ICTNET Assessment Paper 1

The impact of ICT on Productivity and Growth

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Differences in productivity growth between Europe and the US

Since the mid 1990s, the patterns of productivity growth between Europe and the United States have been diverging. Slower labour productivity in Europe reverses a long-term path toward convergence. Van Ark *et al.* (2008) divide Europe growth performance relative to the United States into three periods:

- 1950-1973: productivity growth in Europe follows a traditional catching up pattern sustained by strong investment and supporting institutions. This process came to an end by the mid 1970s.

- 1973-1995: productivity growth in both Europe and the United States began to slow down. However, average annual labour productivity growth in the EU-15 was still twice as fast as in the United States and the productivity gap was very narrow by 1995.

- 1995 onwards: the U.S. productivity growth accelerated while the rate of productivity growth in Europe fell. By 2004, GDP per hour worked in the EU was about 10 percentage points below the U.S. level.

The causes of the strong U.S. productivity resurgence have been extensively discussed. A growing body of research points out that the U.S. acceleration in productivity growth reflects underlying technology acceleration. The findings of this research stream, along with considerable anecdotal and microeconomic evidence, suggest that Information and Communication Technologies (ICTs) have played a substantial role.

In the mid 1990s, a burst of productivity in the industries producing ICT equipment (computer hardware, software and telecommunications) led to falling relative prices of ICTs, increasing investments in ICT assets and capital-deepening across the whole economy (Jorgenson *et al.*, 2008).

With some delay, arguably due to the changes in production processes and organisational practices necessary to adjust to the new technology, industries using ICTs intensively also experienced a surge in multifactor productivity (MFP), particularly in market services (Triplett and Bosworth, 2006). In the United States the MFP uptake in the late 1990s was supported by the industries using ICTs rather than by those producing them.

Although the European economies experienced the same fall in the prices of ICTs and an increase in the returns from ICT investment, in Europe the diffusion of ICTs has been much slower since the mid 1990s. A number of studies have tried to explain the reasons for this pattern.

Benefiting from ICTs requires substantial complementary investments in learning, reorganisation and the like, so that the payoff in terms of measured output may take long to materialise. Investment in ICTs may even be associated with lower MFP growth in the short run as resources are diverted to reorganisation and learning. Basu *et al.* (2003) find that industries with higher ICT capital growth rates in the 1980s also had higher MFP growth rates in the late 1990s, whereas ICT capital growth in the late 1990s was negatively correlated with contemporaneous MFP growth, when controlling for lagged effect.

The successful implementation of ICTs requires reorganisation of the firm around the new technology - fees paid to consultants, management time and expenditures in training (Yang and Brynjolffson, 2001; Brynjolffson *et al.*, 2002). Evidence from micro panel studies also suggests that U.S. firms have a greater organisational capital than European firms (Bloom *et al.*, 2005).

As most literature attributes the European slow-down in productivity growth to the lag in ICT adoption by the ICT-using sector, factors related to national regulations may play a role in explaining the slow reorganisation of European firms around the new technology. Gust and Marquez (2004) and Van Reenen *et al.* (2010) provide evidence that labour market and product market regulations explain a significant part of the differences between U.S. and European productivity. They also suggest that policies should promote product market competition, faster adjustment in labour market and openness to trade.

The rise in productivity growth in the U.S. lasted through the middle of 2004, but it has slowed down in more recent years. While the contribution of ICTs to productivity growth remain large as compared to the relative importance of ICTs production in the U.S. economy, after 2000 productivity growth has significantly slowed down in both the ICT producing and the ICT using industries. Given that the increase in MFP after 2000 is mainly driven by sectors that are intensive in ICT usage, continued fall in ICT prices is likely to be an important factor for sustained MFP growth over time.

Growth accounting: From the Solow Paradox to the ICT-driven Productivity Resurgence

Early studies on the impact of ICTs on productivity resulted largely inconclusive. The well-known Solow's paradox (2005) for which "computers are visible everywhere except in productivity statistics" summarizes the state of art in the early 90s. 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, 2009) have opened the way to a new stream of analysis on the productivity effects of ICTs. While, the work carried out by the OECD to internationally harmonise ICT prices (Wyckoff, 1995; Schreyer, 2000; Colecchia and Schreyer, 2002) allowed controlling for differences in methodologies among countries.

