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ICT investments and productivity: Measuring the contribution of ICTs to growth

by
Vincenzo Spiezia*

This study uses an econometric approach to estimate the contribution of three types of ICT investments (computer, software and communication) in 26 industries (the whole business sector) in 18 OECD countries over 1995-2007, based on the EU KLEMS Database. *The estimated contribution of ICT investments to value added growth in the business sector varies from 1.0% a year in Australia to 0.4% a year in Japan. In one-third of the countries considered, the contribution of ICT investment was bigger or equal to the contribution of non-ICT investments. In most countries, computing equipment provided the largest contribution and accounted for over 50% of the overall ICT contribution. The only exceptions are Finland, where investments in communication equipment exceeded those in computing equipment, and Japan, where software was the most dynamic component of ICT investments. ICT producing industries account for no less than two-thirds of total factor productivity (TFP) growth in Germany, Slovenia and the United Kingdom, about 60% in the United States and just below 50% in France and the Netherlands. In Denmark, the Czech Republic and Italy, TFP increased in the ICT producing industries whereas it decreased for the total business sector.*

JEL classification: O47, E23, E22.

Keywords: Growth accounting, ICT, GMM, EU KLEMS.

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Growth accounting is the most widely used approach to measure the contribution of ICT investment to economic growth. It consists in decomposing the growth of value added into the growth of production inputs, namely labour, ICT investments and non-ICT investments.

This decomposition requires some measure of the *elasticity* of value added to each input, *i.e.* the increase in value added associated with a 1% increase in a given input. However, inputs' elasticities are not observable and researchers have to rely on some method to estimate them. Economic studies have adopted two different approaches.

In the first approach (non-parametric), the elasticity of each input is assumed to be equal to its share in the value added. The assumption, however, is valid on a set of strong hypotheses about the technology of production (constant returns to scale), the behaviour of firms (profit maximisation) and the characteristics of technological progress (Hicksian neutrality). Furthermore, this approach assumes that every increase in value added which is not explained by growth in production inputs is due to an increase in total factor productivity (TPF). As a result, all deviations from the above hypotheses and all measurement errors in the statistical data are misinterpreted as differences in TFP across countries and over time.

The second approach (parametric) consists in estimating the inputs' elasticity through econometric techniques. This approach has two advantages. First, it does not impose any *a priori* hypotheses on the technology of production, the behaviour of firms or the degree of competition in the markets. Second, it permits a direct estimation of the inputs' productivity, in a way that measurement errors are not incorrectly accounted as total factor productivity. The drawback of the econometric approach is that it is less flexible – as coefficients are fixed across at least one dimension of the data – and requires a larger set of observations.

This study adopts the econometric approach to estimate the contribution of three types of ICT investments (computer, software and communication) in 26 industries (the whole business sector) in 18 OECD countries over the period 1995-2007.

The study is organised as follows. Sections 1 and 2 discuss the non-parametric and the parametric approach, respectively, and review the main studies on ICT investments based on these approaches. Section 3 describes the EU KLEMS dataset which is used in the present analysis. Section 4 introduces the econometric model and reports its estimates. The results for the total business sector are discussed in Section 5 while Section 6 summarises the main findings and indicates the direction for further research.

1. The non-parametric approach to growth accounting

The characteristic feature of the non-parametric approach to growth accounting is to assume the elasticity of each input to be equal to its share in the value added. Input shares are measured either in relation to total income, if the product market is regarded as perfectly competitive, or in relation to total costs, if the product market is believed to operate under monopolistic competition.

The above assumption relies on three main hypotheses, which are generally un-tested.

First, the technology of production is characterised by constant returns to scale. Based on this hypothesis, any increase in value added which is not accounted for by an increase in the production inputs is interpreted as technical progress. However, if returns to scale are increasing rather than constant, technical progress is over-estimated and the contribution of the inputs is under-estimated (and vice versa). Although some progress has been made recently to loosen this hypothesis (see Diewert and Nakamura, 2007 for a survey), it still remains crucial for this approach.

Second, firms can change the level of production inputs at any time without incurring any adjustment costs. The hypothesis of instantaneous profit maximisation permits the measurement of the elasticity of each input as its (cost or income) share. However, if the hypothesis fails to hold, observed input shares deviate from the production elasticities and some of the contribution of production inputs are erroneously accounted as TFP (or vice versa).

