University of Groningen

Are intangibles more productive in ICT-intensive industries? Evidence from EU countries

Chen, Wen; Niebel, Thomas; Saam, Marianne

Published in:
Telecommunications Policy

DOI:
[10.1016/j.telpol.2015.09.010](https://doi.org/10.1016/j.telpol.2015.09.010)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2016

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Chen, W., Niebel, T., & Saam, M. (2016). Are intangibles more productive in ICT-intensive industries? Evidence from EU countries. *Telecommunications Policy*, 40(5), 471-484.
<https://doi.org/10.1016/j.telpol.2015.09.010>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Are intangibles more productive in ICT-intensive industries? Evidence from EU countries

Wen Chen^{a,*}, Thomas Niebel^b, Marianne Saam^b

^a Faculty of Economics and Business, University of Groningen, Nettelbosje 2, Groningen 9747 AE, The Netherlands

^b Research Department Information and Communication Technologies, Centre for European Economic Research (ZEW), L7, 1, 68161 Mannheim, Germany

ARTICLE INFO

Available online 22 December 2015

Keywords:

Intangible capital

ICT

Economic growth

Labour productivity

ABSTRACT

There is much firm-level evidence that maximising productivity benefits from investments in information and communication technologies (ICT) requires complementary investments in organisational structures, employee training, and other intangible assets. Yet convincing macro-level analysis to quantify the importance of this effect was not possible until industry-level data on investment in intangibles were developed. With such data now available for 10 European countries, this research shows that the output elasticity of intangible capital is stronger in more ICT-intensive industries. This suggests that intangible capital and ICT capital are complements in production.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Investment in information and communication technologies (ICT) and investment in intangible assets are key sources of growth in advanced economies. Much anecdotal and micro-evidence confirms that ICT and intangible assets do not only contribute to labour productivity growth individually, but do even more so in combination (Bloom, Sadun, & Van Reenen, 2012; Bresnahan, Brynjolfsson, & Hitt, 2002; Brynjolfsson & Hitt, 2000, 2003; Hall, Lotti, & Mairesse, 2013). While evidence on this complementary relationship between investment in ICT and intangibles is well-established in microeconomic studies, little is known about this relationship at the macroeconomic level as there were no explicit data on intangible investment at the level of the economy or industries.¹ Since the pioneering measurement work of Corrado, Hulten, and Sichel (2005, 2009), which standardised and popularised the approach of measuring business investments in intangible assets, quantifying the impact of intangibles on productivity and economic growth has been made possible in recent years. Many researchers incorporate such assets into a standard 'sources-of-growth' framework and find that intangible capital contributes significantly to labour productivity growth (Borgo, Goodridge, Haskel, & Pesole, 2013; Corrado et al., 2009; Fukao, Miyagawa, Mukai, Shinoda, & Tonogi, 2009; Roth & Thum, 2013). However, the effect of labour productivity from the combined investment in ICT and intangibles is still not taken into account in those macroeconomic studies.

* Corresponding author. Tel.: +31 50 363 3917.

E-mail addresses: wen.chen@rug.nl (W. Chen), niebel@zew.de (T. Niebel), saam@zew.de (M. Saam).

¹ To note, there have been other attempts to provide macroeconomic evidence on the complementarity between investment in ICT and intangibles (Basu, Fernald, Oulton, & Srinivasan, 2004; Corrado, Haskel, & Jona-Lasinio, 2014). This paper however differs from the previous works, as this is the first study to explicitly account for intangible investment at the industry level. This is potentially a very useful source of variation that could help to pin down the complementary relationship between ICT and intangibles.

By using the industry-level intangible investment data for 10 European countries, this paper tests a much-discussed hypothesis in firm-level studies, namely that intangible capital investment is needed to gain the largest benefits from investment in ICT, and provides corroborating macroeconomic evidence. It is important to establish such evidence at the macroeconomic level as the existing microeconomic evidence may not hold in general and even if the findings can be generalised, the quantitative results could still differ if data with comprehensive coverage are used. This paper also contributes to the literature by shedding light on the magnitude of the output elasticity of intangible capital. Thus, in addition to its qualitative importance this paper also discusses the quantitative importance of intangible capital for labour productivity growth. More importantly, the quantitative implication enables the paper to quantify the growth differentials between industries with varying degrees of ICT intensity, which might be of great interest to policymakers in designing industry-specific policies.

This paper is also related to the strand of literature that studies the productivity gap between the US and continental Europe, as the poorer productivity performance observed in Europe since the mid-1990s may not only be the result of its lower level of investment in ICT relative to the US (Van Ark, O'Mahony, & Timmer, 2008), but also to a less effective exploitation of ICT due to lower investment in intangible capital.²

To empirically examine to what extent the growth impact of intangible capital is dependent on an industry's ICT intensity, this paper first defines an industry characteristic that ranks the industries by the extent to which they rely on the use of ICT and calculates this ranking as the ratio of ICT capital services to labour services. The resulting intensity indicator is then interacted with the growth of intangible capital and the interaction term is estimated in an intangibles-augmented Cobb–Douglas production function. Under the assumption of constant returns to scale, this paper tests whether a one percent increase in intangible capital deepening increases output per worker more strongly in more ICT-intensive industries.

Three key findings emerge from this study. First, intangible capital contributes systematically to labour productivity growth and its productive impact is found to be significantly higher in ICT-intensive industries than in those that use little ICT. This result supports the complementarity of intangible capital and ICT in production found in prior microeconomic studies. Second, using industry-level instead of country-level data on intangibles, this paper finds a much smaller mean output elasticity of intangible capital (0.17 as opposed to 0.4–0.7 found in Corrado et al., 2014), as well as a larger differential effect of labour productivity growth across industries. The output elasticity of intangible capital amounts to 9.9% for industries at the lowest quartile of ICT intensity, while it exceeds 19% for industries at the highest quartile. Third, by distinguishing various different intangible asset types, this paper finds that not every single intangible asset exhibits a higher output elasticity in ICT-intensive industries. In the sample of assets investigated, this is only true for organisational structures and research and development (R&D).

The remainder of the paper is organised as follows. Section 2 discusses the concept and measurement of intangible capital and how capitalisation of intangibles changes the traditional output measure and growth accounting framework. The econometric approach to investigate the impact of intangible capital accumulation on labour productivity growth is outlined in Section 3. Section 4 elaborates on the proxy of industry ICT intensity measures. Empirical analyses and robustness checks are presented in Section 5. Section 6 concludes.

2. Measuring intangible inputs and output

This section considers issues related to the concept and measurement of intangible capital. It begins with a discussion on the definition of intangible capital: what is it and how can it be measured? Then, it outlines how capitalising investment in intangible assets changes the conventional output measure, followed by a descriptive overview of the data used for analysis. It is important to emphasise that this section only highlights the main issues, readers should refer to Niebel, O'Mahony, and Saam (2013) for more extensive details regarding the construction of the intangible investment data by industry.