Most macroeconomic and industry studies are based on the growth accounting framework, where the contribution of each input to production is assumed to be proportional to the corresponding share in total input costs. Increases in production above the inputs' contribution are ascribed to growth in multifactor productivity (MFP), i.e.: technological progress not embodied in production inputs.

Jorgenson and Stiroh (2000) apply the Jorgenson's *production possibility frontier* (1967) to explain the increase in productivity growth in the U.S. 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 MFP.

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 1974-1995 and 1996-1999 and that MFP growth also increased by 40% in the period 1996-1999.

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. The contribution of ICT investment to economic growth has been the 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 U.K., using U.S. producer price indices adjusted for exchange rates to deflate the value of ICT investments. He finds that 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 MFP gains in ICT-producing industries. They find that, over the period 1987-1998, ICTs accounted for 0.7 percentage points of the yearly value added growth, 0.3 points from capital deepening and 0.4 points from MFP growth in ICT-producing industries. This amounts to over one-fourth of the yearly value added growth (2.6%).

Improving the measurement of ICT capital is also at the core of the work led by Van Ark *et al.* (2002a) to explain the different impact of ICTs on productivity between the U.S. and Europe. Using data on manufacturing and service industries from 1980 to 2000, they find that the pattern of ICT diffusion in Europe has not been much different from that in the U.S., 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 U.S.

The slowdown in productivity growth in the EU contrasts sharply with the rapid acceleration in productivity growth in the U.S. after 1995. Van Ark *et al.* (2002b) show that this slowdown has affected all sectors of the economy and, in particular, services. However, intensive ICT-using services in Europe have kept up their productivity growth. This evidence suggests that ICT is not the only factor explaining differences in productivity growth between Europe and the U.S.

A detailed account of the sources of labour productivity in the service industry is made by Inklaar *et al.* (2008) using the EU KLEMS database. The focus on market services is particularly useful, not only because the U.S. experience shows that they can be a substantial source of growth, but also because services are amongst the most intensive users of new technologies and skilled labour. The study shows that growth differences in market services closely mirror aggregate growth differences across countries. A large part of that growth is due to the investments in ICT and human capital. However, cross-country growth differences are not explained by the variation in these investments rates but by the differences in the efficiency gains from these two inputs.

Mas (2010) shows that the efficiency gains in the ICT-producing sector in the United States spilt over ICT-using sectors but these spill-overs did not occur in Japan and in Europe.

If ICT capital deepening and MFP growth in ICT-producing sectors measure the direct growth contribution of the use and the production of ICTs, microeconomic studies emphasize the complexity of the link from technology to productivity. To leverage ICT investment successfully, firms must typically make large complementary investments in human capital and other intangible assets and to change their business organisation and workplace practices. Corrado *et al.* (2006) have been made important progresses in incorporating these variables into a macro growth accounting framework. They find that the growth rates of output and output per worker increase at a noticeably faster rate when intangibles are included then under the baseline case in which intangible capital is ignored 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. In fact, Van Ark (2010) estimates that about a quarter of both the U.S. labour productivity growth in the 1995-2006 period was due to the contribution of intangible assets.

After 2007 the economic crisis draws a fairly different picture in the advanced economies, with negative rates of GDP growth in both the U.S. and the European Union: GDP growth in the EU-15 slowed down to 0.3% in 2008 and then dropped to -4.3% in 2009; in the U.S., GDP growth was almost null in 2008, falling to -2.6% in 2009 (Timmer *et al.*, 2011). However, in the U.S. the adjustment to the crisis mainly occurred in the labour market and resulted into a dramatic increase in unemployment, whereas in Europe employment losses were smaller and the adjustment occurred through a decrease in labour productivity. Nevertheless, labour quality and ICT investment continue to provide a positive contribution to growth (Van Ark, 2010).

The growth potential of ICTs in the long run is at the core of the work by Oulton (2010). Based on a two sector growth accounting model, he shows that the main boost to growth comes from ICT use, not ICT production (Figure 1). Even a country which has zero ICT production can benefit via improving terms of trade. In the long run, the falling relative price of ICT products boosts the growth of GDP and consumption by inducing faster accumulation of ICT capital. The author quantifies this effect on the long run growth rate of 15 European and 4 non-European countries, using data from the EU KLEMS database. The ICT intensity of production (the ICT income share) is much lower in many European countries than it is in the United States or Sweden. Nevertheless the contribution to the long run growth of labour productivity stemming from even the current levels of ICT intensity is substantial: about half a percent per annum on average in the countries considered in the study. Eventually, the ICT revolution may diffuse more widely so ICT intensity may reach at least the same level as currently in the U.S. or Sweden, which would add a further 0.2 percentage points per annum to long run growth. These findings suggest that policies should help to remove existing barriers to the adoption and use of ICT.