Finally, the rate of technical progress is assumed to be equal for all factors (Hicksian neutrality). This hypothesis permits the separation of changes in the production technique along a given isoquant – due to changes in the relative cost of production inputs – from upward shifts of the isoquant – due to technical progress. In particular, under the hypothesis of Hicksian neutrality, input shares are independent from technical progress and provide the correct measure of input elasticity. However, if technical progress is capital (labour) augmenting and the production function is not a Cobb-Douglas, the input share of capital (labour) would increase as a result of technical progress itself (Antràs, 2004). Therefore, the hypothesis of Hicksian neutrality would lead to overestimating the contribution of capital (labour) to growth and underestimating TFP. This bias is likely to be significant for ICT capital, where the rate of technical progress over the last few decades has been faster than for labour and other types of capital.

1.1. Previous findings

Early studies on the impact of ICTs on productivity yielded largely inconclusive results. The well-known Solow paradox for which "computers are visible everywhere except in productivity statistics" summarises the state of art in the early 1990s. The lack of correlation between ICT investment and productivity growth was mostly due to incorrect measurement of ICT capital prices and quality.

Significant improvements in the measurement of ICT capital (OECD, 2001 and 2009) have opened the way to a new stream of analysis on the growth effects of ICTs, while, the work carried out by the OECD to internationally harmonise ICT prices (Wyckoff, 1995; Schreyer, 2000; and Colecchia and Schreyer, 2002) allowed controlling for differences in methodologies among countries.

Jorgenson and Stiroh (2000) apply Jorgenson's *production possibility frontier* (1967) to explain the increase in productivity growth in the United States after 1995. They find that computer hardware played an increasing role as a source of economic growth and that average labour productivity grew much faster between 1995-99 due to capital deepening as a direct consequence of the fall in ICT prices and the increase in TFP.

Oliner and Sichel (2000, 2002) reach similar results, based on a Solow-like growth accounting model. They find that the contribution of ICT capital increased between the periods 1974-95 and 1996-99 and that TFP growth also increased by 40% in the period 1996-99.

Colecchia and Schreyer (2002) extend the approach followed by Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) to nine OECD countries up to the year 2000. They found that in the preceding two decades ICT contributed between 0.2 and 0.5 percentage points per year to economic growth, depending on the country. During the second half of the 1990s, this contribution rose to 0.3 to 0.9 percentage points per year. They showed that the United States had not been alone in benefiting from the positive effects of ICT capital investment on economic growth and in experiencing an acceleration of these effects. However, effects have clearly been largest in the United States followed by Australia, Finland and Canada. Of the nine countries considered Germany, Italy, France and Japan registered the lowest contribution of ICT to economic growth.

Oulton (2002) applies a modified growth accounting approach to the United Kingdom, using US producer price indices adjusted for exchange rates to deflate the value of ICT investment. He finds that the ICT contribution to GDP growth increased from 13.5% in 1979-89 to 20.7% in 1989-98. ICTs contributed 55% of capital deepening during the period 1989-98 and 90% in the period 1994-98.

Using data on ICT investments from the tax declarations of 300 000 French firms, Crepon and Heckel (2002) evaluate the contribution of ICTs to the growth of value added via two channels: the accumulation of IT capital across all industries and the TFP gains in ICT-producing industries. They find that, over the period 1987-98, ICTs accounted for 0.7 percentage points of the yearly value added growth, 0.3 points from capital deepening and 0.4 points from TFP growth in ICT-producing industries. This amounts to over one-quarter of the yearly value added growth (2.6%).

Improving the measurement of ICT capital is also at the core of the work of Van Ark *et al.* (2002) to explain the different impact of ICTs on productivity between the United States and Europe over the period 1980-2000. They find that the pattern of ICT diffusion in Europe has not been much different from that in the United States, beginning with a rapid increase in office and computing equipment, followed by a surge in communication equipment, and backed up by increased investment in software. However, EU countries started from much lower stocks of ICT capital so that both the intensity of ICT and its contribution to productivity growth have been lagging behind the United States.

This perspective is further developed by Timmer *et al.* (2010), who provide a detailed analysis of the sources of growth from a comparative industry perspective. The authors argue that Europe's slow growth is the combined result of a severe productivity slowdown in traditional manufacturing and other goods production, and a concomitant failure to invest in and reap the benefits from ICT, in particular in market services.