2.1. Defining intangible capital

Intangible capital, also known as knowledge-based capital, comprises a variety of distinctive assets, which create long-lasting benefits for the firm and the economy. Unlike machinery, equipment, and structures, intangible assets do not have a physical embodiment. Well-known examples of intangible assets include computer software and scientific research and development (R&D), both of which are currently recognised as part of the official National Accounts of a country.³ Since the ground-breaking work of Corrado et al. (2005), a more comprehensive measure of intangible capital that is compatible with National Accounts has been developed and it consists of three categories: (1) computerised information, (2) innovative property, and (3) economic competencies.⁴ The first category mainly includes investment in software and computerised

² According to Corrado, Haskel, Jona-Lasinio, and Iommi (2013), the US has a much higher propensity to invest in intangibles than the EU. Between 1995 and 2009 (the period during which the productivity gap widened), intangible investment as a share of GDP is averaged around 10.6% for the US, while the share is only about 6.6% for the EU.

³ Software has been recognised as investment in National Accounts since the 1993 revision of the System of National Accounts (SNA); R&D has been newly added since the SNA 2008 revision.

⁴ The need to measure and incorporate these intangible assets into National Accounts is also extensively discussed in Nakamura (2010).

Table 2.1
Industry coverage.

Industries covered (NACE Rev. 1.1 classification)	Acronym
Agriculture, hunting, forestry, and fishing	(AtB)
Mining and quarrying	(C)
Total manufacturing	(D)
Electricity, gas, and water supply	(E)
Construction	(F)
Wholesale and retail trade	(G)
Hotels and restaurants	(H)
Transport and storage, and communication	(I)
Financial intermediation	(J)
Renting of machinery and equipment, and other business activities	(K)
Other community, social and personal services	(O)

Table 2.2
Asset groups.^a

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)

^a The composition of ICT and non-ICT assets is consistent with the distinction made in EU KLEMS database (see O'Mahony & Timmer, 2009).

databases. The second is composed of scientific R&D and a number of non-scientific R&D, such as new financial products, designs, and artistic originals. The last category, arguably the largest in size, contains brand equity, firm-specific human capital and organisational structures.

This measurement breakthrough by Corrado et al. (2005) sparked great interests among economists and unleashed increasing efforts to measure overall business investment in intangibles, which in the end led to the development of the INTAN-Invest database (Corrado, Haskel, Jona-Lasinio, & Iommi, 2012, European Commission, 2013). It provides market sector data on the above-mentioned intangible assets for 27 EU countries plus Norway and the US. The data set used in this paper is a breakdown of the INTAN-Invest database by industry and it was developed by Niebel et al. (2013) in the INDICSER project.⁵ This data cover 11 industries according to the NACE 1.1 classification (see Table 2.1) and 7 different intangible assets that are not included in the EU KLEMS database,⁶ where the industry-level data on output, non-ICT assets, ICT assets, and labour input are derived from (see Table 2.2 and further discussions on these variables in Section 3). The term “new intangibles” is used to designate those investments that are not capitalised in National Accounts prior to the SNA 2008 revision. As a result, computer software is counted as part of “ICT” assets instead of “new intangibles” in this paper.

2.2. Measurement approach

Measuring business investment in intangibles is extremely difficult as they are often created for internal use and suffer from a lack of observable market transaction data for valuation. To circumvent this problem, the cost approach has been widely used as an alternative. The underlying assumption of the cost approach is that firms are willing to invest in intangible assets until the discounted present value of the expected income stream equals to the cost of producing the marginal asset (Jorgenson, 1963). A key challenge and caveat of the cost approach, however, is that it is not known how much (i.e. what portion) of intangible spending can be counted as investment. The current consensus is to apply a capitalisation factor equal to one. That is, all expenditures on intangibles are believed to have long-lasting impacts (i.e. longer than a year) and are counted as investment.⁷

⁵ INDICSER refers to Indicators for Evaluating International Performance in Service Sectors.

⁶ The EU KLEMS database provides detailed statistics on growth and productivity accounts at industry level for individual EU member states, various EU aggregates, Japan, and the United States. See O'Mahony and Timmer (2009) for details.

⁷ Known exceptions to this rule are spending on advertising and own-account organisational structures. Existing research on advertising suggest that only about 60% of advertising expenditures have a long-lasting impact (i.e. longer than one year). As for own-account organisational structures, 20% of managers' wage is counted as investment (Corrado et al., 2005).

To convert nominal values into real terms, a price deflator for intangible investment is needed. Following the broad literature on intangibles, this paper uses an output deflator that is based on the value added price index for the total business sector as the proxy.⁸ The industry-specific intangible capital stock is then constructed using the usual perpetual inventory method (PIM):

$$R_{k,i,t} = (1 - \delta_k) \cdot R_{k,i,t-1} + \frac{N_{k,i,t}}{p_t} \quad (1)$$

where $R_{k,i,t}$ is the capital stock for intangible asset k in industry i at time t . Nominal investment in intangibles N is deflated by the value added price deflator p_t obtained from the EU KLEMS database (except for training, see footnote 8). This deflator is assumed to be the same across all industries and asset types. δ_k is the time- and industry-invariant depreciation rate for asset k , following Corrado et al. (2012). By assuming that the economy is in a steady-state, the initial capital stock in year 1995 is calculated by the following relationship:

$$R_{k,i,1995} = \left(\frac{N_{k,i,1995}}{p_{1995}} \right) / (\delta_k + \bar{g}) \quad (2)$$

where $\bar{g}$ is the average rate of growth of real value added in the total business sector between 1991 and 1999. Under the assumption of marginal productivity pricing, (industry) output measured by nominal value added is accordingly expanded as follows:

$$VA_{adj,i,t} = VA_{i,t} + \sum_{k \in INT} N_{k,i,t} \quad (3)$$

where the conventional output measure $VA_{i,t}$, taken from EU KLEMS, is augmented to include the flow of new intangibles $N_{k,i,t}$. Thus, after capitalisation intangible capital is both a productive input ($R_{k,i,t}$) that provides capital services and a part of adjusted output ($N_{k,i,t}$). To convert the nominal adjusted value added to volumes, an adjusted value added deflator is required and it is calculated as:

$$\Delta \ln VA_P_{adj,i,t} = \bar{v}_{VA,i,t} \Delta \ln VA_P_{i,t} + \bar{v}_{INT,i,t} \Delta \ln p_{i,t} \quad (4)$$

where $\bar{v}_{VA,i,t}$ is the two-period average share of nominal value added in adjusted value added, and $\bar{v}_{INT,i,t}$ is the two-period average share of nominal intangible investment N in adjusted value added.