What is growth accounting not taking into account?

There are several well-known issues with the growth accounting approach. First, growth accounting describes but it does not explain. There is no attempt to claim that there is any causal relationship between changes in input, such as ICT capital, and growth.

Second, the assumptions underlying the growth accounting are strong and generally not tested. It is assumed, in particular, that all markets are perfectly competitive and that production in every sector is characterised by constant returns to scale. Labour and capital are assumed to be completely mobile, an assumption that implies a single wage rate for labour across all sectors and a single rental rate for each type of capital.

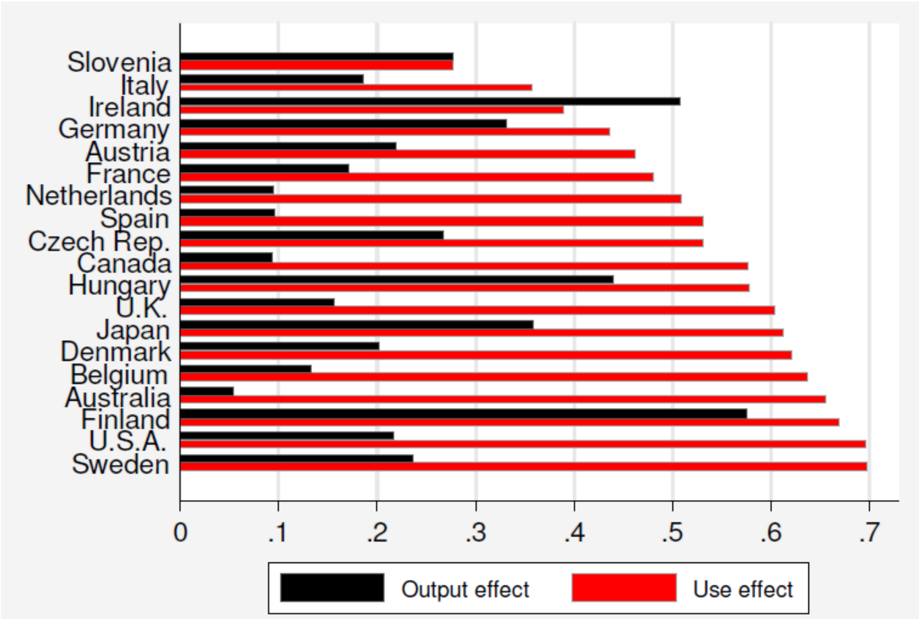
Third, within this competitive market structure, firms are assumed to be price-takers and to make their investment and hiring decisions to maximise profits. In addition, when firms purchase new capital goods or hire more workers, they are assumed not to incur any adjustment cost not to experience any temporary decrease in output while these new inputs are integrated into the production process. Also, growth accounting does not allow for cyclical changes in intensities with which firms use their capital and labour.

Fourth, this approach assumes that all increase in value added which is not explained by the growth in production inputs (the so-called residual) is due to an increase in total factor productivity

(TPF). As a result, all deviation from the above hypotheses and all measurement errors in the statistical data are misinterpreted as differences in TFP across countries and over time.

Finally, if there are externalities related to production factors, they will be included in the residual (TFP), and the contribution of these factors will be underestimated.

Figure 1. ICT output and ICT use effects on long run growth of Gross Domestic Product, p.p.p.a.



Note: Calculated using shares averaged over 2000-latest year; ICT relative prices assumed falling at 7% per annum; market sector. The abbreviation "p.p.p.a." stands for percentage points per annum.
Source: Oulton (2010).

Evidence from macroeconomic studies

Econometric estimation of the production function provides an alternative approach to growth accounting. In order to estimate the production function, 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 the firms. Second, econometric estimates may provide better prediction for some unit, e.g. some industries or some countries, than for others (heteroskedasticity).

Under such conditions, standard econometric techniques like Ordinary Least Squares (OLS) generate biased estimates, i.e. underestimate or overestimate the contribution of different inputs. Some studies use estimation methods that are better suited for dealing with these problems, such as the General Method of Moments (GMM) and the Olley-Pakes method.

