

Strauss, Hubert; Samkharadze, Besik

**Article**

## ICT capital and productivity growth

EIB Papers

**Provided in Cooperation with:**

European Investment Bank (EIB), Luxembourg

*Suggested Citation:* Strauss, Hubert; Samkharadze, Besik (2011) : ICT capital and productivity growth, EIB Papers, ISSN 0257-7755, European Investment Bank (EIB), Luxembourg, Vol. 16, Iss. 2, pp. 8-28

This Version is available at:

<https://hdl.handle.net/10419/54664>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

## ABSTRACT

*ICT capital is an important driver of productivity growth. Using data from the EUKLEMS growth accounts, we show that ICT has made smaller contributions to labour productivity growth in the EU-15 than in the US, both at the macro level and at the level of individual sectors. At the same time, progress in productive efficiency – as measured by total factor productivity (TFP) growth – sharply declined in Europe and has remained weak since the mid-1990s whereas the US has seen acceleration in TFP. The near-stagnant TFP in market services in the EU-15 is particularly worrying. In both the EU-15 and the US, the growth contributions from ICT are found to be smaller than those from TFP. However, our empirical analysis suggests that the full effect of ICT capital on productivity is larger than what the growth accounts suggest because many ICT benefits occur with a delay.*

**Hubert Strauss** (h.strauss@eib.org) is a Senior Economist in the Economics Department of the EIB and the editor of the EIB Papers. **Besik Samkharadze** (Besik.Samkharadze@uclouvain.be) is a Ph.D. candidate at Université Catholique of Louvain-la-Neuve (Belgium).

The authors would like to thank, without implicating, Kristian Uppenberg, Timo Väilä, Jussi Hätönen and Andreas Kappeler for helpful comments and discussions. The views expressed in this article do not necessarily reflect those of the EIB.

# ICT capital and productivity growth

## 1. Introduction

Fostering economic growth has been high on the EU policy agenda for more than a decade. However, Europe as a whole has not delivered on its growth targets (e.g. as set in the Lisbon Strategy). While the EU had an impressive job creation record until the outbreak of the economic and financial crisis, productivity growth has suffered from a drawn-out slowdown (Uppenberg 2011). In the future, however, GDP growth will be about making the European workforce more productive given that employment growth will be more and more constrained by demographic ageing.

Growth in output – be it aggregate GDP or real value-added in individual sectors – is driven either by increases in employment or by increases in labour productivity. This paper focuses on labour productivity, thereby distinguishing between three types of contributions: more capital per worker (“capital deepening”), a more productive composition of the capital stock, and increases in economic efficiency (total factor productivity – TFP).<sup>1</sup>

As to the composition of the capital stock, information and communication technology (ICT) equipment is an asset type that has been found to make particularly large contributions to output growth (see e.g. Oliner and Sichel 2000; Jorgenson and Stiroh 2000; Stiroh 2002; Oliner *et al.* 2007). This is for at least three reasons. First, as a general-purpose technology, ICT enables efficiency gains in existing production throughout the economy. Second, the production of ICT equipment itself is subject to technological progress (e.g. higher processor speed) that is so rapid that users have seen significant price declines coincide with quality improvements for at least two decades. This implies persistent stimulus for ICT investment. Third, there are indications that ICT, by its versatility and widespread applicability could raise the pace of technological change and hence, GDP growth (Brynjolfsson 2011, in this issue).

Throughout the paper, we use the EUKLEMS database as our data source.<sup>2</sup> It is uniquely suited to analyze the growth effect of ICT capital across countries and sectors. EUKLEMS provides detailed breakdowns of outputs and inputs at the sector level, thereby distinguishing between nine types of capital – three ICT types (information technology equipment, communication technology equipment, and software) and six conventional types – and 18 types of labour, distinguishing between three levels of educational attainment, three age groups, and gender. Another attractive feature of the database is that it makes available long time series of hours worked, enabling a refined analysis of labour inputs. In the 2009 release version, the period from 1970 through 2007 is covered.

A major drawback, however, is that the time period covered (1970-2007) ends before the economic and financial crisis. We therefore are not able to cover the effects of the crisis on ICT and productivity.<sup>3</sup> Unfortunately, there is no solution to this problem. In fact, most statistical agencies do not even report ICT investment separately; the latter is lumped together with other non-transport machinery and equipment (Timmer *et al.* 2007).



**Hubert Strauss**



**Besik Samkharadze**

1 Conceptually, the latter expresses by how much output grows at unchanged quantities of inputs because production becomes more efficient. In the empirical reality, TFP indices reflect both improvements in economic efficiency and data measurement errors.

2 The name “KLEMS” refers to capital (K), labour (L), energy (E), materials (M) and services (S), referring to EUKLEMS’ unique quality of providing cross-country comparable sector-level annual data on gross output and value added, productivity, intermediate inputs, employment, capital formation, as well as growth accounts for EU countries, Japan and the US. Output and input measures are harmonized across countries, including harmonization of labour types and capital assets as well as measurement of capital stocks and services. See O’Mahony and Timmer (2009) and Timmer *et al.* (2007) for detailed descriptions of the EUKLEMS database and methodology.

3 For a brief discussion on how the Great Recession has affected GDP and its basic components (employment and labour productivity), one may refer to Uppenberg (2011).

**We show the breakdown of labour productivity growth into contributions from (ICT-) capital-deepening, 'up-skilling' and TFP.**

To keep the amount of information manageable, our paper limits the discussion of capital deepening to the distinction between ICT and non-ICT. As far as labour inputs are concerned, we either report the overall labour composition effect on productivity (Section 2), or provide one basic distinction into high-skilled and low-skilled workers (Section 3). Moreover, while in principle, EUKLEMS provides input and output measures for 72 detailed sectors, growth accounting results are available for 31 broader sectors, hence this will be the lowest level of aggregation used in this paper. As a rule, we use the data published in the November 2009 release, except for the information on the share of hours worked by the high-skilled, which is taken from the March 2008 release (see EUKLEMS 2009).

The paper is organized as follows. Section 2 presents a breakdown of labour productivity growth into its various contributors from a growth accounting perspective, thereby looking both at the total economy and at broad sectors. Moving beyond the growth accounting perspective, Section 3 analyzes the connection between ICT and efficiency, first by searching for lagged effects of ICT investment on TFP growth, and then by estimating a production function for a panel of 13 countries and 22 sectors for the period 1995-2007. Section 4 concludes and draws some policy implications.