The internal rate of return irr for each industry i also needs to be recalculated and it is redefined as follows:

$$irr_{i,t} = \frac{(VA_{adj,i,t} - LAB_{i,t})_{adj,i,t} + \sum_k (p_{k,i,t}^I - p_{k,i,t-1}^I) R_{k,i,t} - \sum_k p_{k,i,t}^I \delta_{k,i} R_{k,i,t}}{\sum_k p_{k,i,t-1} R_{k,i,t}} \quad (5)$$

where the adjusted value added (VA_{adj}) minus the labour compensation (LAB) denotes the industry-specific adjusted total capital compensation; p , δ , and R are the investment price index, the rate of depreciation and the real stock of both tangible and intangible assets k . The asset-specific user cost of capital $uc_{k,i,t}$ is calculated using the following relation:

$$uc_{k,i,t} = p_{k,i,t-1}^I irr_{i,t} + p_{k,i,t}^I \delta_{k,i} - [p_{k,i,t}^I - p_{k,i,t-1}^I] \quad (6)$$

As Eq. (6) shows, the user cost of capital is determined by the nominal rate of return, the rate of depreciation, and the asset-specific capital gains. The user cost, in turn, is used to calculate the capital compensation for each asset type and industry:

$$COMP_{adj,i,t} = uc_{k,i,t} \cdot R_{k,i,t} \quad (7)$$

The industry-specific growth of each intangible capital services R^s is calculated as follows:

$$\Delta \ln R_{i,t}^s = \ln R_{i,t}^s - \ln R_{i,t-1}^s = \sum_{k \in INT} \bar{w}_{k,i,t}^{INT} \Delta \ln R_{k,i,t} \quad (8)$$

where $\bar{w}_{k,i,t}^{INT}$ is the two-period average share of intangible asset k in total intangible capital compensation.

The aggregation of input and output volumes to the total business sector is calculated based on the Törnquist quantity index as described in O'Mahony and Timmer (2009):

$$\Delta \ln R_{BS,t}^s = \bar{\mu}_{i,t}^{INT} \sum_i \Delta \ln R_{i,t}^s \quad (9)$$

where $\bar{\mu}_{i,t}^{INT}$ is the two-period average share of industry i in total business sector intangible capital compensation.

⁸ The exception is investment in firm-specific human capital, which is deflated using an earnings deflator following O'Mahony (2012). The rationale for using an earnings deflator for investment in training is that training costs are related more to wage payments than to prices in general.

2.3. Price and depreciation issues

The growth of intangible capital stocks and services calculated above may be sensitive to the assumptions on price deflation and depreciation rates. As widely acknowledged, the overall business output price is only a place-holder when used as the price index for intangible investment. It could be argued that rather than the business-sector price deflator, more appropriate asset deflators would be the price indices of the industries that produce (in part) intangible assets, such as the management consulting (organisation capital), advertising (brand equity) and architectural and engineering services (architectural designs) industries. Although this might not be a perfect match, especially for own-account investment, a similar procedure is used to deflate investment in own-account software in the National Accounts of countries like the United States. Appropriate output deflators for intangible-producing industries, however, are not widely available for the set of EU countries covered in this paper.

In order to assess the plausibility of the assumption that the growth of intangible capital stocks is robust to changing the deflator from the overall business output deflator to output deflators of intangible-producing industries, this paper uses data for the US, where more detailed industry prices are available. Intangible capital stocks are reconstructed for investments in R&D, advertising, market research, organisational capital, and architectural design and engineering services. One of the findings is that the growth of intangible capital stock calculated using the business-sector price deflator correlate very highly with the growth of the stock calculated using detailed industry-specific prices (i.e. correlations are all above 0.92). Although the degree to which this analysis holds true for other countries is unknown, it does provide comforting evidence that the scope of bias resulting from the choice of the price deflator is likely to be limited. As for the depreciation rates, these are the ‘standard’ rates used in all research on intangibles. The sensitivity of capital stock growth to changing the standard depreciation assumptions seems minor, as shown in studies like O’Mahony (2012).

2.4. Descriptive statistics

The industry intangible investment data cover 10 European countries and for the period of 1995–2007: Austria, Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain, and the United Kingdom. One of the key insights of the industry data is that investment in intangibles is found to be concentrated most intensively in Manufacturing industry (D), which has an average share of total intangible investment of 38% across 10 EU countries (see Table 2.3). This result is in line with the work of Goodridge, Haskel, and Wallis (2012) who find that the Manufacturing industry has the highest ratio of intangible investment to value added. The Business services industry (K) and the Wholesale and retail trade industry (G) also show relatively large shares of intangible investment in comparison to other industries. With an average share of less than 0.3%, the Mining and quarrying industry (C) has the lowest level of investment in intangible capital.

Table 2.3
Industry share in total business sector intangible investment – mean of 1995–2007.

Industry	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 et al. (2013). The last column Mean is calculated as the cross-country average.

Table 2.4
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: Value added is adjusted to include intangible capital as in Eq. (3). Growth rates are calculated as ln differences and are averaged over the period 1995–2007. The letter N in the last column denotes the total number of observations. To note, the actual total number of observations is 1430 (10 countries times 11 industries times 13 years), but one year is lost for computing the growth rate.

Table 2.4 provides some basic descriptive statistics on the key variables of interest. As can be seen in this table, the most rapid growth of inputs over the period of observation is found for ICT capital (with an average growth rate of 12%). Although the growth is much slower than for ICT, growth in intangible capital input is the second largest. It grew by over 4% between 1995 and 2007. The amount of labour services provided, on the other hand, experienced the slowest growth. It grew by an average of merely 1% over the same period.

3. Econometric approach

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

$$V_{c,i,t} = A_{c,i,t} F(L_{c,i,t}, \mathbf{K}_{c,i,t}) \quad (10)$$

where V denotes value added adjusted to include intangible capital.⁹ 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 $\mathbf{K}$ is composed of three types: non-ICT (NICT), ICT, and intangible capital (INT) and assume a Cobb–Douglas functional form for the production function. Eq. (10) can be written out as follows:

$$V_{c,i,t} = A_{c,i,t} \cdot L_{c,i,t}^{\alpha} \left(K_{c,i,t}^{\text{NICT}} \right)^{\beta_1} \left(K_{c,i,t}^{\text{ICT}} \right)^{\beta_2} \left(K_{c,i,t}^{\text{INT}} \right)^{\beta_3} \quad (11)$$

where L denotes labour input measured by labour services, which accounts for differences in labour qualities (i.e. human capital)¹⁰; $\mathbf{K}$ is the capital services provided by non-ICT, ICT, and intangible capital. The 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, Eq. (11) can be rewritten as:

$$\Delta(v-l) = \beta_1 \Delta(k^{\text{NICT}} - l) + \beta_2 \Delta(k^{\text{ICT}} - l) + \beta_3 \Delta(k^{\text{INT}} - l) + \mu \quad (12)$$

where lower-case denotes variables in natural logarithms and the subscripts are suppressed for simplicity of exposition. The efficiency term A is modelled as part of the error term μ . 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 $\epsilon_{c,i,t}$. To examine whether the output elasticity of intangible capital differs across industries with varying degrees of ICT intensity, intangible capital is interacted with an ICT intensity indicator ($D_{c,i}^{\text{ICT}}$) that is measured as the ratio of ICT capital services to labour services¹¹:

$$\Delta(v-l) = \beta_1 \Delta(k^{\text{NICT}} - l) + \beta_2 \Delta(k^{\text{ICT}} - l) + \beta_3 \Delta(k^{\text{INT}} - l) + \gamma \Delta(k^{\text{INT}} - l) \cdot D_{c,i}^{\text{ICT}} + \omega_{c,i} + \tau_t + \epsilon_{c,i,t} \quad (13)$$