Spiezia (2011) uses a two-step GMM estimation to estimate the contribution of ICT investments (classified into computer, software and communication) to the value added growth in the business sector across 18 OECD countries over the period 1996-2007. The estimated contributions go from 0.3% a year in Japan to 1.1% a year in Australia. Investments in computer equipments exert the largest contribution in almost all of the countries, except for Finland and Japan where communication and software, respectively, are the most dynamic elements. The contribution of the ICT sector to total factor productivity largely varies by country: in Germany and the United Kingdom it represents over 2/3 of TFP growth, about 60% in the United States and just below 50% in France and the Netherlands. In some other countries the TFP increased in the ICT sector, but it decreased for the total business sector. Such different patterns suggest that other inputs such as skills, R&D and the institutional environment might be playing a role.

Gust and Marquez (2004) provide some insights on the factors explaining cross-country growth differences. They model labour productivity growth as a function of ICTs and other controls (like employment to population ratio and countries fixed effects). They find that ICT production and, to a lesser extent, ICT expenditures are associated with higher productivity growth. They also point out that regulation affects the speed of diffusion of information technologies. Burdensome regulations have impinged on firms' incentives to adopt new technologies in several countries, slowing down the rate of adoption of ICTs: a wide variety of regulatory regimes across countries, ranging from product market regulations, which may result into lower market competition, to business regulation, which may raise the entry costs of new firms, to labour market regulations, which may reduce the ability of firms to adjust their workforce in a flexible manner.

Nicoletti and Scarpetta (2003) show that lower entry barriers stimulate MFP growth in the manufacturing sector in OECD countries. Whether their results also apply to services, it remains an interesting question as market services are intensive ICT users and among the most highly regulated industries (Conway and Nicoletti, 2006). Inklaar *et al.* (2008) look at the impact of regulatory barriers to entry in services, but they find only limited evidence in support of this hypothesis. MFP growth in post and telecommunications benefited substantially from entry liberalisation during the 1990s. This supports the view that deregulation fosters productivity, but similar evidence has not been found for other industries. The analysis, however, does not reject the notion that a decline in entry barriers in services may unlock the productivity growth potential of other market services.

While ICTs have been a major source of innovation over the last few decades, most of the measured MFP acceleration has taken place outside of the production of ICT goods. This pattern is consistent with the view of ICTs as a "general purpose technology" (GPT): an innovation in one sector, the ICT-producing industries, causes unexpected waves of ICT-related invention and investment in sectors that seem far away.

The hypothesis of ICTs as a GPT suggests that measured MFP should rise in ICT-using sectors - due to the accumulation of intangible capital, change in organisation and spillovers - but only with some lags. In fact, contemporaneous investments in ICT may even be associated with lower MFP as resources are diverted to reorganisation and learning.

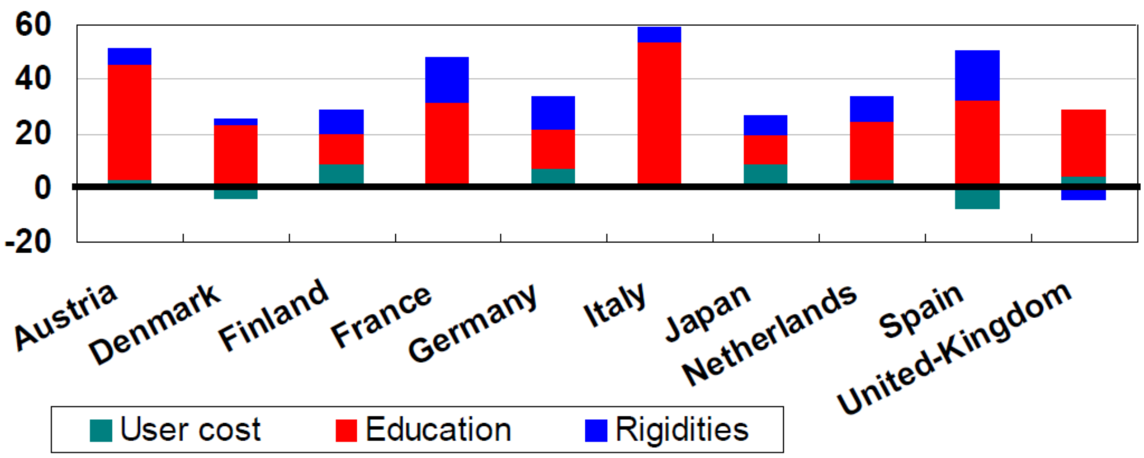
Basu *et al.* (2003) and Basu and Fernald (2007) tested these predictions of the GPT hypothesis using BLS data on capital input by industry. They found that the impact of ICT investments on MFP growth has a lagged effect while ICT capital growth in the late 1990s turned out to be negatively correlated with contemporaneous MFP growth. They also find that industries that had high ICT capital growth rates in the 1980's or early 1990s also had high MFP growth rates in the late 1990s.

