and Restaurants	*(H)*
Netherlands	Transport and Storage and Communication	*(I)*
Spain	Financial Intermediation	*(J)*
United Kingdom	Renting of Machinery and Equipment and Other Business activities	*(K)*
	Other Community, Social and Personal Services	*(O)*

Table 4.2: INDUSTRY SHARE IN TOTAL INTANGIBLE INVESTMENT – MEAN OF 1995-2007

	AUT	**CZE**	**DNK**	**FIN**	**FRA**	**DEU**	**ITA**	**NLD**	**ESP**	**GBR**	*Mean*
(AtB)	.00	.01	.01	.01	.01	.01	.01	.01	.01	.01	.009
(C)	.00	.01	.00	.00	.00	.00	.00	.01	.00	.01	.003
(D)	.38	.29	.34	.60	.33	.57	.35	.32	.39	.22	.379
(E)	.01	.02	.01	.02	.02	.02	.01	02	.03	.01	.017
(F)	.05	.08	.09	.03	.04	.03	.05	.04	.07	.05	.053
(G)	.16	.15	.17	.08	.12	.08	.21	.14	.12	.14	.137
(H)	.02	.02	.01	.01	.01	.01	.02	.02	.03	.03	.018
(I)	.05	.05	.06	.06	.06	.03	.07	.09	.08	.08	.063
(J)	.09	.09	.07	.06	.10	.10	.07	.09	.11	.15	.093
(K)	.20	.24	.19	.10	.27	.14	.18	.22	.12	.25	.191
(O)	.04	.04	.04	.03	.03	.02	.04	.04	.04	.06	.038

Source: Niebel, O'Mahony and Saam (2013). The last column *Mean* is calculated as the cross-country average.

Each capital input is further distinguished by the individual asset types shown in Table 4.3 and some descriptive statistics on these key variables of interest are provided in Table 4.4.

Table 4.3: ASSET-COMPOSITION OF EACH CAPITAL INPUT

Non-ICT Assets	**ICT Assets**	**New Intangible Assets**
Transport Equipment	Computing Equipment	Scientific Research and Development
Other Machinery and Equipment	Communications Equipment	Firm-Specific Human Capital
Total Non-residential Investment	Software	New Financial Product Development
Residential Structures		New Architectural and Engineering Design
Other Assets		Market Research
		Advertising Expenditures
		Organisational Structures (Own)
		Organisational Structures (Purchased)

Table 4.4: GROWTH RATES OF THE KEY VARIABLES

Variable	Median	Mean	S.D.	Min.	Max.	N
Value added	0.03	0.02	0.06	-0.55	0.34	1320
Non-ICT	0.02	0.02	0.04	-0.40	0.19	1320
ICT	0.10	0.12	0.10	-0.23	0.85	1320
Total intangibles	0.04	0.04	0.06	-0.23	0.63	1320
Labour	0.01	0.01	0.04	-0.24	0.15	1320

Note: Growth rates are calculated as *ln* differences and are averaged over the period 1995-2007. The letter N in the last column denotes total number of observations.