## 2. The contribution of ICT investment to labour productivity growth: Growth-accounting evidence

This section provides a breakdown of labour productivity growth into contributions from capital deepening, improving labour composition and TFP growth from a growth accounting perspective. Our starting point is labour productivity (output per hour worked) rather than GDP, *i.e.*, we do not show the evolution of employment. In that sense, our paper is complementary to Uppenberg (2011) who illustrates and discusses the breakdown of GDP growth into contributions from employment and labour productivity across sectors in the US and Europe over the past three decades. We focus on the comparison between the US and the EU-15 as a whole (see Uppenberg 2011 for a detailed discussion of developments in 15 old and new EU countries).<sup>4</sup>

Throughout Section 2, we use the following framework (leaving out the sector subscript for simplicity):

$$(1) \quad \hat{\lambda}_t = \alpha_I \hat{k}_{I,t} + (1 - \alpha_I) \hat{k}_{N,t} + \hat{Skill}_t + \hat{T}_t$$

where  $t$  is a time subscript and a hat denotes the annual growth rate. Equation (1) states that the growth rate of real value-added per hour worked ( $\lambda$ ) is equal to the weighted sum of growth rates in ICT- ( $k_I$ ) and non-ICT ( $k_N$ ) capital<sup>5</sup> per hour worked, an effect from the changing skill composition of the workforce, and TFP growth. To weigh the growth rates of the two capital stocks, we use the share of ICT in total capital income,  $\alpha_I$ , and the corresponding share of non-ICT capital,  $(1 - \alpha_I)$ . The labour composition effect ("Skill") is based on the idea that more educated or more experienced workers deliver more labour services (or efficiency units) per hour. So even if the total number of hours worked remains constant, the amount of labour services may nevertheless increase as workers accumulate experience and as higher-educated labour market entrants replace less educated retiring workers. The last contribution in Equation (1), TFP growth, is in fact a residual since it is equal to the difference between growth in real value-added and the sum of the first three contributions on the right-hand side.

With these preliminaries in mind, we show the respective contributions to labour productivity first at the aggregate level (Sub-section 2.1) and then at the level of broad sector groups (Sub-section 2.2) to find out to what extent the roles of ICT capital and productive efficiency (TFP) differ across sectors.

4 EUKLEMS growth accounts are only available for two of the ten new EU member states (Czech Republic and Slovenia), making representative statements on the drivers of productivity in Central and Eastern Europe impossible.

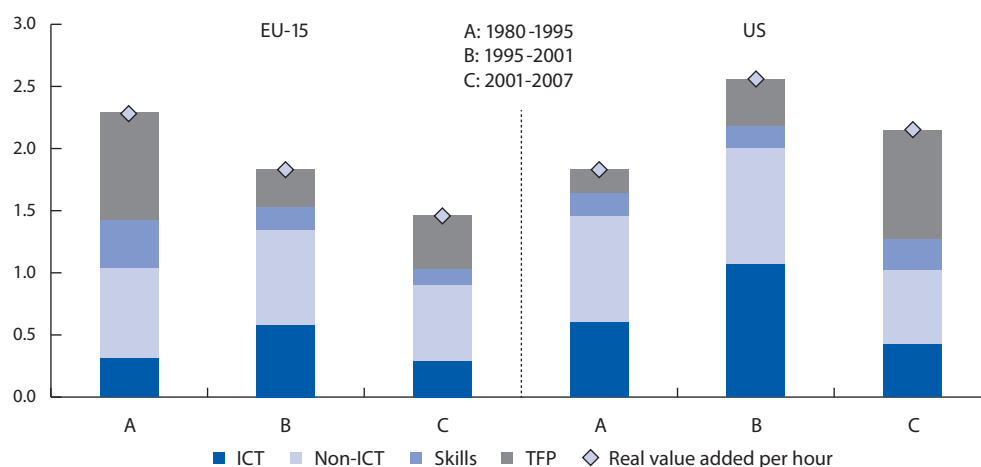
5 More precisely, EUKLEMS uses capital services (not stocks) to match the character of value-added and hours worked, which are flow variables. Since growth in capital services is proportional to growth in the capital stock for most sectors and countries, we use the terms "growth in capital stock" and "growth in capital services" interchangeably.

## 2.1 Total-economy perspective

Figure 1 depicts the decomposition of average annual labour productivity growth for the three periods 1980-1995, 1995-2001 and 2001-2007, with the left half showing results for the EU-15 and the right half the corresponding results for the US economy. Looking first at the EU-15, the figure gives three main messages. First, overall labour productivity growth has steadily declined, coming down to only 1½ percent per year in the last period. Second, ICT capital contributed half a percentage point (pp.) to annual productivity growth during the second period – spanning the ICT boom –before falling back to ¼ pp. And third, the temporary acceleration in ICT capital-deepening during the second half of the 1990s was too timid to compensate for the sharp drop in TFP growth. The latter hardly recovered during the 2000s.

**Labour productivity growth has steadily declined in the EU-15 as the temporary wave of ICT investments in the 1990s was not enough to stem the decline in TFP.**

**Figure 1. Contributions to labour productivity growth in the EU-15 and the US**  
Total economy, average annual contribution (pp.), 1980-2007



Source: EUKLEMS

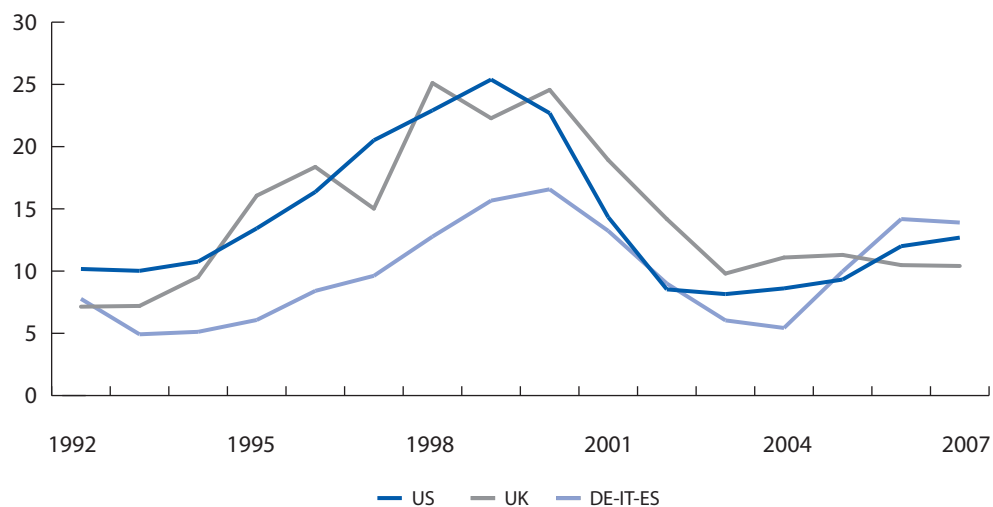
Notes: "pp." denotes "percentage point". The annual growth rate in real value-added per hour is an approximation. It is obtained by subtracting the contribution of hours worked from the growth rate of real value-added in the EU KLEMS growth accounting database. "Skills" refers to the labour composition effect on productivity, reflecting increases in the average education attainment and/or work experience. For the purpose of EUKLEMS growth accounting, EU-15 includes the following nine member states: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, and Spain.