This specification is akin to the difference-in-differences approach which has its antecedents in the literature that analyses the impact of financial development on industry growth (Rajan & Zingales, 1998)¹² and has been used in the previous work on productivity in ICT-intensive industries (Corrado et al., 2014). If the complementarity hypothesis holds true, γ is expected to be positive and statistically significant. Given that ICT investment is highly correlated with intangible investment (the correlation coefficient is larger than 0.8), one may argue that it is perhaps not intangible capital that has a higher output elasticity in ICT-intensive industries but ICT investment itself or even non-ICT assets. To account for these potential omitted variable biases, the full model is specified as follows:

$$\Delta(v-l) = \gamma_1 \Delta(k^{\text{NICT}} - l) \cdot D_{c,i}^{\text{ICT}} + \gamma_2 \Delta(k^{\text{ICT}} - l) \cdot D_{c,i}^{\text{ICT}} + \gamma_3 \Delta(k^{\text{INT}} - l) \cdot D_{c,i}^{\text{ICT}} + \beta \mathbf{X}' + \omega_{c,i} + \tau_t + \epsilon_{c,i,t} \quad (14)$$

where $\mathbf{X}'$ indicates the vector of the main variables including the growth of capital inputs. γ_1 and γ_2 are not expected to be different from zero, as there is no theoretical underpinning for assets other than intangibles to complement ICT investment. To ensure a meaningful interpretation of the coefficients of the variables of interest, the interaction terms are demeaned for estimation following the suggestion of Balli and Sørensen (2013).¹³

It is important to note that the econometric specification presented above has several limitations. First, assuming a Cobb–Douglas production function is equivalent to assuming a constant output elasticity. This differs from the typical growth

⁹ Value added is used as the output measure because: (1) there is no readily available intangibles data on gross output; and (2) labour productivity based on value added is measured more accurately in the presence of outsourcing, a feature that is commonly observed at the industry level (Schreyer & Pilat, 2001).

¹⁰ Labour input is taken from the EU KLEMS database which adjusts for the productivity of various types of labour input such as low- versus high-skilled. EU KLEMS cross-classifies labour input by educational attainment, gender, and age, resulting in a total of 18 different labour categories. Interested readers should refer to O'Mahony and Timmer (2009) for more details.

¹¹ This is one of the most commonly used measures for (ICT) capital intensity (e.g. Corrado et al., 2014). Other proposed measures, such as ICT capital compensation as a share of total value added (e.g. Jorgenson & Timmer, 2011; Michaels, Natraj, & Van Reenen, 2014) and ICT capital share of total capital services (e.g. Stiroh, 2002), are considered in sensitivity analysis.

¹² For a more extensive review on using the difference-in-difference estimation approach and its pros and cons, see Ciccone & Papaioannou (2010).

¹³ From an econometric point of view, demeaning the interaction terms does not change the result. It is a reparameterisation of the same statistical model, but the added benefit is that the coefficient estimates of the main variables will remain similar to the simple model without interaction terms. As for the coefficient estimate of the interaction term as well as its standard errors, it will be exactly identical whether the interaction variables are demeaned or not.

accounting framework where output elasticities, approximated by the cost shares, can change over time. Allowing for changing output elasticities, though, would require the use of a translog production function. Despite its greater flexibility, estimating a translog production function comes at the cost of a larger number of parameters that need to be estimated. Having distinguished four different production factors in the paper (i.e. three capital inputs plus labour input), the amount of parameters that need to be estimated in a translog framework increases to 14, imposing hard constraints on the feasibility of the analysis.¹⁴ The probability of the occurrence of a harmful collinearity between the explanatory variables significantly increases as the number of considered production factors increases. Given this practical constraint, estimating a Cobb–Douglas production function remains preferred in spite of the assumption of a constant output elasticity.

Another issue in the estimation of Eq. (14) 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, it is advised to include time dummies and (the country–industry specific) fixed effects in the error term ([Akerberg, Berkard, Berry, & Pakes, 2007](#)). The rationale for this is that 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. This within estimator is also preferred to the between estimator, as by collapsing the time series as an average it would lead to a too small number of observations (i.e. 110), resulting in a larger scope for simultaneity bias than the within estimator.

Following [Michaels et al. \(2014\)](#), this paper further accounts for the potential endogeneity of the ICT intensity indicator ($D_{c,i}^{ICT}$) by instrumenting the measure with the industry-level US values at the beginning of the period of observation. The idea behind this strategy 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 US, a country that is widely seen as the technological leader. Last but not least, 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 US productivity growth using industry-level data.

4. 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 4.1](#)).

Table 4.1
Definition of ICT intensity indicators.

$D^{ICT} \equiv$ ICT intensity indicator	
* (1) $D_1^{ICT} = \frac{\bar{W}^{ICT} K^{ICT}}{LS}$	§ (2) $D_2^{ICT} = \frac{p^{ICT} K^{ICT}}{p^{ICT} K^{ICT} + p^{NICT} K^{NICT} + WL}$
* (3) $D_3^{ICT} = \frac{\bar{W}^{ICT} K^{ICT}}{\bar{W}^{ICT} K^{ICT} + \bar{W}^{NICT} K^{NICT}}$	§ (4) $D_4^{ICT} = \frac{p^{ICT} K^{ICT}}{p^{ICT} K^{ICT} + p^{NICT} K^{NICT}}$

* $\bar{W}$ 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. This paper follows [Corrado et al. \(2014\)](#) in using ICT capital services divided by labour services as the baseline measure of ICT intensity and applies the other three alternative measures for sensitivity analysis. [Fig. 4.1](#) displays the average values of all four intensity measures. If ICT intensity is split at the median intensity value, Transport (I), Financial intermediation (J), and Business services (K) would be classified as ICT-intensive industries across all four measures; while Agriculture (AtB), Manufacturing (D), and Construction (F) are always ICT non-intensive. Mining and quarrying (C) remain below the median value for three measures.¹⁵

¹⁴ In translog production function estimation, the number of estimated parameters is equal to $\frac{n(n+3)}{2}$, where n denotes the number of production factors.