4.2 Proxy ICT intensity indicator

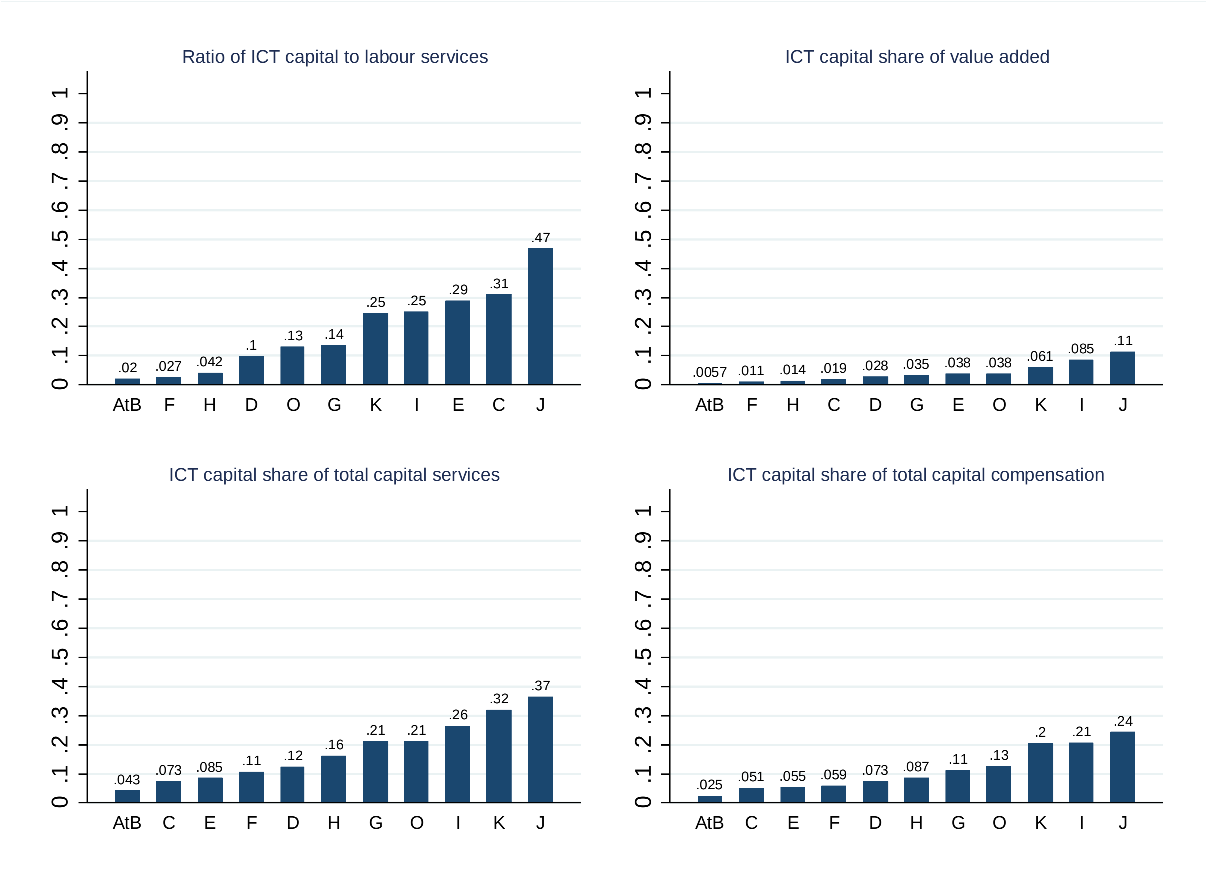
Following the literature, there are various ways to proxy for country-industry variant ICT intensities: (1) the ratio of ICT capital services to labour services, (2) the ICT capital share - of total value added, (3) - of total capital services, and (4) - of total capital compensation.

Table 4.5: DEFINITION OF ICT INTENSITY INDICATORS

$D^{ICT} \equiv ICT\ intensity\ indicator$	
*(1) $D^{ICT} = \frac{\overline{W}^{ICT}K^{ICT}}{LS}$	§(2) $D^{ICT} = \frac{P^{ICT}K^{ICT}}{P^{ICT}K^{ICT}+P^{NICT}K^{NICT}+WL}$
*(3) $D^{ICT} = \frac{\overline{W}^{ICT}K^{ICT}}{\overline{W}^{ICT}K^{ICT}+\overline{W}^{NICT}K^{NICT}}$	§(4) $D^{ICT} = \frac{P^{ICT}K^{ICT}}{P^{ICT}K^{ICT}+P^{NICT}K^{NICT}}$
*$\overline{W}$ is the two-period ICT capital compensation share in total nominal capital compensation; K^{ICT} and K^{NICT} denote capital stocks. LS indicates labour services measured by total number of hours worked.	§P is the rental price of the capital stock. The superscripts denote capital types: namely ICT and non-ICT. WL indicates the labour share of income.