In the US, by contrast, labour productivity growth accelerated during the 1990s, mainly due to rapid increases in ICT capital. ICT contributed a full percentage point to annual productivity growth in the second period, twice as much as in Europe. Moreover, the US has seen a striking increase in TFP growth after 2000 (the end of the ICT boom).<sup>6</sup>

The slowdown in the ICT contribution to productivity growth is for the largest part due to the slower pace of ICT investment after the burst of the dot-com bubble in 2000. Figure 2 shows the growth rate of the ICT capital stock in the US, the UK and major euro area countries (Germany, Italy and Spain). At the height of the ICT boom, annual growth rates peaked at 25 percent. Despite the marked slowdown after 2000, the ICT capital stock still expanded by more than 5 percent every year, *i.e.* faster than the stock of non-ICT capital.

<sup>6</sup> Another peculiar (if quantitatively less important) US-EU difference is that growth contributions from upskilling (labour composition) increased slightly in the US but declined significantly in the EU-15 during the past three decades.

**Figure 2. Growth in ICT capital stock, 1992-2007**  
Year-on-year percentage change, total economy



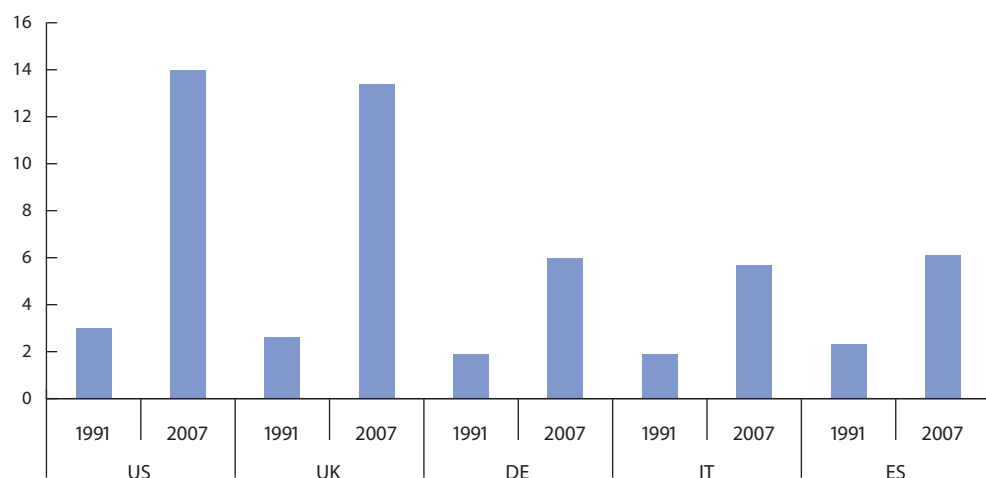
Source: EUKLEMS

There is a striking similarity between the ICT capital growth profiles of the US and the UK. Both are in stark contrast to the shallower expansion path in the major euro area countries where ICT capital growth rates peaked at 16 percent at the height of the dot-com bubble. The euro area outpaced the Anglo-Saxon partners only in 2006 and 2007 when the ICT capital expansion nearly matched its pace seen in the late 1990s.

**From 1991 to 2007, the share of ICT in the aggregate capital stock tripled in Germany, Italy and Spain and it quintupled in the US and the UK.**

As a result of the developments depicted in Figure 2, the share of ICT in the aggregate capital stock has increased substantially in virtually all economies, albeit at different speeds: while it tripled from 1991 to 2007 in Germany, Italy and Spain, it quintupled in the US and the UK (Figure 3). Since both countries already had a higher ICT share in total capital in the early 1990s, cross-country differences in the composition of the capital stock have become very large even for countries at similar levels of economic development. In 2007, ICT represented 14 percent of the economy-wide capital stock in the US and the UK, compared with only 6 percent in Germany, Italy and Spain.

**Figure 3. Share of ICT in the capital stock of selected countries, 1991 and 2007 (percent)**



Source: EUKLEMS

To some extent, this finding hides a “denominator effect”: aggregate capital stocks are relatively smaller in the US and the UK, partly reflecting the more advanced stage of deindustrialization in these countries. Therefore, cross-country differences are somewhat less pronounced when the ICT capital stock is expressed as a fraction of GDP rather than the aggregate capital stock. The US and the UK thus have in common a smaller overall capital stock, yet one in which ICT plays a much bigger role than in continental Europe.

Why has the US economy invested more vigorously in ICT equipment than the EU? While a full-fledged discussion of the determinants of ICT investment is beyond the scope of this paper, Box 1 provides some answers that reflect a growing consensus in the economic literature. Over and above good ICT network infrastructure, a competition-friendly regulatory framework, high levels of co-investment in intangibles and sufficient availability of skills are all conducive to higher levels of ICT investment. What is more, each of these three elements has a direct influence on productive efficiency, too and might thus be the “third force” driving both ICT capital-deepening and TFP growth.

## 2.2 Sectoral perspective

We now turn to the sector evidence, focusing on the broad sectors manufacturing, “utilities” (NACE sector E – electricity, gas, water supply), construction, and market services.<sup>7</sup> We ignore agriculture and mining for their relatively small size in advanced economies. Despite being hugely important (one third of employment), non-market services are not shown either because productivity statistics are notoriously poor and value-creation processes still badly understood in this broad sector (see e.g. Timmer *et al.* 2010, pp. 257-259).<sup>8</sup> Given our focus on the business economy, the numbers shown in the following cannot be expected to “average up” to the total-economy evidence on labour productivity shown in Section 2.1. Furthermore, we concentrate on the two periods 1995-2001 and 2001-2007.