¹⁵ Results for individual countries are available upon request. For the preferred measure, the values for industries J and K exceed the median in nine out of ten countries and the values for industry I in eight countries. The values for industries AtB, F, and H fall below the median in all countries. The values for Manufacturing (D) tend to lie close to the median.

Table 4.2

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
ICT non-intensive	AtB, F, H, D, O	AtB, F, H	AtB, F, H, D, O, G

Fig. 4.1. Four measures of EU industry ICT intensity. **Fig. 4.2.** US industry ICT intensity in 1995.

Since the ICT intensity might be endogenous, this paper follows [Michaels et al. \(2014\)](#) in using the industry-specific US 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 10 EU countries and time – is also carried out, but instrumentation with US values remains to be the benchmark specification. The US ICT capital intensity in 1995 is shown in [Fig. 4.2](#). Comparing this industry ranking to the ranking of average EU ICT intensities in the upper left panel of [Fig. 4.1](#), the main differences are the higher position for industry D and the lower position of industry C in the US in 1995, while other industries remain largely unchanged.

These ICT intensity measures vary continuously, both across industries and over time. This could lead to volatility in an industry's ranking. As an alternative to these continuous ICT intensity indicators, this paper also uses a discrete indicator by grouping industries into ICT-intensive and ICT non-intensive in the spirit of [Stiroh \(2002\)](#) and [Bloom et al. \(2012\)](#). This 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 ratio of ICT capital to labour services as the preferred proxy (i.e. D_1^{ICT}), three alternative criteria can be applied to distinguish ICT-intensive industries from those that are ICT non-intensive. The first one is the standard practice of dividing the groups at the median value of ICT intensity (observed in industry G). Industries with ICT-intensity values larger than 0.14 are labelled as ICT-intensive industries (i.e. K, I, E, C, J); while others with intensity values smaller than the median value are labelled as ICT non-intensive (i.e. AtB, F, H, D, O). For robustness checks, this paper also looks for 'structural breaks' of the intensity values and use that criterion to split industries. The two largest structural breaks are observed in industries D and K. For the former, the ICT intensity value became more than twice as large as the preceding industry H; while for industry K, it is about 80% more ICT-intensive than the preceding industry G (see [Table 4.2](#) for an overview of the criteria used to split industries).

5. Empirical results

This section discusses the main empirical findings. It begins with the analysis on the importance of intangible capital for labour productivity growth, followed by the test whether the output elasticity of intangible capital is higher in industries that invest more in ICT. It provides a brief discussion on the quantitative implication of the results and on how it differs from [Corrado et al. \(2014\)](#). By distinguishing various different intangible asset types, this section ends with the analysis on which specific intangible asset is most conducive to the exploitation of ICT investment.

5.1. Analysis for total intangible capital

[Table 5.1](#) presents the 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 labour productivity growth, a result conforming to the rapidly growing literature calling for an equal treatment of intangible investment vis-à-vis the tangible counterparts ([Corrado et al., 2005](#); [Van Ark, Hao, Corrado & Hulten 2009](#); [Niebel et al., 2013](#)).

The differential impact of intangible capital across industries with varying degrees of ICT intensity is revealed in columns (3) and (4). The former uses the 'endogenous' industry ICT intensity indicator, calculated as a time average across all EU country–industry pairs. Column (4), as the baseline specification, employs the 'exogenous' ICT intensity values from the US as instrument. The interaction between intangible capital growth and ICT-intensity (i.e. γ_3) is found to be positive and significant in both 'endogenous' and 'exogenous' specifications. Meanwhile, no (robust) evidence is found for ICT and non-ICT capital. This suggests that the output elasticity of intangible capital is, as expected, significantly larger in industries characterised by higher levels of investment in ICT. In other words, among all capital inputs only intangible capital exhibits a higher output elasticity in ICT-intensive industries. With a larger coefficient, this complementarity effect seems to be stronger in the baseline specification when the ICT intensity is instrumented with the exogenous US values (see column 4 in [Table 5.1](#)). Since the interaction terms are demeaned for estimation, the main effect of intangible capital represents the output elasticity of an industry with average ICT intensity, which amounts to 17.4%.

The positive correlation between the ICT intensity and the output elasticity of intangible capital is visualised in [Fig. 5.1](#) where the partial effect of intangibles is plotted against the (demeaned) ICT-intensity defined by country–industry pairs. The upward sloping line suggests that the output elasticity of intangible capital goes hand in hand with the level of investment in ICT. The demeaned ICT intensity at the lowest quartile is (minus) 0.138, which corresponds to an output elasticity of 9.89%. At the highest quartile, the demeaned ICT intensity takes the value 0.35 and the output elasticity amounts to 19.28%. Since ICT intensities assume very high values in some country–industry pairs, the output elasticity at the 90th percentile (a demeaned intensity value of 0.22) rises to nearly 30%.¹⁶

As argued in the previous section various ICT intensity indicators have been suggested in the past. If the output elasticity of intangible capital is truly different across industries with varying degrees of ICT-intensity, this finding should be robust to these alternative ICT intensity measures. [Table 5.2](#) provides comforting results. No matter which ICT intensity measure is used, the output elasticity of intangibles is consistently higher in more ICT-intensive industries. This is true whether the endogenous ICT intensity measure is used or the instruments of the US values are used.¹⁷ The results are also robust to

¹⁶ This is derived by taking derivatives with respect to intangible capital in Eq. (14). Doing so, one arrives at $\hat{\beta}_3 + \hat{\gamma}_3 \cdot D_{c,t}$, where $(D_{c,t})$ refers to the demeaned ICT intensity. Plugging in the estimates obtained under column (4) in [Table 5.1](#), an output elasticity of 9.89% at the lowest quartile and 19.28% at the highest quartile are obtained for intangible capital.

¹⁷ For the ICT intensity measured by ICT share of total capital services, only the OLS estimation is reported. This is because the validity test of the instruments is not met. The first stage F statistic for excluded instruments has a value close to zero ($F=0.02$).

Table 5.1
Cobb–Douglas production function estimation.