On theoretical grounds, there is no proxy that is superior to the others. We follow Corrado, Haskel and Jona-Lasinio (2014) in using ICT capital per worker as our main measure of ICT intensity and apply alternative measures for sensitivity analysis. Figure 4.1 displays average values of all four intensity measures for our sample of E.U. countries. If we split the industries at the median, we observe that transport (I), financial intermediation (J), and business services (K) are ICT-intensive industries according to all four measures; while agriculture (AtB), manufacturing (D), and construction (F) are always ICT non-intensive. Mining and quarrying (C) remain below the median for three measures.[8]

Figure 4.1: FOUR MEASURES OF E.U. INDUSTRY ICT INTENSITY

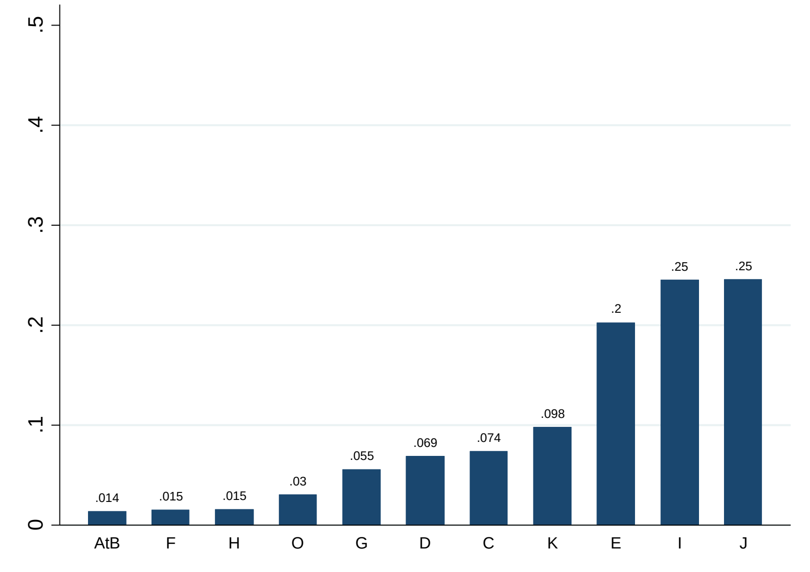


Since the ICT intensity might be endogenous, we follow Michaels, Natraj and Van Reenen (2014) in using the industry-specific U.S. ICT intensity at the beginning of the period of observation (in 1995) as an instrument. For comparison purposes, analysis using the endogenous indicator – the average of ICT intensity across ten EU countries and time – is also carried out, but instrumentation with U.S. values remains as the benchmark specification. The

[8] Results for individual countries are available upon request. For our preferred measure, the ICT capital intensity, the values for sectors J and K exceed the median in nine out of ten countries and the values for sector I in eight countries. The values for sectors AtB, F, and H fall below the median in all countries. The values for manufacturing (D) tend to lie close to the median.

U.S. ICT capital intensity in 1995 is shown in Figure 4.2. Comparing this industry ranking to the ranking of average E.U. ICT intensities in the upper left panel of Figure 4.1, the main differences are the higher position for sector D and the lower position of sector C in the U.S. in 1995; while other industries remain largely unchanged.