Starting with manufacturing (left half of Figure 4), which represents roughly one fifth of total-economy value-added and employs one worker in six, this sector has seen its annual labour productivity growth accelerate somewhat in the EU-15 after 2000 (from 2 to 2½ percent) and substantially so in the US (to almost 5 percent). At first glance, the US record is surprising since the contributions from capital deepening (ICT and other) fell from somewhere around 1 pp. in the earlier period to essentially nothing after 2000. In both the EU and the US, the growth contribution of ICT capital stayed below that observed for the total economy in both periods, and the deceleration of the ICT contribution has been somewhat sharper. In fact, the manufacturing productivity revival in the US and in some parts of Europe is entirely due to the sharp acceleration in annual TFP growth (by 1 pp. in the EU-15 and by as much as 2.7 pp. in the US).

These trends have had a number of drivers. The deceleration of capital deepening and the acceleration of TFP may be seen against the backdrop of a wave of corporate restructuring after the burst of the dot-com bubble (see Uppenberg 2011 for a discussion of the revival in manufacturing productivity). Globalization is another central theme in this context. Rapid growth in international production sharing has resulted in pushing low-productivity manufacturers out of the market while favouring the expansion of high performers. This selection process accounts for the concomitant increases of internationalization and TFP at the sector level (Altomonte and Ottaviano 2011). Some authors also claim that higher TFP growth in the 2000s was the delayed benefit from innovation efforts as patent and trademark applications as well as investment in research and development (R&D) scored high in the late 1990s (e.g. Dupont *et al.* 2009).

If manufacturing TFP has outgrown aggregate TFP since the mid-1990s, this can be partly traced back to the ICT-goods-producing sector. As depicted in the right half of Figure 4, US TFP growth in this sector

***In manufacturing, a sharp acceleration in TFP growth more than compensated for slower capital-deepening, thus labour productivity soared.***

7 Detailed sector and country information on real value-added, capital and labour inputs and TFP is given in the Annex.

8 This sector is dominated by government-provided services (e.g. public administration, education and health), for which the absence of market prices in many countries prevents a meaningful distinction between outputs and inputs.

### Box 1. Determinants of investment in ICT

To see what drives ICT investment, one should first consider the classical determinants of investment, foremost the cost of capital. In the case of ICT, another key is the high pace of quality changes, largely determined by advances in processor speed. Further, as users communicate over networks, benefits increase in the number of users (network externalities), enabling self-sustained increases in demand. As shown by Hätönen (2011, in this issue), the size and speed of communication networks have a strong impact on the development of new ICT-enabled services and thus, the demand for ICT.

However, as Guerrieri *et al.* (2010) put it, "ICT is a General Purpose Technology, its diffusion can be understood only by considering the interaction with institutional and structural factors". They find that changes in regulation, human capital and the sectoral composition of the economy are drivers of ICT investment at the macro-level in a panel regression for ten OECD countries for 1992-2005. In the following, we briefly review product market regulation; intangible capital and human capital and their connection with ICT investment, which is clearly visible in the data (*e.g.* Strauss 2011a).

On product market regulation, there is evidence that a lack of competition slows down price declines for ICT (Arnold *et al.* 2008). In addition, since new firms usually enter the market with newer equipment than incumbents and ICT equipment life-cycles are short, market entry is important for the dynamics of ICT-intensive sectors, especially in services. Accordingly, product market regulations that act as barriers to entry are relatively more harmful and translate into lower aggregate stocks of ICT. Moreover, as discussed in Arnold *et al.* (2011), anti-competitive regulations in essential services such as electricity, telecommunications and professional services reduce the incentives for productivity-enhancing innovations also in downstream sectors. They show that ICT-intensive sectors suffer more than others from over-regulated service input markets. All this suggests less ICT investment in highly regulated economies.

Regarding the link between ICT capital and innovation, the variability of inter-firm dispersion in productivity effects of ICT reflects firms' varying ability and willingness to make necessary intangible co-investments so as to exploit the full potential of ICT (Brynjolfsson 2011, in this issue), as will be further discussed in Section 2.3. Intangible investment is mostly innovation expenditure. Put simply, firms that re-organize business processes, train their workers on new ICT applications and implement new ICT-enabled ways of interacting with suppliers and customers reap larger productivity effects from ICT. Yet, this implies greater incentives to invest in ICT for those firms, sectors and countries that invest a greater fraction of their GDP in intangibles, implying the positive correlation between intangible investment and ICT investment. Countries like the US, Japan, Sweden and the UK have the highest expenditures on intangibles and are also among the countries with the highest ICT-investment-to-GDP ratios.

Finally, turning to human capital, empirical studies show that the demand for labour from the highest skill group has increased as a result of ICT, leading to a rising share of that group in employment and the wage bill, and *vice versa* for the lowest skill group (O'Mahony *et al.* 2008). ICT increases the demand for skills because implementing and using ICT systems requires a well-educated workforce. For example, expenditures required to train workers in new IT tools are arguably lower for highly-literate workers whose education prepares them for job variety and life-long learning.

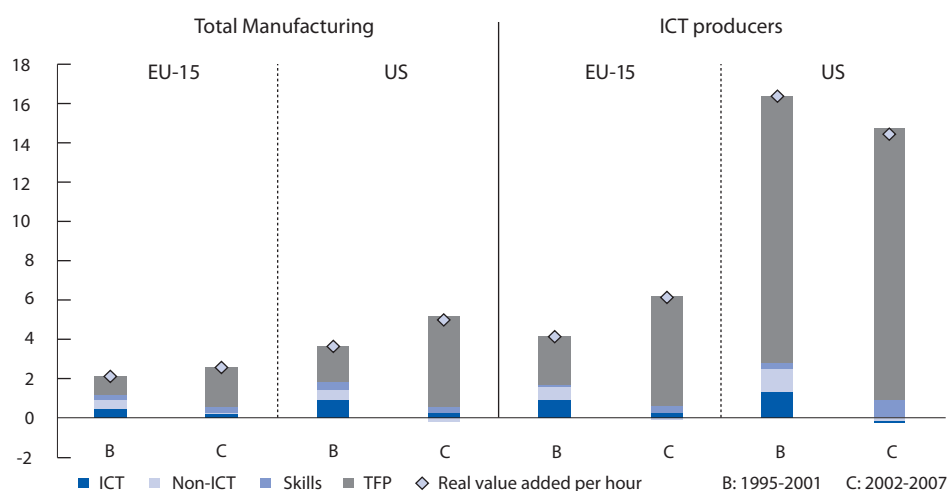
One may also turn the direction of causality around and argue that technical progress and ICT adoption adjust to the availability of skills (*e.g.* Acemoglu 2002 who claims that the rapid up-skilling of the US workforce in the 1960s and 1970s made the US a privileged place for rapid high-tech capital adoption during the 1980s. As a matter of fact, the availability of high-skilled workers is a given. Changing this endowment *via* schooling or immigration takes time and is costly, so a shortage of high-skilled workers constrains ICT use.