	(1) Two-capital OLS	(2) INT augmented OLS	(3) Full OLS	(4) Full IV
$NICT_{c,i,t}$	0.372*** (0.050)	0.313*** (0.048)	0.312*** (0.049)	0.306*** (0.055)
$ICT_{c,i,t}$	0.087*** (0.026)	0.080*** (0.025)	0.0656*** (0.024)	0.075*** (0.028)
$INT_{c,i,t}$		0.130*** (0.031)	0.161*** (0.034)	0.174*** (0.038)
$NICT_{c,i,t} \times D_{c,i}^{ICT}$			−0.060 (0.284)	0.057 (0.389)
$ICT_{c,i,t} \times D_{c,i}^{ICT}$			−0.207** (0.088)	0.001 (0.224)
$INT_{c,i,t} \times D_{c,i}^{ICT}$			0.340* (0.193)	0.540* (0.317)
Year dummies	Yes	Yes	Yes	Yes
N	1320	1320	1320	1320
R^2	0.187	0.209	0.214	0.206
F statistic for excluded instruments				7.96

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 as an output. Hence, output V is adjusted for intangibles in these columns. All specifications in column (1)–(4) include the country–industry specific fixed effect and the interaction terms are in demeaned forms. Standard errors shown in parentheses are heteroskedastic-robust to country–industry clustering. Column (3) and (4) calculate the industry ICT intensity as the ratio of ICT capital services to labour services. Column (3) uses the ‘endogenous’ ICT intensity indicator measured as the time average across all EU country–industry pairs. Column (4) instruments for the industry ICT intensity using the industry-level measures of ICT from the US in 1995. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Fig. 5.1. Marginal effect of intangible capital.

discretely splitting industries into ICT-intensive and ICT non-intensive groups using various alternative grouping criteria (see Table 5.3).

The qualitative evidence is clear that labour 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 intangible capital is four percent (see Table 2.4). Considering the difference between an industry accumulating at an annual 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 0.35% ($0.174\% \times 2$). If one further assumes 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 0.677 percentage points. Comparing these results to similar considerations in Corrado et al. (2014), the following differences are noteworthy. First, after taking into account industry-specific measures of intangible investment, the average output elasticity of intangible capital at 17.4% found in this paper is much lower than the 40–70% found in Corrado et al. (2014). Second, the growth differentials of labour productivity are larger than the magnitude suggested by Corrado et al. (2014).¹⁸ These differences

¹⁸ An exact comparison of the values in this paper with those from Corrado et al. (2014) is difficult because of different levels of aggregation. But considering both country-level accumulation of intangibles and industry-level ICT intensity at the lowest and the highest quartile, they find a differential growth effect between 0.4 and 0.5. One notable difference with the specification used in Corrado et al. (2014) is that this paper accounts for both country and industry fixed effects, while the industry fixed effect is omitted in their estimation.

Table 5.2
Alternative measures of ICT intensity.

	(1)	(2)	(3)	(4)	(5)
	ICT capital share of total value added (D_2^{ICT})		ICT capital share of total capital compensation (D_3^{ICT})		ICT capital share of total capital services (D_4^{ICT})
	OLS	IV	OLS	IV	OLS
$NICT_{c,i,t}$	0.305*** (0.050)	0.304*** (0.050)	0.308*** (0.052)	0.308*** (0.054)	0.365*** (0.045)
$ICT_{c,i,t}$	0.071*** (0.025)	0.077*** (0.025)	0.077*** (0.025)	0.077*** (0.024)	0.078*** (0.024)
$INT_{c,i,t}$	0.160*** (0.032)	0.151*** (0.031)	0.146*** (0.033)	0.148*** (0.035)	0.123*** (0.026)
$NICT_{c,i,t} \times D_{c,i}^{ICT}$	−0.387 (1.275)	−0.433 (1.424)	−0.462 (0.568)	−0.796 (0.794)	−0.789*** (0.248)
$ICT_{c,i,t} \times D_{c,i}^{ICT}$	−0.475 (0.653)	0.082 (0.802)	0.036 (0.230)	0.084 (0.281)	0.087 (0.125)
$INT_{c,i,t} \times D_{c,i}^{ICT}$	2.393*** (0.873)	1.895* (0.990)	0.838** (0.369)	0.982* (0.505)	0.859*** (0.218)
N	1320	1320	1320	1320	1320
R^2	0.215	0.214	0.215	0.214	0.228
F statistic for excluded instruments		32.63		28.69	

Note: Column (1)–(5) apply three alternative continuous ICT intensity measures and the interaction term in all specifications are in demeaned forms. Column (1) and (2) calculate ICT intensity as the ratio of ICT capital compensation to total value added; column (3) and (4) calculates ICT intensity as the ratio of ICT capital services to total capital services; and column (5) divides ICT capital compensation by total capital compensation to proxy for ICT intensity. All specifications include the country–industry specific effect. Standard errors shown in parentheses are heteroskedastic-robust to country–industry clustering. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 5.3
Discrete measures of ICT intensity.

	(1)	(2)	(3)	(4)	(5)
	Average EU ICT intensity			US ICT intensity in 1995	
	Median split (G)	Structural break (D)	Structural break (K)	Median split (D)	Restrictive split ^a
$NICT_{c,i,t}$	0.275*** (0.049)	0.293*** (0.050)	0.296*** (0.050)	0.295*** (0.049)	0.262*** (0.050)
$ICT_{c,i,t}$	0.087*** (0.028)	0.074*** (0.024)	0.080*** (0.026)	0.070*** (0.024)	0.077*** (0.028)
$INT_{c,i,t}$	0.156*** (0.036)	0.127*** (0.032)	0.155*** (0.035)	0.160*** (0.035)	0.165*** (0.037)
$NICT_{c,i,t} \times Intensive$	−0.035 (0.100)	0.056 (0.098)	−0.076 (0.102)	−0.047 (0.098)	−0.020 (0.099)
$ICT_{c,i,t} \times Intensive$	0.005 (0.043)	−0.004 (0.035)	0.009 (0.041)	−0.036 (0.035)	−0.020 (0.042)
$INT_{c,i,t} \times Intensive$	0.116* (0.070)	0.143** (0.061)	0.116* (0.068)	0.168** (0.067)	0.159** (0.074)
Year dummies	Yes	Yes	Yes	Yes	Yes
N	1200	1320	1320	1320	1080
R^2	0.206	0.217	0.213	0.217	0.188

Note: Column (1) to (3) splits the industries into ICT-intensive and non-intensive groups based on the EU average ICT intensity values observed in the upper-left panel of Fig. 4.1; Column (1) only has a sample of 1200 observations. This is because industry G has an ICT intensity value nearly identical to the Manufacturing industry D. It seems inappropriate to include industry G as ICT-intensive industry, as doing so would also mean industry D should be classified as ICT-intensive industry as well. On the other hand, include industry G as ICT non-intensive would result in an identical specification as the one shown in Column (3). As a result, industry G does not belong to any of the groups and is intentionally omitted. Column (4) and (5) apply or combine the splitting criterion from the US ICT intensity values. All specifications include the country–industry specific effect and the interaction terms are in demeaned forms. Standard errors shown in parentheses are heteroskedastic-robust to country–industry clustering. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

^a Restrictive split means that only industries that are above (below) the median value of ICT intensity in both EU and US rankings are considered ICT-intensive (ICT non-intensive). Manufacturing industry D and Wholesale and retail trade industry G are dropped from analysis because their ICT intensity rankings are not consistent across the EU and US ICT intensity measures. As a result, the analysis only has a sample of 1080 observations.

seem to indicate that the aggregate growth of intangibles is an imperfect proxy for industry-level growth. It tends to overstate the mean output elasticity of intangibles and to understate the complementarity effect between ICT and intangible capital.