Figure 4.2: US INDUSTRY ICT INTENSITY IN 1995 (CAPITAL-LABOUR RATIO)



In addition to using these continuous intensity values in the regression analysis, we apply a discrete ICT intensity measure by grouping industries into ICT intensive and non-ICT intensive ones in the spirit of Stiroh (2002) and Bloom, Sadun and Van Reenen (2012). Since the previous continuous measure is averaged over time (i.e. 13 years in our sample) in Figure 4.1, the actual ranking of an industry is prone to change from one year to the next. Splitting industries into intensity groups helps to keep the volatility of an industry's ranking to a minimum. At the same time it remains an accurate description of the actual ranking of ICT intensities, as the changes are likely to occur within rather than between the intensity groups. Using the capital-labour ratio as the preferred proxy, we apply three alternative criteria to distinguish ICT intensive sectors from those that are non-ICT intensive. One is the standard practice of dividing at the median value of ICT intensity (observed in sector G). Industries with ICT-intensity values larger than 0.14 are labelled as ICT-intensive sectors (i.e. K, I, E, C, J); while others with intensity values smaller than the median are labelled as non-ICT intensive (i.e. AtB, F, H, D, O). For robustness checks we also looked for structural breaks of the intensity values and use that to divide industries. The two largest structural breaks are observed in sectors D and K. For the former, the ICT intensity value became more than twice as large as the preceding sector H; and sector K is about 80 percent more ICT-intensive than the preceding sector G. Thus, we alternatively split industries based on these two criteria (see Table 4.6).

Table 4.6: DISCRETE MEASURES OF ICT INTENSITY

	Split at median (G)*	Split at break point (D)	Split at break point (K)
ICT-intensive	K, I, E, C, J	D, O, G, K, I, E, C, J	K, I, E, C, J
Non-ICT intensive	AtB, F, H, D, O	AtB, F, H	AtB, F, H, D, O, G

*Results do not change if industry G is also included as ICT-intensive.

5. Empirical Results

In this section, we discuss the main findings and examine how robust the results are across alternative specifications.

5.1 Analysis for total intangible capital

Table 5.1 presents our first set of results. Under the assumption of constant returns to scale, columns (1) and (2) estimate the Cobb-Douglas production function first without intangibles and then adding them. Both non-ICT and ICT capital are found to be significantly associated with labour productivity growth. In the augmented estimation in column (2), intangible capital is also identified as an important driver of productivity growth, a result conforming to the rapidly growing literature that calls for an equal treatment of intangible investment vis-à-vis the tangible counterparts (e.g. CHS, 2005; Van Ark, et al., 2009; Niebel, O'Mahony and Saam, 2013). The differential impact of intangible capital is revealed in columns (3) and (4) in Table 5.1. In column (3) we use the average ratio of ICT capital to labour services within industries and countries as a measure of ICT intensity. Column (4) represents our baseline specification using the *exogenous* U.S. ICT intensity indicator as an instrument. Among the three interaction terms, only the interaction between intangible capital growth and industry ICT-intensity (i.e. γ_3) is found to be significantly positive in both estimations. This suggests that intangible capital is more productive in industries characterised by higher levels of investment in ICT. This differential impact becomes even more pronounced in the baseline specification when the ICT intensity is instrumented with the industry-specific initial levels of U.S. ICT intensity (see column 4 in Table 5.1). Since the interacted variables are demeaned for estimation, the main effect of intangible capital represents the output elasticity for an industry with average ICT intensity, which amounts to 12.6 percent in column (4) (i.e. the benchmark estimation).

Table 5.1: COBB-DOUGLAS PRODUCT FUNCTION ESTIMATION

DV: $\Delta\ln(V/L)_{c,i,t}$	(1) Two-capital inputs OLS	(2) INT augmented OLS	(3) Full Model OLS	(4) Full Model IV
NICT (β_1)	0.372*** (0.050)	0.313*** (0.048)	0.312*** (0.049)	0.312*** (0.056)
ICT (β_2)	0.087*** (0.026)	0.080*** (0.025)	0.066*** (0.024)	0.034 (0.024)
INT (β_3)		0.130*** (0.031)	0.161*** (0.034)	0.126*** (0.029)
$\widetilde{NICT} \times \widetilde{D_{c,i}^{ICT}}$ (γ_1)			-0.060 (0.284)	-0.251 (0.271)
$\widetilde{ICT} \times \widetilde{D_{c,i}^{ICT}}$ (γ_2)			-0.207** (0.088)	0.086 (0.354)
$\widetilde{INT} \times \widetilde{D_{c,i}^{ICT}}$ (γ_3)			0.340* (0.193)	0.752*** (0.208)
Year dummies	Yes	Yes	Yes	Yes
N	1320	1320	1320	1320
Adjusted R^2	0.187	0.209	0.214	