There are thus supply as well as demand considerations to rationalize the positive correlation between economy-wide ICT investment and the share of the highly educated in the working-age population.



progressed at double-digit annual rates throughout. In Europe, TFP growth was much slower during the 1990s but picked up to 5½ percent after 2000. Rapid progress in chip-making (processor speed) goes a long way in explaining the stellar performance of US manufacturing.<sup>9</sup> Faster labour productivity growth implies that the ICT-producing sector's share in total-manufacturing output has kept rising: evaluated at 1995 prices, that share reached about one half in the US by the mid-2000s and one quarter in the EU-15, compared with employment shares of just one eighth and one tenth, respectively. While the contributions from ICT capital-deepening pale compared to the very large TFP growth, ICT capital contributed more to labour productivity in the ICT-producing sector than it did in other manufacturing sectors.

**Figure 4. Contributions to labour productivity growth in the EU-15 and the US**  
Manufacturing, average annual contribution (pp.), 1995-2007



Source: EUKLEMS

Notes: See Figure 1. "ICT producers" in the right half refers to NACE sectors 30-33 (Electrical and optical equipment). It is part of Total manufacturing.

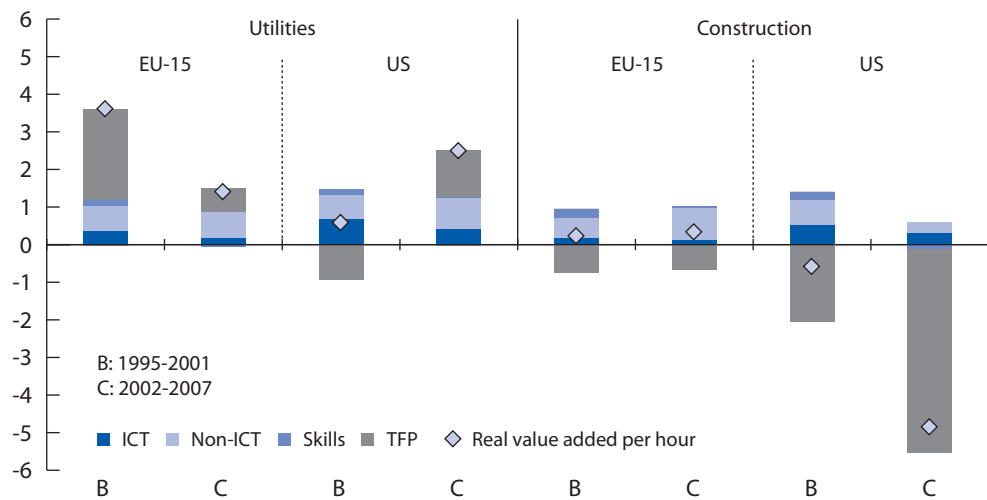
Figure 5 shows the decomposition of labour productivity growth for utilities (left half) and for the construction sector (right half). Both these sectors have seen consistently smaller growth contributions from ICT capital-deepening than the economy as a whole, whether one looks at the EU-15 or the US. Utilities had better productivity growth performance in the EU-15 than in the US in the late 1990s, possibly reflecting efficiency-enhancing effects of regulatory reform. In the 2000s, EU-15 productivity growth slowed while it picked up in the US. In the construction sector, labour productivity, on average, nearly stagnated in the EU-15 and fell in the US, mildly until 2001 and at a worrying pace thereafter. On both sides of the Atlantic, a dismal TFP performance drives these outcomes while sub-par ICT capital growth further adds to the below-average annual growth in labour productivity.

**High productivity growth in utilities contrasts with stagnant or declining productivity in the construction sector.**

We now turn to market services, which is by far the largest of the four broad sectors discussed in this subsection. In 2008, the share of market services in aggregate employment was 43 percent in the EU-15 (up from 32 percent in 1980), compared with 46 percent in the US. Productivity performance in this sector thus carries an ever-larger weight for the growth prospects of the economy as a whole. The sharp contrast between weak labour productivity growth in Europe and sustained productivity gains in the US has sparked a lot of attention from researchers and policy advisors (see e.g. Inklaar *et al.* 2008; Timmer *et al.* 2010; Uppenberg 2011).

<sup>9</sup> Sector "ICT producers" is larger than chip- and computer making alone. It also includes more traditional makers of electrical and optical equipment, which carry a larger weight in Europe, hence the less buoyant TFP expansion.

**Figure 5. Contributions to labour productivity growth in the EU-15 and the US**  
Utilities and Construction, average annual contribution (pp.), 1995-2007

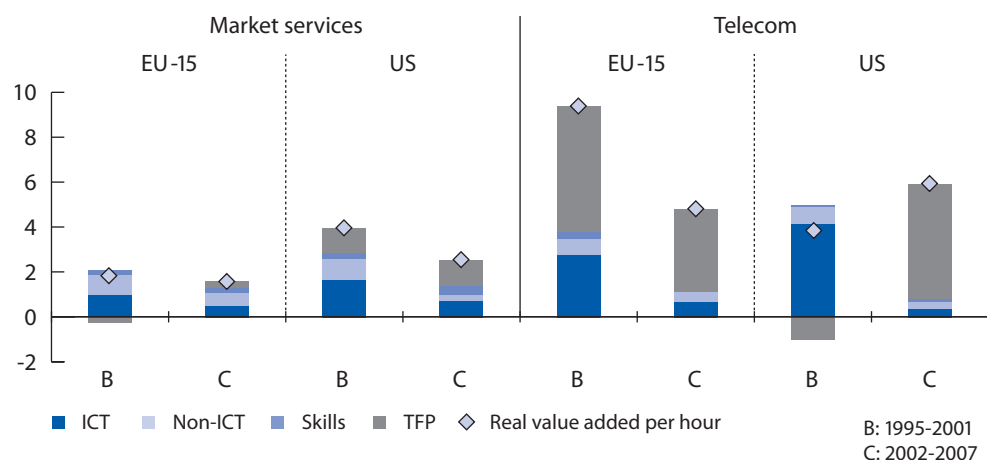


Source: EUKLEMS  
Notes: See Figure 1.