If ICT capital deepening and TFP growth in ICT-producing sectors measure the direct growth contribution of the use and the production of ICTs, microeconomic studies emphasise the complexity of the link from technology to productivity. To leverage ICT investment successfully, firms must typically make large complementary investments and innovate in areas such as business organisation, workplace practices, human capital and intangible capital.

Important progress has been made in incorporating intangible assets into a macro growth accounting framework by Corrado *et al.* (2006). They find that the role of multifactor productivity is significantly diminished, the growth rates of output and output per worker increases at a noticeably faster rate and capital deepening becomes the unambiguously dominant source of labour productivity growth. More broadly, the factors typically associated with the growth of the knowledge economy take up a greater importance when intangibles are included.

2. The parametric approach to growth accounting

The parametric approach to growth accounting provides an alternative method to measure the contribution of ICT investment to growth. It avoids postulating a relationship between production elasticities and income shares, which may or may not correspond to reality, and indeed puts researchers in a position of testing these relationships.

Further possibilities arise with econometric techniques: allowance can be made for adjustment cost (the possibility that changes in factor inputs are increasingly costly the faster they are implemented) and variations in capacity utilisation (*e.g.* Basu, Fernald and Shapiro, 2001). In addition, it is possible to investigate forms of technical change other than the Hicks-neutral formulation implied by the conventional growth accounting approach; and there is no *a priori* requirement to assume constant returns to scale of production functions. The literature on the econometric approach is large, and examples of integrated, general models can be found in Morrison (1986), Boskin and Lau (1990) and Nadiri and Prucha (2001).

All these possibilities come at a cost, however. The econometric approach allows for less flexibility, as coefficients are fixed across at least one dimension of the data. Fully-fledged models raise complex econometric issues and sometimes put a question mark on the robustness of results. Often, researchers are constrained by the sample size of observations, and have again to revert to *a priori* restrictions (for example constant returns to scale) to increase the degrees of freedom for estimation.

More fundamentally, the output and input data used in the econometric analysis have been estimated based on the non-parametric approach itself. "Thus, the question of whether or when to use econometrics to measure productivity change is really a question of the stage of the analysis" at which the non-parametric approach should be abandoned (Hulten, 2001). The two approaches, therefore, should be regarded as complementary, in that the non-parametric estimates provide a benchmark for interpreting the more complicated results of the parametric approach.

2.1. Previous findings

In an interesting meta-study, Stiroh (2002) compares the methods, data and results of a set of 20 studies. He finds that the estimated ICT elasticity to output differs among studies due to the econometric method, the sample period or the level of aggregation. Studies reporting excess returns to ICT investments are characterised by the omission of important variables – such as improved workplace practices and firm re-engineering – related to ICT deployment. When controlling for unobserved heterogeneity via fixed effects, the ICT coefficient falls substantially. The General Method of Moments (GMM) estimation, which accounts for unobserved heterogeneity and simultaneity, suggests that ICT matters but excess returns are replaced by normal returns. Overall, most results show a productivity effect from IT-use, but the point estimate of the elasticity is fragile and depends on the details of the estimation.

O'Mahony and Vecchi (2005) use a dataset of US and UK non-agricultural market industries to estimate the impact of ICT capital on output growth. As traditional industry panel data analysis fails to find a positive contribution, they employ a dynamic panel data approach in order to account for heterogeneity across industries. Pooled estimates show a positive and significant return of ICT capital on output growth. ICT investment produces excess returns as compared with the prediction from growth accounting. Individual countries' estimates imply a larger long-run impact in the United States than in the United Kingdom.

Some macroeconomic studies focus on specific ICT infrastructures such as telecommunication or broadband infrastructure and find positive and significant impacts on growth. Roller and Waverman (2001) investigate the relationship between investment in telecommunication infrastructure and economic performance in 21 OECD countries over the period 1971-90. Controlling for simultaneity and country-specific fixed effects, they find a causal relationship between telecommunication infrastructure and aggregate output. Their results suggest that a 1 percentage point increase in the telecommunication penetration rate (main telephone lines per capita) increases aggregate output growth by an average 0.045 percentage points.