Note: The output *V* (i.e. value-added) in Column (1) is not adjusted for the inclusion of intangible capital; whereas for column (2)-(4), intangibles are added both as an input and an output. Hence, output *V* is adjusted for intangibles in these columns. All specifications in column (1)-(4) include the country-industry-specific fixed effects. Standard errors shown in parentheses are heteroscedastic-robust to country-industry clustering. Column (3) and (4) calculate the country-industry ICT intensity as the ratio of ICT capital services to labour services. This intensity is demeaned with the mean over all countries and industries. Column (3) uses the EU country-industry average values; while column (4) instruments for the country-industry ICT intensity using industry-level measures of ICT in the U.S. in 1995. The first stage F-test for excluded instruments is satisfied but is omitted in the table for conciseness. *** p<0.01, ** p<0.05, * p<0.1

The positive correlation between ICT intensity and the output elasticity of intangible capital is visualised in Figure 5.1 below where the partial effect of intangibles is plotted against the industry ICT-intensity. The upward sloping line suggests that the productive nature of intangible capital goes hand-in-hand with the level of investment in ICT. The demeaned ICT intensity (scaled up by 100 for ease of computation) at the lowest quartile is (minus) 13.8, which corresponds to an output elasticity of 2.2 percent. At the highest quartile we observe a demeaned ICT intensity value of 3.5 and an output elasticity of 15.3 percent. Since ICT intensities assume very high values in some industries, the output elasticity at the 90th percentile (a demeaned intensity value of 22.23) rises to nearly 30 percent.

If the impact of intangibles is truly different across sectors with varying degrees of ICT-intensity, we would expect this result to hold with alternative ICT-intensity indicators. Table 5.2 confirms our conjecture. For all four indicators used, intangible capital is consistently found to be more productive in more ICT-intensive sectors. Comforting results also emerge from discretely splitting industries into ICT–intensive and non-ICT intensive groups using alternative grouping criteria (see Table 5.3).