***In market services, the US combined strong ICT contributions with decent TFP growth while the EU-15 saw timid ICT adoption and no TFP growth.***

Figure 6 (left half) illustrates this sharp transatlantic contrast. While labour productivity grew at rates between 1½ and 2 percent in the EU-15, it advanced at annual rates of 4 percent (1995-2001) and 2½ percent (2001-2007), respectively in the US. As a consequence, the US-EU productivity gap kept widening, albeit at a reduced pace after 2000. The US success rests both on swift ICT capital-deepening and TFP. Typical for market services, ICT made above-average contributions to productivity growth in both regions. As argued in Uppenberg and Strauss (2010), Europe's weak productivity record in services cannot be traced back to an overall under-investment problem. However, the composition of the EU capital stock in services is still more tilted towards non-ICT assets, implying relatively slow diffusion of ICT. Concomitantly, Europe has seen a dismal TFP performance over the past one and a half decades: the level of TFP in market services was not higher in 2007 than in 1995.

**Figure 6. Contributions to labour productivity growth in the EU-15 and the US**  
Market services, average annual contribution (pp.), 1995-2007



Source: EUKLEMS  
Notes: See Figure 1. "Market services" excludes Telecom.

One particularity of the EUKLEMS dataset is that the aggregate “Market services” does not include “Telecom”, i.e. NACE sector 64 (Post and telecommunications). This sector is reported separately given its critical importance for the deployment of (new) ICT-enabled services and Internet penetration of households (see Hätönen 2011, in this Issue).<sup>10</sup> High productivity dynamics in this sector would likely have positive knock-on effects on the economy as a whole.

Average productivity growth in Telecom is shown in the right half of Figure 6 above. It shows that Telecom labour productivity growth in the EU-15 is a success story, making Telecom one of the few sub-sectors where Europe compares favourably with the US. Powered by swift ICT capital-deepening and very high TFP advances, labour productivity grew by 9 percent per year on average during 1995-2001 and still by half that rate in the later period as the ICT contribution fell to below 1 pp. per year while TFP held up relatively well. Telecom in the US, although investing heavily in ICT as well, did not experience any TFP gains during the 1990s but staged an impressive TFP revival during the 2000s, which might be linked to the preceding ICT investment boom.

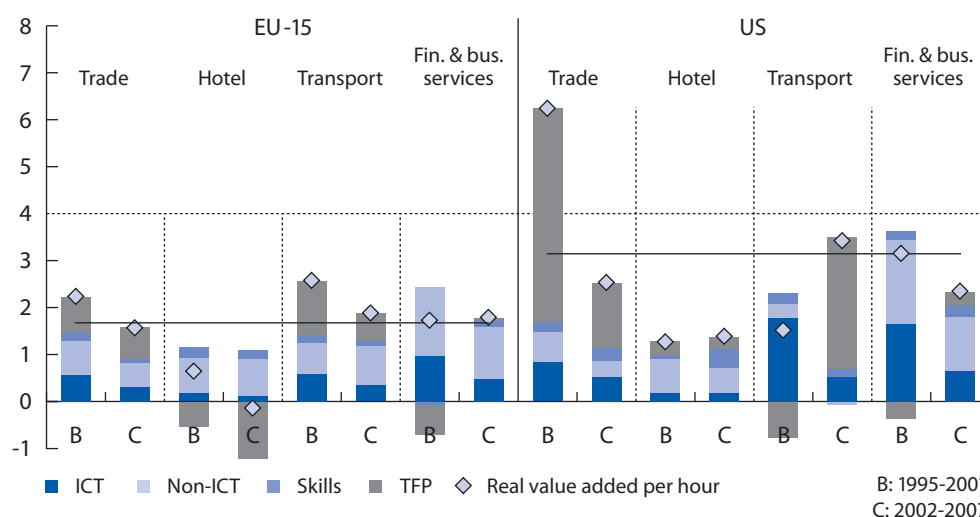
**Productivity growth in Telecom is a European success story – one of the few sectors where Europe compares favourably with the US.**

Market services consist of a number of sectors that are quite heterogeneous in terms of skill intensity and the type of capital (ICT versus non-ICT) they use intensively. This is why we conclude this sub-section by zooming back in on Market services (excluding Telecom) to discuss productivity developments in the following component sectors (2005 EU-15 employment shares in parentheses)<sup>11</sup>:

- “Trade”: Wholesale and retail trade and repair (0.36);
- “Hotel”: Hotels and restaurants (0.12);
- “Transport”: Transport and storage (0.12);
- “Fin. & bus. services”: Financial and business services (0.40).

Figure 7 illustrates labour productivity growth and its components for these sub-sectors and for each of the two periods, depicting EU-15 results on the left and US results on the right. The horizontal bar indicates average labour productivity growth in market services in each region for the entire 1995-2007 period, which allows putting the results into perspective.

**Figure 7. Contributions to labour productivity growth in the EU-15 and the US**  
Market services sectors, average annual contribution (pp.), 1995-2007



Source: EUKLEMS  
Notes: See Figure 1.

<sup>10</sup> While the employment share of Telecom in total market services (EUKLEMS “Market services” plus Telecom) was only 2.8 percent, its share in real value-added (at 1995 prices) amounted to as much as 11 percent, reflecting very high levels of value-added per hour.

<sup>11</sup> See Annex for the corresponding NACE codes of each sub-sector.

Looking at the EU-15, three observations stand out. First, Transport outperforms the sector average while Hotel underperforms in terms of labour productivity. Second, growth contributions from ICT capital deepening were highest in Fin. & bus. services, lowest in Hotel and comparable with total-economy outcomes in the other sub-sectors. Third, Europe's dismal TFP performance in market services can be entirely attributed to Fin. & bus. services and Hotel, whereas Trade and Transport each posted solid annual TFP growth of between ½ and 1 percent. The dismal TFP performance in Fin. & bus. services is surprising insofar as that sector has increased its ICT capital stock more rapidly than other parts of the economy from 1995 to 2007.

***The pattern of ICT capital-deepening and TFP growth being stronger in the US than in the EU-15 is remarkably consistent across sectors.***

Turning to the US, the most striking difference from the EU-15 is the stellar productivity performance of Trade. Labour productivity in Trade progressed by more than 6 percent annually in the first and another 2½ percent in the second period, two thirds of which can be attributed to TFP. A second observation is that ICT capital-deepening has made larger contributions in the US than in the EU-15 across all sub-sectors, with the starkest difference seen in Transport. Finally, it is remarkable that sectors like Transport as well as Fin. & bus. services – but also Telecom shown above – which saw particularly strong ICT capital-deepening during the 1990s were able to accelerate TFP growth in the 2000s or at least to turn it around from negative to modestly positive growth contributions.