Czernich *et al.* (2009) test the effect of broadband infrastructure on economic growth using an annual panel of 25 OECD countries over 1996-2007. In order to control for the endogeneity of the broadband penetration, they specify a technology diffusion model in which the ceilings of the broadband diffusion curve across countries are determined by the size of the pre-existing traditional networks. The results show a positive effect of broadband diffusion on economic growth, suggesting that a 1 percentage point increase in the broadband penetration rate results in a 0.09-0.15 percentage point increase in annual per capita growth.

Koutroumpis (2009) analyses the effect of broadband infrastructure on GDP growth in OECD countries between 2002 and 2007. To control for the bidirectional relationship between infrastructure and growth, he uses a simultaneous equation model that endogenises supply, demand and output. His results suggest that a 1 percentage point increase in the penetration rate increases GDP growth by an average of 0.025 percentage points. In addition, there is evidence of increasing returns to broadband telecommunication investment, consistent with the persistence of network effects. The critical mass in broadband infrastructure investment is estimated to be at 30% of broadband penetration, which effectively translates into half of the population having access to broadband connection.

3. Data source

The data source for the present analysis is the EU KLEMS Growth and Productivity Accounts (*www.euklems.net*). This database includes measures of output and input growth at the industry level. The input measures include various categories of capital (K), labour (L), energy (E), material (M) and service inputs (S). The measures are developed for 25 individual EU member states, Australia, the United States and Japan and cover the period from 1970 to 2007. However, industry data on ICT capital are available in only 18 of these countries.

Labour input service is estimated so as to reflect the actual changes in the amount and quality of labour input over time. Total employment is divided into types based on various characteristics: age, gender and educational attainment. Aggregate labour services are assumed to be a translog function of the services of individual types. In addition, it is assumed that the flow of labour services for each labour type is proportional to hours worked, and workers are paid their marginal productivities. In this way, changes in the composition of total employment, *e.g.* an increase in the proportion of skilled workers, would lead into an increase in labour input service.

According to the recommendations of the *OECD Productivity Manual* (OECD, 2001), capital input is measured as capital services, rather than stocks. Capital is divided into different asset types and it is assumed that the flow of capital services for each asset type is proportional to its stock, independent of time. For each individual asset, stocks have been estimated on the basis of investment series using the perpetual inventory method (PIM) with geometric depreciation profiles. Depreciation rates differ by asset and industry but have been assumed identical across countries. O'Mahony and Timmer (2009) provide more details on capital service calculations.

For the aggregation of capital services over the different asset types it is assumed that aggregate services are a translog function of the services of individual assets, where the weights are given by the average shares of each component in the value of capital compensation. As observed in Section 2, this aggregation method is a direct application of the non-parametric approach.

The basic investment series by industry and asset have been derived from capital flow matrices and benchmarked to the aggregate investment series from the National Accounts. Although the ESA provides a classification of capital assets, it is not always detailed enough to back out investment in information and communication equipment. Additional information has been collected to obtain investment series for these assets, or assumptions concerning hardware-software ratios have been employed. When the deflator for computers did not contain an adjustment for quality change, a harmonised deflator based on the US deflator has been used as suggested by Schreyer (2002).

While the *EU KLEMS Database* provides information on capital services for nine types of assets, this article focuses on the distinction between ICT and non-ICT capital services and, within the first asset type, among Information Technology, Communication Technology and Software services.

The *EU KLEMS Database* provides data at a detailed industry level. This article examines the business sector (26 industries)[1] in 18 OECD countries over the period 1995-2007.

4. Econometric model and estimates

This study uses an econometric approach to estimate the contribution of ICT investments to the growth of value added. Following a well-established approach (Boskin and Lau, 1990), it is assumed that all economies and industries have potential access to the same technology but each may operate on a different part of it depending on specific individual circumstances. More formally, the production function has the same functional form across all countries and industries but that inputs differ in efficiency unit.

The advantage of this approach is that it reduces the number of elasticities to be estimated (one for each input) while it permits the estimation of different TFP trends for each industry within each country. Its shortcoming is that the measure of the contribution of production inputs may be inaccurate in industries and countries that operate on a technology very different from the average.

The production function is approximated by the following functional form:[2]

$$\ln Y^*_{ijt} = a_L \ln L^*_{ijt} + a_{ICT} \ln ICT^*_{ijt} + a_{NICT} \ln NICT^*_{ijt} \quad (1)$$

where Y denotes value added, L labour services, ICT and NICT the respective capital services; i = 1,…18 indicates the country, j = 1,…, 26 the industry and t = 1996-2007 time. All variables are expressed in "efficiency unit" and denoted by an asterisk.