Figure 5.1: MARGINAL EFFECT OF INTANGIBLE CAPITAL

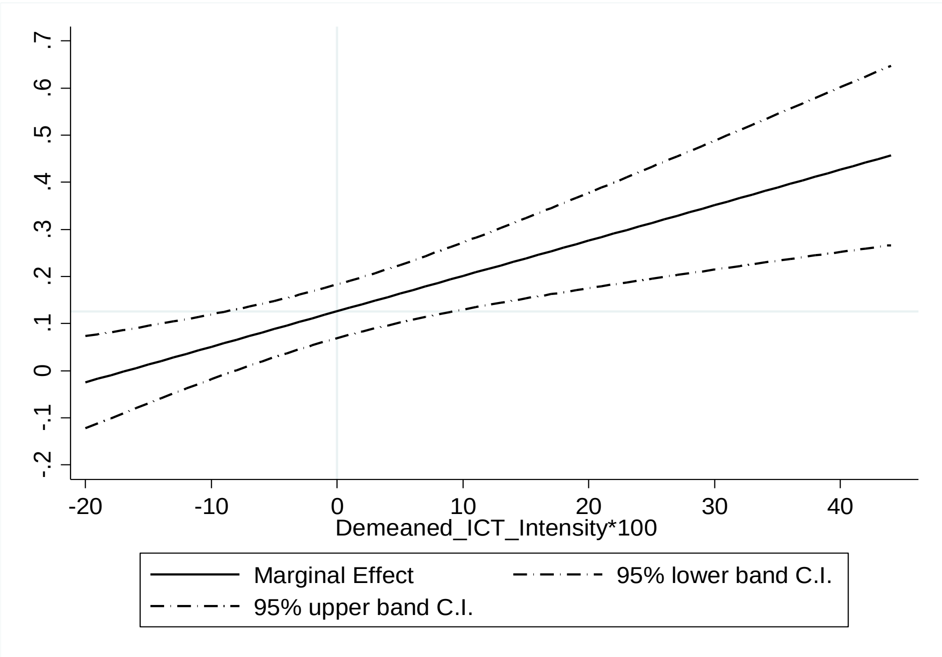


Table 5.2: ALTERNATIVE MEASURES OF ICT INTENSITIES

DV: $\Delta\ln(V/L)_{c,i,t}$	(1) ICT share of value added	(2) ICT share of total capital compensation	(3) ICT share of total capital services
NICT	0.305***	0.318***	0.308***
	(0.050)	(0.051)	(0.052)
ICT	0.071***	0.075***	0.077***
	(0.024)	(0.025)	(0.025)
INT	0.160***	0.143***	0.146***
	(0.032)	(0.031)	(0.033)
$\widetilde{NICT}\times\widetilde{D_{c,\iota}^{ICT}}$	-0.387	-0.631*	-0.462
	(1.275)	(0.371)	(0.568)
$\widetilde{ICT}\times\widetilde{D_{c,\iota}^{ICT}}$	-0.475	-0.112	0.036
	(0.653)	(0.154)	(0.230)
$\widetilde{INT}\times\widetilde{D_{c,\iota}^{ICT}}$	2.393***	0.607**	0.838**
	(0.873)	(0.247)	(0.369)
Year dummies	Yes	Yes	Yes
N	1320	1320	1320
Adjusted R^2	0.215	0. 216	0. 215

Note: Column (1)-(3) apply three alternative continuous ICT intensity measures. All measures are averaged per country-industry pairs and are demeaned with the average intensity over all E.U. countries and industries. Column (1) calculates ICT intensity as the ratio of ICT capital to total value added; column (2) calculates ICT intensity as the ratio of ICT capital services to total capital services; and column (3) divides ICT capital compensation by total capital compensation to proxy for ICT intensity. All specifications include the country-industry-specific fixed effect. Standard errors shown in parentheses are heteroscedastic-robust to country-industry clustering. *** p<0.01, ** p<0.05, * p<0.1

Table 5.3: DISCRETE MEASURES OF ICT-INTENSITY

DV: $\Delta\ln(V/L)_{c,i,t}$	(1) Split at the median value (G)	(2) Structural break observed in (D)	(3) Structural break observed in (K)
NICT	0.293*** (0.065)	0.265*** (0.074)	0.334*** (0.067)
ICT	0.084*** (0.029)	0.076** (0.030)	0.076*** (0.027)
INT	0.098** (0.039)	0.056 (0.042)	0.097** (0.037)
NICT× Dummy (γ_1)	-0.035 (0.099)	0.056 (0.098)	-0.076 (0.102)
ICT× Dummy (γ_2)	0.005 (0.043)	-0.004 (0.035)	0.009 (0.041)
INT× Dummy (γ_3)	0.116* (0.069)	0.143** (0.061)	0.116* (0.067)
Year dummies	Yes	Yes	Yes
N	1200	1320	1320
Adjusted R^2	0.206	0. 217	0. 213

Note: We follow Stiroh's (2002) dummy approach by splitting industries into ICT-intensive and non-ICT-intensive sectors. Column (1) splits the two groups according to the median value observed in sector (G) in the upper left panel of Figure 4.1; columns (2) and (3) uses the alterative splitting criterion. The former splits the groups at the structural break point D, and the latter splits at the structural break point K. All specifications include the country-industry-specific fixed effect. Standard errors shown in parentheses are heteroscedastic-robust to country-industry clustering. The coefficient estimate for γ_3 in column (1) has a p-value equal to 0.101, which is marginally significant at 10 percent level. *** p<0.01, ** p<0.05, * p<0.1