O'Mahony and Vecchi (2005) use a dataset of U.S. and U.K. 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 to the prediction from growth accounting. Individual countries estimates imply a larger long-run impact in the U.S. than in the U.K.

Cette and Lopez (2010) provide some empirical explanations for the gaps in ICT diffusion between industrialized countries, especially European countries vis-à-vis the United States. The study shows that, over the period 1981-2005: (i) the impact of the level of education and market rigidities on ICT diffusion has changed over time. The correlation of ICT diffusion, positive with the level of education and negative with market rigidities, increased over time (in absolute terms) until the middle of the 1990s; (ii) In each country, the estimates show a decrease over time of the price-elasticity of demand for ICT (in absolute terms). More precisely, the elasticity of substitution of ICT vis-à-vis all production factors are close to or greater than 2 at the beginning of the 1980s and close to 1 in the middle of the 2000s; (iii) The estimates confirm the positive impact of the share of the population with a higher education and the negative impact of market rigidities on ICT diffusion (Figure 2). These effects are heightened when ICT diffusion is already substantial.

These findings confirm the results of previous studies (Aghion *et al.*, 2008), which show a positive effect of education over ICT diffusion, particularly when diffusion is already large. Therefore, complementary investments in education and skills seem necessary to support firms' investment in ICTs.

Figure 2. Factors underlying the simulated ICT diffusion gap vis-à-vis the United States, 2005



Notes: User cost refers to user capital cost and is reckoned with data from EU KLEMS database. Education considers the share of population with tertiary education. Rigidities are measured by two OECD indicators: the indicator on employment protection legislation (EPL) for labour market rigidities; and the indicators of regulation in energy, transport and communications (ETCR) for product market rigidities. Source: Cette and Lopez (2010).

Guerrieri *et al.* (2011) undertake an analysis similar to that by Cette and Lopez (2010) but they did not find any significant effect of labour market regulation on ICT investment. Their analysis, however, suggests that a reduction in administrative burdens and an increase in competition in services would have a positive effect on ICT investment. A possible reason for the different results of these two studies may lie in the time period of analysis and in the use of price deflators in Cette and Lopez but not in Guerrieri *et al*.(2011).

The interactions between ICTs and trade openness also appear an important driver of growth. Meijiers (2010) addresses the issue of the causality between ICT and trade and the way they both affect economic growth. In contrast to previous evidence (Choi and Yi, 2009), his study shows that Internet use is not directly related to growth but that it has an indirect impact through trade. This result, however, does not control for the role of human capital as a determinant of growth.

Jona-Lasinio (2010) presents some evidence at country and industry levels on the links between ICT, off-shoring and productivity. The hypothesis behind her study is that off-shoring allows firms to focus on their core activities and to reallocate resources to investments in ICT, which may enable further innovations and thus improve their performance. Based on a cross-country cross-industry approach, she finds that countries with higher level of service off-shoring tend to show faster labour productivity growth in the ICT-intensive industries.

Another line of research has focused on specific ICT infrastructures such as telecommunication or broadband infrastructure and their impacts on growth. Czernich *et al.* (2011) test the effect of broadband infrastructure on economic growth using an annual panel of 25 OECD countries in 1996-2007. In order to control for the endogeneity of broadband penetration, they estimate 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 into 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 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.

Gruber and Koutroumpis (2011) apply the same approach for mobile telecommunications infrastructure. Using a panel of 192 countries over the period 1990–2007, they find increasing returns from mobile adoption. Hence, countries with higher mobile penetration rates register higher contributions from mobile infrastructure to growth. Since penetration is largely correlated with income, these authors estimate that the contribution of mobile telecommunications infrastructure to annual GDP growth is 0.11% in low-income countries, compared to 0.20% in high-income.