### **2.3 Main points and perspective**

The main insights of Section 2 are that US productivity has outgrown the EU-15 mainly because of stronger ICT capital deepening and faster progress in productive efficiency (TFP). These two patterns are remarkably consistent across all sectors shown above even though they contributed to the growth gap to varying extents: While the US manufacturing revival is essentially a TFP story, faster US productivity growth in services reflects a combination of faster and deeper ICT diffusion and higher TFP growth. The single most remarkable (macro and sectoral) feature for the US is that TFP growth accelerated after 2000 even as ICT capital growth slowed down markedly.

The pick-up in US TFP growth following the wave of ICT investment in the late 1990s is no coincidence. Early firm-level studies find the productivity effects of ICT to be abnormally high on average – but with large dispersion across firms (for a survey see Stiroh 2004). Further studies, for example Brynjolfsson and Hitt (2000) and Brynjolfsson *et al.* (2002), find that the most successful firms are those which, following large-scale ICT investments, also devote significant resources to reorganizing their businesses. These efforts often cost a multiple of the new ICT equipment and the resulting efficiency gains may take years to materialize. When explicitly accounting for this additional intangible investment, returns to ICT are no longer found to be abnormally high.

At the sector level, Inklaar and Timmer (2007) show that the US economy enjoyed a sectorally more broad-based pick-up in TFP growth in the first half of the 2000s whereas dynamic TFP developments in the EU were a matter of a few sectors. This matches the fact, illustrated in this section that ICT diffusion in the US has not only been more intense for the economy as a whole but also for most individual sectors, including in sectors using ICT less intensively.

While it may be possible to account for intangible investment (*e.g.* expenditures for staff training and business reorganization) at the firm level, the national accounts treat the bulk of intangible investment as expenses. To the extent that it is exactly this omitted complementary investment that allows “wringing out” the full productivity potential of ICT, growth accounting is bound to deliver huge TFP contributions. It should be borne in mind, however, that some of these contributions have been triggered by ICT investment.

In recent years, empirical researchers have undertaken efforts to conceptualize and measure intangible investment and capital (Corrado *et al.* 2005, van Ark *et al.* 2009) for the (market) economy as a whole and to quantify their impact on labour productivity growth by way of enhanced growth accounting (*e.g.* Corrado *et al.* 2009). Indeed, these studies find that the share of the TFP contribution in average labour productivity growth shrinks thanks to this sophistication. Estimations of intangible investment and capital start coming into existence at the sector level too (*e.g.* Haskel and Pesole 2011) but are still rare and incomplete.

The reasons just discussed suggest that there seems to be a link between ICT capital-deepening and TFP that is worth investigating further, if only indirectly given the data constraints. This is done in Section 3.

### **3. The connection between ICT and TFP at the sector level**

The growth accounting approach used in the previous section is a useful first step in linking growth in output to growth in inputs. It has, however, several weaknesses. A first weakness is that it links current growth in output to current growth in inputs. Thus, any delayed output and productivity effects from ICT capital-deepening “end up” in the TFP growth contribution of the periods following the ICT capital-deepening rather than being accounted for as ICT effects. It is therefore interesting to study the ICT-TFP correlation over time. We do this in Section 3.1.

*While growth accounting is useful, the approach has several weaknesses.*

Another set of weaknesses are the relatively restrictive assumptions made in growth accounting. First, as the true marginal contribution of each factor is not directly observable, it is assumed that the elasticity of real value-added with respect to each factor of production equals the income share of the factor, reflecting perfectly competitive input and product markets. Related to this is the assumption of constant returns to scale: the income shares of factors sum up to 100 percent and so must the input elasticities. In reality, it could well be that an increase in all inputs by, say 10 percent, increases real value-added by more (or less) than 10 percent, reflecting increasing (or decreasing) returns to scale. If the assumptions were violated, the growth contributions from ICT capital and TFP would be misrepresented. In Section 3.2, we therefore estimate the true input elasticities from an econometric model, which also allows testing whether returns to scale are constant. Since the model is multi-period and controls for the interdependence of input and output decisions, it is able to gauge the true, long-run effect of factor accumulation (*e.g.* ICT capital-deepening) on real value-added.

#### **3.1 TFP growth and lagged ICT investment**

To address the unduly contemporaneous focus of growth accounting, we now look at current TFP growth and lagged ICT capital-deepening. As a starting point, we use the fact that firm level studies have shown a positive correlation between firms’ TFP levels and their ICT capital intensity. For example, Figure 4 in Brynjolfsson (2011, in this issue) shows strong correlation between US firms’ TFP levels and their ICT capital intensity (both relative to sector average).

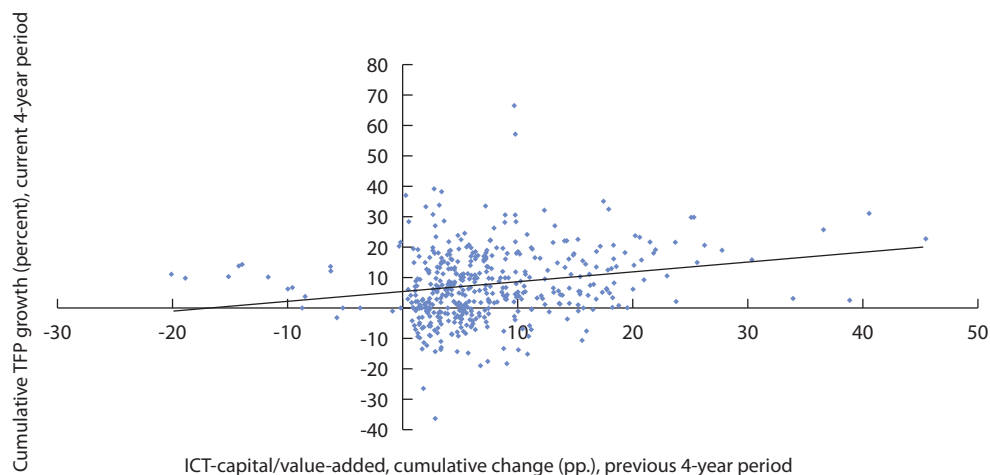
It is natural to ask whether this correlation holds at the industry level, too. We cannot answer the question directly since in the EUKLEMS dataset, TFP is an index that equals 100 in the base year (1995), so all historical differences across countries and sectors in the level of productive efficiency are wiped out. To circumvent the problem, we look at cumulative changes in ICT capital intensity and cumulative changes in the TFP index.