Qualitatively, the evidence is clear that productivity growth is higher in ICT-intensive industries complemented by intangible capital, but what is the quantitative implication in terms of productivity growth? The mean rate of accumulation of intangibles is four percent (see Table 4.4). If we consider the difference between an industry accumulating at a rate of three percent and an industry accumulating at a rate of five percent (which is a difference far below the standard deviation of 0.06), this translates into a difference in labour productivity growth of 0.25 percent (0.126*2). If we additionally assume that the industry with slow accumulation of intangibles has an ICT intensity at the lowest quartile and the other industry has an ICT intensity at the highest quartile, the difference in labour productivity growth rises to 0.699 percentage points. Comparing this result to similar considerations in Corrado, Haskel and Jona-Lasinio (2014), we conclude that taking into account industry-specific measures of intangible investment reduces that main effect of intangibles and may increase the effect dependent on ICT intensity.[9]

[9] An exact comparison of our values with theirs is difficult because of different levels of aggregation. But considering both country-level accumulation of intangibles and industry-level IT intensity at the lowest and the highest quartile, they find a differential growth effect between 0.4 and 0.5.

5.2 Analysis by asset types

Intangible capital is highly heterogeneous containing a wide range of distinctive asset types. To gain a deeper insight, we follow the broad classification as in CHS (2005, 2009) by distinguishing two general intangible asset categories: *innovative properties* and *economic competencies*. The former consists of R&D, development of new financial products, and architectural design. The latter is the sum of capital services provided by organisational capital (own-account and purchased combined), firm-specific human capital, advertising and marketing research. We interact the demeaned growth rates of these two asset categories with our demeaned measure of ICT intensity.

Table 5.4: ANALYSIS BY ASSET TYPES

	(1)		(2)
DV: $\Delta\ln(V/L)_{c,i,t}$	**EC & IP**		**Asset type**
NICT	0.283***	NICT	0.248***
	(0.052)		(0.071)
ICT	0.072***	ICT	0.074***
	(0.024)		(0.024)
EC	0.517*	OC	0.086***
	(0.027)		(0.019)
IP	0.158***	RD	0.059***
	(0.041)		(0.015)
$\widetilde{NICT}\times\widetilde{D^{ICT}_{c,i}}$	-0.132	FSHK	0.029**
	(0.279)		(0.013)
$\widetilde{ICT}\times\widetilde{D^{ICT}_{c,i}}$	-0.148	MKTR	-0.001
	(0.103)		(0.018)
$\widetilde{EC}\times\widetilde{D^{ICT}_{c,i}}$	-0.035	Arch	0.143**
	(0.153)		(0.059)
$\widetilde{IP}\times\widetilde{D^{ICT}_{c,i}}$	0.544**	ADV	-0.054*
	(0.236)		(0.027)
		$\widetilde{NICT}\times\widetilde{D^{ICT}_{c,i}}$	-0.195
			(0.461)
		$\widetilde{ICT}\times\widetilde{D^{ICT}_{c,i}}$	-0.101
			(0.120)
		$\widetilde{OC}\times\widetilde{D^{ICT}_{c,i}}$	0.282**
			(0.132)
		$\widetilde{RD}\times\widetilde{D^{ICT}_{c,i}}$	0.304***
			(0.085)
		$\widetilde{FSHK}\times\widetilde{D^{ICT}_{c,i}}$	0.066
			(0.092)
		$\widetilde{MKTR}\times\widetilde{D^{ICT}_{c,i}}$	-0.209*
			(0.119)
		$\widetilde{Arch}\times\widetilde{D^{ICT}_{c,i}}$	0.433
			(0.348)
		$\widetilde{ADV}\times\widetilde{D^{ICT}_{c,i}}$	-0.091
			(0.122)
Year dummies	Yes	Year dummies	Yes
N	1320	*N*	1320
Adjusted R^2	0.221	Adjusted R^2	0.239