These two papers are drawn on the methodological approach used by Roller and Waverman (2001) to investigate the relationship between investment in telecommunication infrastructure and economic performance in 21 OECD countries over the period 1971-1990. Controlling for simultaneity and country-specific fixed effects, they find a causal relationship between telecommunication infrastructure and aggregate output. Their results suggest that 1 percentage-point increase in telecommunication penetration rate (main telephone lines per capita) increases aggregate output growth by an average 0.045 percentage points.

Stiroh (2004) early drew attention on the varying estimates obtained in the large literature on ICTs and economic growth. In his meta-study, he compares the methods, data and results of a set of 20 studies. He finds out 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 reengineering - related to ICT deployment. When controlling for unobserved heterogeneity via fixed effects, the ICT coefficient falls substantially. The GMM estimation, which accounts for unobserved heterogeneity and simultaneity, suggests that ICT matter but excess returns are replaced by normal returns.

Further research is needed to reconcile these different findings. While macroeconomic analyses of the productivity effects of ICT treat labour as homogeneous, considering the role of different occupations and qualification levels would provide a more complete picture of the productivity potentials of ICTs.

Evidence from firm-level studies

Firm-level studies help to disentangle the hidden factors in multifactor productivity (Draca *et al.*, 2007). Most firm-level studies show a positive and significant association between ICTs and productivity growth. In addition, the magnitude of the ICT coefficients is larger than it might be expected from the standard neoclassical assumptions underlying the growth accounting framework. This finding suggests the existence of positive spillovers from ICT investments.

A plausible explanation of why positive spillovers are apparent at the firm-level but not in more aggregated estimates, is that they reflect the increase in the market shares of more productive firms. If two firms invest equally in ICTs but they differ in their capability to introduce complementary organisational changes, the productivity increase associated to their ICT investments will also differ. As a result, the increase in productivity at the industry level will be lower than at the firm level. Eventually, lagging firms will either exit the market or catch-up with the leaders due to competitive pressure, but this process inevitably takes time. In the meantime, country or industry performances would reflect the performances of both lagging and leading firms.

Firm-level studies also permit to account for improvements in output quality, such as faster delivery and customisation of products, which are among the most characteristic effects of ICT investments. The problem of unmeasured quality changes in aggregate statistics is especially important in the case of unmeasurable services (trade, finance, insurance, etc.) where ICT investment has grown more rapidly. As a consequence, aggregate data may lead to underestimate the contribution of ICTs to real output growth. On the contrary, firm-level studies suffer less from measurement bias because micro data permit to account for differences in output quality among firms and through time. Controlling for these differences is likely to result into higher estimates of the output elasticity to ICT investment.

Most of the studies on the impact of ICT carried out at the firm level employ a production function framework to estimate the elasticity of output with respect to ICT capital. The quantitative results of these studies, however, vary considerably. Apart from differences in the definition of ICT capital stocks and sample design, much of this variation may be due to differences in the econometric techniques and model specifications.

Brynjolffson and Hitt (2003) apply standard growth accounting and productivity measurement approaches to examine the relationship between computer spending and growth in output and MFP in 527 large U.S. firms. They estimate that the contribution of computerisation to productivity and output growth in the short term (1-year difference) is roughly equal to the cost of computers. However, the ICT contribution is up to five times greater over longer periods (5 to 7-year differences). This suggests that, in order to generate productivity gains, ICTs require investments in complementary assets, such as organisational capital, over a prolonged period of time.

Bloom *et al.* (2005) compare productivity growth among U.S. multinational, non-U.S. multinational and domestic firms based in the U.K. Their results point out that the way U.S. firms are managed or organised enables better exploitation of ICTs. This finding supports the view that faster productivity growth in the U.S. is mainly due to organisational capital.

Bresnahan *et al.* (2002) investigate the hypothesis that the combination of three related innovations - information technology, complementary workplace reorganisation and new products and services – resulted into skill-biased technical change and affected labour demand in the United States. Using detailed firm-level data, they find evidence of complementarities among all three types of innovation in factor demand and productivity regressions. In addition, firms that adopt these innovations tend to use more skilled labour. The effects of IT on labour demand are greater when IT is combined with the particular organisational investments that they identify, highlighting the importance of IT-enabled organisational change.