The measured quantities of outputs and inputs of the different economies may be converted into the unobservable standardised, or "efficiency-equivalent", units of outputs and inputs by multiplicative industry-, economy-, output- and input-specific time-varying augmentation factors, $A_{ij}(t)$'s.

In this study, the commodity-augmentation factors are assumed to have a constant geometric form with respect to time:

$$L^*_{ijt} = \exp(c_{Lij}t)\, L_{ijt} \quad (2)$$

$$ICT^*_{ijt} = \exp(c_{ICTij}t)\, ICT_{ijt} \quad (3)$$

$$NICT^*_{ijt} = \exp(c_{NICTij}t)\, NICT_{ijt}, \qquad i = 1,\dots, 18;\ j = 1,\dots, 26;\ t = 1996\text{-}2007. \quad (4)$$

where c_{ij}'s are constants measuring cross-country and cross-industry differences in the growth rate of inputs' productivity.[3]

By replacing 2, 3 and 4 into 1, the production function is expressed in terms of observable variables and can be estimated as:

$$\ln Y_{ijt} = a_L \ln L_{ijt} + a_{ICT} \ln ICT_{ijt} + a_{NICT} \ln NICT_{ijt} + p_{ij}\, t + \varepsilon_{ijt} \quad (5)$$

where $p_{ij} = (a_L\, c_{ijICT} + a_{ICT}\, c_{ijNICT} + a_{NICT}\, c_{ijL})$ is the annual rate of increase of total factor productivity (TFP) and $\varepsilon_{ijt} \sim N(0,\sigma^2_{ijt})$ is an error term. As no constraint is imposed on the input elasticities (a_L, a_{ICT} and a_{NICT}) nor on the technical progress rates (c_{ij}'s), the production function under (5) make no assumption about economies of scale, instantaneous profit maximisation or technical progress neutrality.

In order to estimate the production function under 5, the researcher has to deal with two main issues. First, changes in inputs are not independent from changes in output as both outputs and inputs are determined simultaneously by firms. Under such conditions, standard econometric techniques like Ordinary Least Squares (OLS) generate biased estimates, *i.e.* underestimate or overestimate the contribution of different inputs.

A common approach to solve the problem of simultaneity is the use of instrumental variables (IV). These are variables that are correlated to the inputs but not to the output and, therefore, allow controlling for variations in inputs that are simultaneous to variations in the output.

One problem with this approach is that finding suitable IV is not easy. The common solution is to use lagged values of the inputs. For instance, last year's employment is likely to be correlated with current employment (because firms cannot fire or hire workers immediately) but the output produced this year only depends on this year's employment. One concern with lagged values is that they may result in weak instruments, and this is an issue that estimation has to check for. An additional concern is that the number of lags will significantly change the results. Therefore, researchers need to test the appropriate number of lags.

The second issue for the econometric approach is that, under certain circumstances, it may erroneously suggest that some inputs, *e.g.* ICT investments, made no contribution to growth. For example, this might be the case when the ICT investments are better measured in an industry, *e.g.* manufacturing, than in another, *e.g.* services, so that the estimates will be more accurate in the former than in the latter industry. This is a specific example of the broader econometric issue of heteroskedasticity: econometric estimates provide better predictions for some units (*e.g.* some industries or some countries) than for others.

When heteroskedasticity is present, the most efficient approach is not the IV but the General Method of Moments (GMM). However, as GMM produces inaccurate estimates in small samples, one has to test for the presence of heteroskedasticy before dismissing the IV approach.

The econometric analysis of this study, therefore, went through the following steps. First, the contribution of labour, ICT and non-ICT capital to value added was estimated though standard OLS. Second, the IV approach was used to control for the simultaneity between output and inputs. Third, the IV estimates were found to be heteroskedastic and the production function was finally estimated by GMM with cluster-robust variance.

Regressions were run in STATA by the *ivreg2* command developed by Bau *et al.* (2007). Lags 1 to 4 of labour, ICT and non-ICT capital were used as IV, based on the results of an LM test which rejected the significance of longer lags. Standards tests on endogeneity of the regressors, over identification of the instruments and the weak identification supported the selected specification. The regression explains over 92% of the observed differences in value added across countries and industries. The regression output is summarised in Table 1 below.