Note: Both specifications include country-industry-specific fixed effect. All interacted variables are again demeaned. Standard errors shown in parentheses are heteroscedastic-robust to country-industry clustering. *** p<0.01, ** p<0.05, * p<0.1

As shown in the first column of Table 5.4, only innovative properties appear to have a stronger impact in more ICT-intensive industries, but its output elasticity looks implausibly high. To pin down which specific intangibles are driving the result, we repeat the analysis by breaking the assets further down to six different types that we observe.[10] As shown in column (2), the differential impact of intangible capital can be mainly attributed to organisational and R&D capital.[11] Meanwhile market research appears to have a higher output elasticity in less ICT-intensive industries. Given the larger number of interaction terms this result should, however, be interpreted with caution.

6. Conclusion

The discussion of intangible capital has undoubtedly gained momentum in both academia and policy-making circles. In this paper, we aim to better understand why productivity growth observed after 1995 took place mostly in industries that intensively use information and communication technologies (ICT). First evidence by Corrado, Haskel and Jona-Lasinio (2014) shows that these industries are more productive in countries with high investment in intangible assets. One puzzle remaining in this result was an implausibly high overall output elasticity of intangible assets of around 0.5. Moreover, it also remained open whether the effect was driven by the actual investment in intangibles in ICT-intensive industries, since only aggregate intangible investment was observed. Using a newly constructed breakdown of intangible investment at the industry level (Niebel, O'Mahony and Saam, 2013), we find a mean output elasticity of intangible assets of 12.6 percent that seems much more plausible than that found by Corrado, Haskel and Jona-Lasinio (2014). The differential effect of the sectoral ICT intensity also persists.

This finding remains robust across various alternative ICT intensity indicators and aligns with the existing firm-level studies arguing that higher productivity growth can only be reached if higher levels of investment in ICT are complemented by investment in intangible assets. A further breakdown of asset types reveals that the complementary role of intangibles is largely driven by *organisational* and *R&D* capital, while the other forms of intangible assets do *not* appear to complement the investment in ICT.

In terms of quantitative implication for productivity growth, we compare an industry with an ICT intensity at the lowest quartile to an industry at the highest quartile that also invests two percentage points more in intangible assets. These differences in inputs leads to a 0.7

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[10] Organisational capital consists of both purchased and own-account components. Asset type *New Financial Product Development* is dropped in estimation because the investment in this asset category is only available for the Financial Intermediation industry and missing for all other industries.

[11] The coefficient estimates for organisational and R&D capital are of comparable size to that of Corrado, Haskel and Jona-Lasinio (2014). E.g. 0.28 versus 0.3 for organisational capital; 0.31 versus 0.35 for R&D.

percentage point higher productivity growth. This effect is economically important, but it remains suggestive and speculative since we fail to uncover a causal relationship between intangible capital accumulation and labour productivity growth. Decomposing the error term in to a correlated country-industry specific fixed effect and a full set of time dummies does not satisfactorily solve the issue of simultaneity bias, since it hinges on a highly restrictive assumption that the unobservable productivity shocks are time-invariant and country-industry specific. The more structural control function approaches of Olley and Pakes (1996) and Levinsohn and Petrin (2003) are not readily applicable to data from an industry-level setting with multiple inputs. Moreover, much remains to be done to improve industry-level measurement of intangibles (e.g. with regard to depreciation rates), where the data constructed by Niebel, O'Mahony and Saam (2013) based on the INTAN-Invest are still to be seen as experimental.

Despite these caveats, we believe that this analysis offers an important insight into the productive nature of intangible capital, a source of growth that the modern economy increasingly relies on.

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