Tambe *et al.* (2011) further explore this issue and categorize the types of organisational changes that are needed in order to obtain IT-derived productivity gains. In particular they find that the IT investments should be combined with decentralised decision-making and "external focus", which refers to those business practices that allow firms to better detect and respond to changes in the operating environment (i.e. project teams that include suppliers, partners, customers …). Garicano (2010) and Van Reenen *et al.* (2010) also confirm that the productivity impact of IT goes along with the introduction of proper organisational changes.

Nevertheless, the link between IT and organisational changes appear to vary across industries. Zand *et al.* (2010) show evidence that IT mainly stimulate the introduction of organisational changes in manufacturing firms, while IT are basically change complements in services industries.

Hempell and Zwick (2007) focus on the links between organisational flexibility, ICTs and firm performance. They argue that ICTs enable flexibility in labour organisation while flexibility enhances innovative capacity. Flexibility increases the workers' mobility between activities and tasks, empowers workers with greater responsibility in decision-making and provides them with a greater variety of activities (team work, autonomous workgroups and flat hierarchies). Flexibility also increases the scope for outsourcing or contracting-out jobs to specialised suppliers, which can produce at lower costs and/or higher quality through economies of scale and learning effects.

At the same time the increasing complexity and widening scope of ICT applications have increased the necessity for external know-how. Firms contract ICT consulting and outsource ICT maintenance and support in order to use these technologies more efficiently. Abramovsky and Griffith (2006) use a large and representative dataset of U.K. establishments to investigate how ICT investments affect outsourcing and offshoring services. They find that more ICT-intensive firms purchase a greater amount of services on the market and they are more likely to purchase offshore than less ICT-intensive firms.

Bartel *et al.* (2005) provide evidence that an increase in the pace of technological change increases outsourcing because it allows firms to use services based on leading edge technologies without the costs of adoption of these new technologies. Furthermore, they find a positive correlation between a firm's ICT capital and the share of ICT-based services outsourced.

Ohnemus (2009) analyses a comprehensive panel survey of German manufacturing and service firms between 2000 and 2007. He compares different estimation techniques (pooled OLS estimation, fixed effects vector decomposition approach, Olley and Pakes approach and system GMM estimation) in order to control for unobserved firm heterogeneity, measurement errors in the variables and simultaneity of inputs and outputs. All specifications show a positive impact of business process outsourcing on firm-level productivity.

Cerquera and Klein (2008) argue that the benefits of ICTs are not equally distributed among adopting firms. As some firms reap those benefits sooner and better than others, the adoption of ICT represents a source of firm heterogeneity that might generate competitive advantages, affect firm strategies and/or influence aggregate productivity growth. Based on the ZEW ICT Survey in Germany, their paper shows that ICTs have a positive impact on firm heterogeneity. This result is shown to be robust to different empirical strategies. In addition, ICT-induced heterogeneity has a significant and positive, albeit small, impact on the incentives to innovate, particularly on the decision to invest in R&D personnel.

Falk (2010) further explore the issue of the unequal distribution of benefits of ICTs and concludes that only those territories that are already well-off take advantage of the potential of ICT for growth. Using a spatial regression model he investigates the role of ICT endowment in the convergence of growth rates of 164 European regions in 2002-2007. His initial estimates show that the endowment of ICT workers has a positive impact on regional growth, though its statistical significance is low (10%). In fact, when a quantile regression is run, ICT workers are found to be significant only for the fastest growing regions, those at the top 25%. This result is in line with that of Forman *et al.* (2011) who find that the impact of ICT is only significant for wealthy American counties.

While most studies refer to ICTs as a homogeneous aggregated input, some recent contributions have been looking at different ICT applications (e.g. e-commerce, enterprise resource planning, supply chain management, customer relationship management, etc.) and their specific effect on productivity.

Bertschek *et al.* (2006) provide evidence of a simultaneous relationship between labour productivity and the adoption of Business to Business e-commerce (B2B) in a dataset of 1460 German firms. Firms deciding to use B2B e-commerce employ their input factors more efficiently than non-B2B users. Conversely, firms seem to refrain from engaging in B2B because they expect the cost of B2B adoption not to be sufficiently compensated by productivity gains.