Table 1. **GMM estimates and tests**

	Coefficient	T	[95% confidence interval]	
Labour	0.635	13.58	0.544	0.727
ICT capital	0.056	3.27	0.022	0.090
Non ICT capital	0.307	7.55	0.227	0.387

Notes: Industry * country * time dummies omitted. Number of observations: 5 278. Number of clusters: 468. Centered R^2 = 0.965. Hansen J statistic: 4.716. IV redundancy test: 30.373.

5. Main findings

This section discusses the results of the analysis for the total business sector.[4] Column 1 in Table 2 reports the estimated value added elasticity of labour, ICT and non-ICT capital. A 1% increase in labour, ICT capital or non-ICT capital services leads to an increase in value added of, respectively, 0.635%, 0.056% and 0.307%. Although no assumption was made on the returns to scale, the data support the hypothesis of constant returns, *i.e.* the sum of elasticities equal to 1.

Table 2. **Estimated value added elasticities to inputs**

Inputs	Elasticity	Cost share
Labour	0.635	0.639
ICT capital	0.056	0.039
Non-ICT capital	0.307	0.322

Column 2 reports the non-parametric values of the elasticities based on the average shares in total costs for the whole business sector over the period considered. On average, the estimated elasticities are not very different from the cost share of the respective inputs. However, the theoretic values tend to be higher for non-ICT capital (0.015) and lower for ICT capital (-0.017). As ICT capital services increased between 50% (in Japan) and 208% (in Australia) over the period considered, this implies that the contribution of ICT investment is between 0.84 and 3.5 percentage points lower according to the non-parametric rather than the econometric approach.

Table 3 reports the contribution of production inputs to the average yearly growth in value added in the business sector of the countries considered. The average contribution of ICT investments varies from 1.0% a year in Australia to 0.4% a year in Japan. In one-third of the countries considered, the contribution of ICT investment was bigger or equal to that of non-ICT investments.

Table 3. **Growth accounting of the business sector**

Per cent

	Period	Value added	Due to growth in:				Residual
			Employment	ICT capital	Non ICT capital	Productivity	
Australia[1]	1995-2007	3.5	1.4	1.0	1.0	0.0	0.0
Austria	1995-2007	2.4	0.7	0.7	0.4	0.6	0.0
Belgium	1995-2006	2.1	0.8	0.9	0.8	-0.4	0.0
Czech Republic	1995-2007	2.8	0.2	0.7	1.2	0.7	0.0
Denmark	1995-2007	1.9	0.9	1.0	0.4	-0.4	0.0
Spain	1995-2007	3.5	2.3	0.7	1.3	-0.8	0.0
Finland	1995-2007	3.6	1.1	0.6	0.5	1.4	0.0
France[1]	1995-2007	2.1	0.7	0.5	0.6	0.4	0.0
Germany	1995-2007	1.6	-0.1	0.6	0.7	0.4	0.0
Hungary	1995-2007	3.9	0.9	0.4	0.3	2.2	0.1
Ireland[1]	1995-2007	7.0	2.8	0.8	2.5	0.8	0.0
Italy[1]	1995-2007	1.4	0.8	0.5	0.7	-0.5	0.0
Japan	1995-2006	1.2	0.0	0.4	0.6	0.2	0.0
Netherlands[1]	1995-2007	2.7	1.0	0.7	0.5	0.4	0.0
Slovenia[1]	1995-2006	4.1	0.6	0.5	2.8	0.2	0.0
Sweden[1]	1995-2007	3.0	0.6	0.5	1.1	0.7	0.0
United Kingdom	1995-2007	2.7	0.9	0.7	0.8	0.3	0.0
United States	1995-2007	3.1	0.9	0.8	0.8	0.6	0.0

[1] Does not add up to “value added” due to rounding.

Growth in total factor productivity accounted for a significant share of value added growth. The average yearly growth in TFP varied between 2.2% in Hungary and -0.8% in Spain. The proportion of value added growth not explained by the regression tends to be very small in all countries.

The contribution of different types of ICT capital goods (Communication equipment, Computing equipment and Software) is detailed in Table 4.[5] In a large majority of countries, computing equipment provided the largest contribution and accounted for over 50% of the overall ICT contribution. The only exceptions are Finland, where investments in communication equipment exceeded those in computing equipment, and Japan, where software was the most dynamic component of ICT investments.