5.2. Analysis by asset types

Intangible capital is highly heterogeneous containing a wide range of distinctive asset types. To gain a deeper insight into which intangible asset is most likely to complement ICT investment, this paper further analyses the complementarity

Table 5.4
Analysis by asset types.

	(1)	(2)	(3)	(4)
	Organisational capital (OC)	Research & development (RD)	OC & RD	All assets
$NICT_{c,i,t}$	0.338*** (0.051)	0.361*** (0.054)	0.317*** (0.058)	0.248*** (0.071)
$ICT_{c,i,t}$	0.073*** (0.024)	0.067** (0.026)	0.062** (0.024)	0.074*** (0.024)
$OC_{c,i,t}$	0.094*** (0.018)		0.093*** (0.018)	0.086*** (0.019)
$OC_{c,i,t} \times D_{c,i}^{ICT}$	0.198** (0.087)		0.205** (0.102)	0.282** (0.132)
$RD_{c,i,t}$		0.074*** (0.016)	0.069*** (0.015)	0.059*** (0.015)
$RD_{c,i,t} \times D_{c,i}^{ICT}$		0.341*** (0.088)	0.324*** (0.078)	0.304*** (0.085)
Year dummies	Yes	Yes	Yes	Yes
<i>N</i>	1320	1200	1320	1200
<i>R</i> ²	0.206	0.206	0.223	0.239

Note: All specifications include the country–industry fixed effect and all interaction terms are demeaned for estimation. The ICT intensity indicator used is the baseline measure calculated as the ratio of ICT capital services to labour services. Standard errors shown in parentheses are heteroskedastic-robust to country–industry clustering. The last column ‘All assets’ means that all seven different intangible asset types (see Table 2.2) are included for estimation. **p* < 0.1, ** *p* < 0.05, and *** *p* < 0.01.

hypothesis for each of the six intangible assets individually.¹⁹ According to the existing microeconomic literature, organisational structures seem most likely to complement ICT investment. The underlying theory, as argued by Brynjolfsson and Hitt (2000) and Brynjolfsson, Hitt, and Yang (2002), is that as a ‘General Purpose Technology’, ICT offers the opportunity to restructure the organisation of a firm so that the firm can be more efficient by minimising the costs of information acquisition and processing. In other words, ICT capital becomes most productive when firms have an organisational structure that really benefits from ICT adoption. Although there is a lack of theoretical underpinning, the other asset that has been tested in the literature for complementarity with ICT is investment in R&D. Few papers using firm-level company accounts data have produced mixed results. Polder, Leeuwen, Mohnen, and Raymond (2010) find a complementarity effect between investment in ICT and R&D for a sample of Dutch services firms, while Hall et al. (2013) fail to identify such an effect for Italian firms.

Using the intangible investment data by industry, this paper is able to show that both organisational capital and R&D capital exhibit a higher output elasticity in more ICT-intensive industries (see Table 5.4). These results are robust whether only one single asset is estimated (i.e. Table 5.4, column 1 and 2), both are included (Table 5.4, column 3), or even all intangible assets are included for estimation (Table 5.4, column 4).

6. Conclusions

The discussion of intangible investment has undoubtedly gained momentum in both academia and policy-making circles. Using an industry breakdown of the INTAN-Invest data to the level of 1-digit NACE industries, this paper is the first to rigorously and systematically examine the potential complementarities between investment in intangible capital and ICT capital at the industry level.

This paper offers three key findings. First, intangible capital contributes systematically to labour productivity growth and its output elasticity is found to be significantly higher in ICT-intensive industries than in those that use little ICT. This means that intangible capital deepening makes a greater contribution to growth when complemented by ICT investment. This finding supports the complementarity hypothesis proposed in prior microeconomic studies. Second, using industry-level rather than country-level data on intangibles, this paper finds a much smaller mean output elasticity of intangible capital, but a larger differential effect of labour productivity growth across industries with varying degrees of ICT intensity. Third, not all individual intangible assets are complementary to ICT investment. In the sample of assets investigated, only organisational structures and research and development (R&D) are found to be conducive to the exploitation of ICT. While other assets, such as design or market research, are not complementary to ICT capital.

These results offer important implications. The poor productivity performance observed in Europe since the mid-1990s does not seem to be solely caused by a lower level of investment in ICT (Van Ark et al., 2008), but also by a lower level of investment in intangible capital, which led to a much less effective exploitation of ICT capital in that period.

To gauge quantitative implications, this paper compares an industry with an ICT intensity at the lowest quartile to an industry at the highest quartile, assuming at the same time a difference in intangible capital growth of two percentage points. Taken the estimates at the face value, these differences in inputs lead to a growth differential of labour productivity

¹⁹ As shown in Table 2.2, seven different intangible assets are identified but the analysis of the complementarity hypothesis was only possible for six assets because data for new financial product (NFP) are only available for one industry (i.e. Financial intermediation) while missing for others. After controlling for the country–industry specific effect, NFP drops out in estimation.

of over 0.677 percentage points. This effect is economically important, but it remains suggestive and speculative, since this paper fails to uncover a definite causal relationship between intangible capital accumulation and labour productivity growth. Decomposing the error term into 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 of 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 appropriate price deflators and depreciation rates), where the industry intangible investment data constructed by Niebel et al. (2013) based on INTAN-Invest are still to be seen as experimental.

Despite these caveats, this paper offers an important insight into the productive nature of ICT capital and intangible capital, the source of growth that the modern economy increasingly relies on.

Acknowledgements

The authors would like to thank two anonymous referees for their highly constructive comments, and suggestions from seminar participants at the Centre for European Economic Research (ZEW), as well as conference participants of the International Association for Research in Income and Wealth (IARIW) and the SGE session at the 2015 ASSA meetings. In particular, the authors would like to thank Robert Inklaar, Cecilia Jona-Lasinio, and Leonard Nakamura for their helpful comments on the paper. All remaining errors are our own.