Engelstätter (2009) studies a number of ICT applications to enterprise systems such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM) and Customer Relationship Management (CRM). The analysis, based on a production function, focuses on the productivity impact of the adoption of more than one enterprise system at a given time. The data refer to German enterprises of different industry branches from the manufacturing and service sector. The results confirm the expected positive effect of the enterprise systems on labour productivity and show a complementary relationship between SCM and CRM, especially if the necessary ICT infrastructure is provided through the ERP system. Therefore, the use of the three enterprise systems together seems to deliver the largest productivity gains. Forman *et al.* (2011) also confirm that the benefits to get from ICT are larger when the adoption of advanced applications is involved compared to more basic uses.

Agrawal and Goldfarb (2008) provide some evidence for network spillovers in telecommunications, where spillover occurs through the increase in the value of the technology as more firms use it.

Overall, the evidence of direct spillovers from ICT investments remains limited. Contrary to the large empirical literature on R&D spillovers, Van Reenen *et al.* (2010) do not find any significant evidence for ICT. The authors argue that, unlike disembodied technologies where knowledge cannot be fully appropriated by the developer and thus spillovers to other firms, embodied technologies like ICTs, generate spillovers through a reduction of price for the users (Griliches, 1979). When technology-producing firms operate in oligopolistic markets, they can charge high prices and appropriate the social benefits from the technology; when they operate in competitive markets, they will charge lower prices and the benefits from ICT will spillover to the users (Griliches, 1979; Mohnen, 1989; Papaconstantinou *et al.*, 1996).

Are there implications for policies?

The economic literature shows that ICTs are an important driver of productivity and growth. However, countries, industries and firms continue to show significant differences both in the intensity of ICT use and in their capability to reap the productivity gains from ICTs. Some of the factors explaining the observed differences may provide an economic rationale for policies.

There is a consensus among economists that ICT investments lead to productivity gains only if accompanied by investments in complementary production factors. In particular, the available evidence points to importance of two "intangible" assets. First, the development of organisational conditions within the firm, e.g.: decentralised decision-making, external information gathering, etc., which are supportive of the use of ICTs. Second, the undertaking of significant investments in human capital, notably in order to increase ICT-related skills.

If organisational changes are limited, e.g.: because labour and product market regulations hamper these changes, and investment in human capital low, e.g.: because the expected returns from training and education are low, policies aimed at increasing the incentives for firms to invest in these complementary assets would also raise the ICT contribution to productivity and growth.

The existence of spillovers from ICTs use would provide a second sound argument in support of policies to foster ICT diffusion and use. If firms set their ICTs investments based on their own returns but the benefits from ICTs spillover onto other firms, private investment would be below their optimal social level. In these circumstances, policy measures to stimulate private investments in ICTs, e.g.: direct subsidies or tax credits like for R&D, would help to raise ICT investments closer to their social optimal level. Unlike R&D, however, the existence of ICT spillovers other than positive network externalities remains uncertain. Furthermore, even in the field of R&D policies, the effectiveness of direct or indirect public support continues to be an issue of economic and policy debate.

Several recent studies have also shown that cross-country differences in the impact of ICT are largely related to market regulation. In particular, tighter regulation in the labour and product markets seems negatively associated to the productivity gains from ICT whereas countries with higher flexibility tend to benefit more from ICTs.

While there is increasing consensus in the ICT policy and academic community about the negative effects of regulation on ICT diffusion and use, the implications of a change in regulation go well beyond the field of ICT policies. Market regulations may be hampering ICT-driven productivity growth but they do serve other policy purposes. In order to gain support for changes in regulations and institutions, compelling evidence is needed that the costs of these changes are more than offset by the benefits delivered by ICTs. This is clearly a piece of evidence that is highly needed but not an easy one to deliver.

In addition, even in areas where ICT policies converge with other policy objectives - such as investment in human capital– their implementation would require a high degree of coordination among different ministries and institutions. While this is an issue of governance that goes beyond the scope of the present analysis, more evidence is necessary to measure the complementarities/externalities between ICT policies and the policy areas.

The severe budgetary constraints faced by many governments as a consequence of the public debt crisis makes the evaluation of ICTs policies even more important. The large investments in broadband infrastructures included in the stimulus packages in the aftermath of the financial crisis show that most countries regard ICTs as one of the keys to emerging from the economic downturn and putting economies back on a path of sustainable growth. However, as policy programs are going under close scrutiny in the search for budgetary cuts, it becomes of foremost importance to provide a rational for ICT policies based on their impact on productivity and growth.

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