TFP estimates at the industry level permit the measurement of the contribution of the ICT-producing industries[6] to total TFP growth in the business sector, as shown in Table 5. ICT-producing industries account for no less than two-thirds of total TFP in Germany, the United Kingdom and Slovenia, about 60% in the United States and just below 50% in France and the Netherlands. In Belgium, Denmark and Italy, TFP increased in the ICT-producing industries whereas it decreased for the total business sector.

Table 4. **The contribution of ICT investment: communication equipment, computing equipment and software**

Per cent

	ICT capital	Communication equipment	Computing equipment	Software
Australia	1.0	0.09	0.85	0.11
Austria	0.7	0.06	0.55	0.13
Belgium	0.9	n.a.	n.a.	n.a.
Czech Republic	0.7	0.05	0.58	0.04
Denmark	1.0	0.02	0.78	0.16
Spain	0.7	0.25	0.34	0.07
Finland	0.6	0.28	0.18	0.13
France	0.5	n.a.	n.a.	n.a.
Germany	0.6	0.12	0.38	0.12
Hungary	0.4	n.a.	n.a.	n.a.
Ireland	0.8	n.a.	n.a.	n.a.
Italy	0.5	0.08	0.36	0.07
Japan	0.4	0.11	0.14	0.14
Netherlands	0.7	0.09	0.51	0.13
Slovenia	0.5	0.07	0.32	0.08
Sweden	0.5	0.07	0.33	0.11
United Kingdom	0.7	0.06	0.53	0.16
United States	0.8	0.16	0.44	0.17

Table 5. **Contribution of ICT-producing industries to TFP**

Per cent

	Productivity growth in:		% due to ICT
	Business sector	ICT industries	
Australia	0.02	0.01	40
Austria	0.58	0.13	23
Belgium	-0.37	0.15	> 100
Czech Republic	0.71	0.19	27
Denmark	-0.39	0.15	> 100
Spain	-0.77	-0.00	0.4
Finland	1.44	0.50	35
France	0.43	0.21	49
Germany	0.41	0.29	69
Hungary	2.21	0.60	27
Ireland	0.78	0.25	32
Italy	-0.48	0.12	> 100
Japan	0.23	0.23	100
Netherlands	0.40	0.19	48
Slovenia	0.23	0.15	66
Sweden	0.66	0.71	> 100
United Kingdom	0.28	0.19	67
United States	0.59	0.35	59

6. Conclusions and further work

This study has used an econometric approach to estimate the contribution of three types of ICT investment (computer, software and communication) in 26 industries (the whole business sector) in 18 OECD countries over the period 1995-2007.

The values of the estimated input elasticities were found to be close to the values of corresponding cost shares used in non-parametric growth accounting, although the latter tend to be smaller for ICT investment. Over the period considered, this implies that the contribution of ICT investment is between 0.84 and 3.5 percentage points lower according to the non-parametric rather than to the parametric approach.

Although the regression explains a very large proportion of the observed differences in value added across countries and industries and over time, the assumption of constant elasticities may lead to underestimate the contribution of the production inputs and to overestimate TFP and vice versa. In addition, the hypothesis does not permit disentangling the productivity growth of each factor in TFP.

Further research should extend the present framework to a more flexible functional form, like a translog production function, in order to account for different elasticities across industries and countries and over time.

Notes

1. Are excluded: Public Admin. and Defence; Compulsory Social Security; Education, Health and Social Work; Other Community, Social and Personal Services; Private Households with Employed Persons; and Extra-Territorial Organisations and Bodies.
2. Attempts to estimate a translog production function were inconclusive due to high collinearity among the independent variables.
3. In EU KLEMS, real value added and the inputs' services are reported as a normalised index with 1995 = 100. Therefore, cross-industry and cross-country differences in the level of efficiency are wiped out by this normalisation.
4. Detailed results by industry are available from the author on request.
5. The contribution of each type of ICT capital is computed based on a common elasticity for ICT capital, as reported in Table 2.
6. ICT-producing industries are defined according to OECD, 2011. However, the level of industry breakdown at which data are available does not permit a precise delimitation of the ICT-producing industry. A common proxy is the sum of ISIC 30 to 33 Electrical and Optical Equipment and ISIC 64 Post and Telecommunications. This aggregate includes Post, which is not part of the ICT sector, and excludes ISIC 72, which is an ICT industry.

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