References

- Akerberg, D., Berkard, C., Berry, S., & Pakes, A. (2007). Econometric tools for analysing market outcomes. In J. Heckman, & E. Leamer (Eds.), *Handbook of econometrics* (pp. 4172–4276). Amsterdam: North-Holland Publishing.
- Balli, H. O., & Sørensen, B. E. (2013). Interaction effects in econometrics. *Empirical Economics*, 45(1), 583–603.
- Basu, S., Fernald, J., Oulton, N., & Srinivasan, S. (2004). The case of the missing productivity growth: or, does information technology explain why productivity accelerated in the United States but not the United Kingdom? In M. Gertler, & K. Rogoff (Eds.), *NBER Macroeconomics Annual 2003* (pp. 9–63). Cambridge, MA: MIT Press.
- Bloom, N., Sadun, R., & Van Reenen, J. (2012). Americans do IT better: US multinationals and the productivity miracle. *American Economic Review*, 102(1), 167–201.
- Borgo, M., Goodridge, P., Haskel, J., & Pesole, A. (2013). Productivity and growth in UK industries: an intangible investment approach. *Oxford Bulletin of Economics and Statistics*, 75(6), 806–834.
- Bresnahan, T., Brynjolfsson, E., & Hitt, L. M. (2002). Information technology, workplace organization, and the demand for skilled labour: firm-level evidence. *Quarterly Journal of Economics*, 117(1), 339–376.
- Brynjolfsson, E., & Hitt, L. M. (2000). Beyond computation: information technology, organizational transformation and business performance. *Journal of Economic Perspectives*, 14(4), 23–48.
- Brynjolfsson, E., & Hitt, L. M. (2003). Computing productivity: firm-level evidence. *Review of Economics and Statistics*, 85(4), 793–808.
- Brynjolfsson, E., Hitt, L. M., & Yang, S. (2002). Intangible assets: how the interaction of computers and organisational structure affects stock market valuations. *Brookings Papers on Economic Activity: Macroeconomics*, 1, 137–199.
- Ciccone, A., & Papaioannou, E. (2010). Estimating cross-industry cross-countries models using benchmark industry characteristics. CEPR Discussion Paper No. 8056.
- Corrado, C., Haskel, J., Jona-Lasinio, C., & Iommi, M. (2013). Innovation and intangible investment in Europe, Japan, and the US. *Oxford Review of Economic Policy*, 29(2), 281–286.
- Corrado, C., Haskel, J., & Jona-Lasinio, C. (2014). Knowledge spillovers, ICT and productivity growth. Retrieved from: <http://www.spintan.net/chj-final/>.
- Corrado, C., Hulten, C., & Sichel, D. (2005). Measuring capital and technology: an expanded framework. In J. Haltiwanger, C. Corrado, & D. Sichel (Eds.), *Measuring capital in the new economy* (pp. 11–46). Chicago, IL: University of Chicago Press.
- Corrado, C., Hulten, C., & Sichel, D. (2009). Intangible capital and U.S. economic wealth. *Review of Income and Wealth*, 55(3), 661–685.
- Corrado, C., Haskel, J., Jona-Lasinio, C., & Iommi, M. (2012). Intangible capital and growth in advanced economies: measurement methods and comparative results. Retrieved from: <http://www.intan-invest.net>.
- European Commission (2013). Joint database on intangibles for European policymaking. Directorate-General for Research and Innovation Socio-Economic Sciences and Humanities EUR 25526. Retrieved from: https://ec.europa.eu/research/social-sciences/pdf/other_pubs/joint_database_on_intangibles_en.pdf.
- Fukao, K., Miyagawa, T., Mukai, K., Shinoda, Y., & Tonogi, K. (2009). Intangible investment in Japan: measurement and contribution to economic growth. *Review of Income and Wealth*, 55(3), 717–736.
- Goodridge, P., Haskel, J., & Wallis, G. (2012). UK innovation index: productivity growth in UK industries CEPR Discussion Papers 9063.
- Griliches, Z., & Mairesse, J. (1998). Production function: the search for identification. In S. Strom (Ed.), *Econometrics and economic theory in the twentieth century: proceedings of the Ragnar Frisch centennial symposium* (pp. 169–203). UK: Cambridge University Press Cambridge.
- Hall, B. H., Lotti, F., & Mairesse, J. (2013). Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. *Economics of Innovation and New Technology*, 22(3), 300–328.
- Jorgenson, D. W. (1963). Capital theory and investment behaviour. *American Economic Review*, 53(2), 247–259.
- Jorgenson, D. W., & Timmer, M. P. (2011). Structural change in advanced nations: a new set of stylised facts. *Scandinavian Journal of Economics*, 113(1), 1–29.
- Levinsohn, J., & Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *Review of Economic Studies*, 70(2), 317–341.
- Marschak, J., & Andrews, A. H. (1944). Random simultaneous equations and the theory of production. *Econometrica*, 12(3), 143–205.
- Michaels, G., Natraj, A., & Van Reenen, J. (2014). Has ICT polarized skill demand? Evidence from eleven countries over twenty-five years. *Review of Economics and Statistics*, 96(1), 60–77.
- Nakamura, L. (2010). Intangible assets and national income accounting. *Review of Income and Wealth*, 56(s1), S135–S155.
- Niebel, T., O'Mahony, M., & Saam, M. (2013). The contribution of intangible assets to sectoral productivity growth in the EU. ZEW Discussion Paper No.13-062. Retrieved from: <http://ftp.zew.de/pub/zew-docs/dp/dp13062.pdf>.
- O'Mahony, M. (2012). Human capital formation and continuous training: evidence for EU countries. *Review of Income and Wealth*, 58(3), 531–549.

- O'Mahony, M., & Timmer, M. P. (2009). Output, input and productivity measures at the industry level: the EU KLEMS database. *Economic Journal*, 119(538), F374–F403.
- Olley, S., & Pakes, A. (1996). The dynamics of productivity in the telecommunication equipment industry. *Econometrica*, 64(6), 1263–1297.
- Polder, M., Leeuwen, G., Mohnen, P., & Raymond, W. (2010). Product, process and organisational innovation: drivers, complementarity and productivity effects. UNU-MERIT Working Paper Series 2010-035.
- Rajan, R., & Zingales, L. (1998). Financial independence and growth. *American Economic Review*, 88(3), 559–586.
- Roth, F., & Thum, A. E. (2013). Intangible capital and labour productivity growth: panel evidence for the EU from 1998–2005. *Review of Income and Wealth*, 59(3), 486–508.
- Schreyer, P., & Pilat, D. (2001). Measuring productivity. *OECD Economic Studies*, 33, 127–165.
- Stiroh, K. (2002). Information technology and the U.S. productivity revival: what do the industry data say?. *American Economic Review*, 92(5), 1559–1576.
- Van Ark, B., Hao, J., Corrado, C., & Hulten, C., (2009). Measuring intangible capital and its contribution to economic growth in Europe (pp. 62–93). EIB Papers, European Investment Bank, 14(1).
- Van Ark, B., O'Mahony, M., & Timmer, M. (2008). The productivity gap between Europe and the United States: trends and causes. *Journal of Economic Perspectives*, 22(1), 25–44.