Motivated by the finding of ICT adoption costs in the management literature, some authors suggest that one should, if anything, expect a positive correlation between *lagged* ICT capital-deepening and TFP growth. Basu and Fernald (2007) use current ICT capital intensity and past ICT capital growth as a proxy for unmeasured intangible co-investment to ICT investment. They find that TFP in the early 2000s indeed followed the ICT investment wave of the 1990s with a considerable lag (5 years or more). They show that when controlling for past ICT investment, the contemporaneous correlation between TFP and ICT investment becomes significantly negative, reflecting that resources are temporarily diverted from current production to implementing new ICT equipment.

**In ICT-using sectors, there is a positive correlation between TFP growth and past ICT investment.**

Figure 8 shows the connection between cumulative TFP growth (EUKLEMS data) over the past 4 years and the cumulative growth rate in ICT capital observed during the preceding 4-year period for 13 countries and six rolling 4-year periods within the sample period (1995-2007), focusing on sectors that use ICT intensively (following the classification by Inklaar *et al.* 2005, see end of Section 3.2). There clearly is a positive correlation between TFP and past ICT investment in ICT-using sectors even though it is less than perfect.<sup>12</sup> We suspect business services, which have been shown in Section 2 to combine strong ICT investment with declining TFP, to blur the picture. Indeed, taking business services out makes the cloud of points look more conclusive and makes for a steeper regression line (results not shown).

**Figure 8. Past ICT capital-deepening and average TFP growth in ICT-using sectors**



Source: EUKLEMS

Notes: Each dot plots the cumulative percentage growth in the TFP index over four years (*e.g.* 2001-2005) of an industry using ICT intensively (*e.g.* machine-tool production) against the cumulative change (in percentage points) in the ICT-capital/value-added ratio during the preceding four-year period (1997-2001 in this example).

### 3.2 The ICT-elasticity of output and intersectoral differences in trend TFP growth

Following up on the second set of weaknesses of growth accounting exercises, we now relax the overly restrictive assumptions of constant returns to scale and perfect competition. We estimate the marginal

<sup>12</sup> Unlike the pattern shown in Figure 8, the correlation coefficients between past growth in the ICT capital stock and TFP are found to be negative for the group of non-ICT-using sectors and zero for ICT-producing sectors, respectively (results not shown). Moreover, and in line with Basu and Fernald (2007), we could not detect any positive correlation between TFP growth and contemporaneous ICT capital growth for any of the three groups of sectors (ICT-using, non-ICT-using, ICT-producing sectors).

productivity of ICT capital and other inputs from an empirical model, rather than relying on factor income shares from the national accounts.

To illustrate why the simplifying assumptions of the growth-accounting exercise of Section 2 might be problematic, assume, first, that the elasticities of real value-added with respect to both ICT capital and high-skilled labour were higher than the respective shares of these factors in total factor income. As a consequence, the contributions to productivity growth of both ICT capital-deepening and skills reported above would understate their true contributions, because any increase in ICT capital and in high-skilled hours worked would deserve higher weights than they get in growth accounting. Second, assume that the sum of the output elasticities exceeded one, reflecting increasing returns to scale (*i.e.*, an increase in all input quantities by 1 percent would lift real value-added by more than 1 percent). As a consequence, the true contributions from both types of capital and up-skilling, taken together, would be higher than the sums shown in the figures of Section 2. In both cases, the contribution from TFP would shrink.

To answer the question whether the ICT contributions and the up-skilling contributions shown above are too small, we estimate a production function for a panel of 13 countries and 22 sectors spanning the years from 1995 to 2007, distinguishing between ICT- and non-ICT capital on the one hand and high-skilled labour (*i.e.* hours worked by higher-education degree holders) and other labour on the other. We do not constrain the input coefficients; hence, the constant-returns-to-scale assumptions can be directly tested for. Table 1 shows the results while Box 2 provides the details on the theoretical framework, specification choices, variables and results.

**Table 1. Estimated output elasticities versus average factor-income shares**

Inputs	Income share (GA)	Estimated output elasticity
High-skilled labour	0.109	0.135***
Low-skilled labour	0.569	0.473***
ICT capital	0.048	0.060 *
Non-ICT capital	0.274	0.330***
Total	1	0.998

Notes: Income shares are simple averages (cross-country, cross-sector and across-time) of the corresponding factor's share in gross income taken from the EUKLEMS growth accounting (GA). Output elasticities are from the Cobb-Douglas production function model estimated using Sys-GMM as described in Box 1.

Indeed, the table suggests that ICT and high-skilled labour make contributions to output in excess of their respective remuneration (factor income share). The same is true for the contribution of non-ICT capital. While the difference between the estimated elasticity and the income share is modest for ICT capital and possibly not statistically significant, the pattern is much clearer for non-ICT and human capital. Taken together, the results suggests that the “true” sum of contributions to productivity growth from capital inputs and skills are somewhat larger than those depicted in Section 2. Accordingly, the true TFP contributions are smaller.

That being said, imposing constant returns to scale, as growth accounting does, does not appear to exacerbate the underestimation problem. Indeed, the sum of the elasticities reported in Table 1 amounts to 0.998, meaning that its deviation from one is not economically important.

***ICT and high-skilled labour make contributions to output in excess of their factor income shares.***

## Box 2. ICT, skills and output: Econometric evidence for a panel of 13 countries and 22 sectors

**Production-theoretical framework.** This box draws on Samkharadze and Strauss (2011). While we owe many ideas to Spiezia (2011), our specification choices deviate from his in several important respects. We start from a neoclassical production function relating real value-added ( $Y$ ) to capital and labour:

$$(B1) \quad Y_{jt} = A_{jt} F(K_{jt}, L_{jt}), \quad i = 1, \dots, N, j = 1, \dots, M, t = 1, \dots, T$$

where  $A$  is Total Factor Productivity (TFP) and  $i, j$  and  $t$  index country ( $N=13$ ), sector ( $M=22$ ) and time ( $T=13$ ); respectively. In our specification, we distinguish between ICT ( $K^I$ ) and non-ICT capital ( $K^N$ ). Moreover, we split labour into hours worked by two distinct skill groups of persons: high-skilled ( $L^H$ ) and low-skilled, *i.e.* all other labour ( $L^L$ ). A Cobb-Douglas production function is chosen and estimated in log-linear form. It satisfies the conditions of monotonicity and quasi-concavity and its individual coefficients can be directly interpreted as factor specific elasticities. However, it is a restrictive functional form insofar as the elasticities are assumed to be constant.

Since TFP is not observable, we assume it to grow with time, permittedly at different rates of growth across countries and sectors. The inclusion of the country-specific time trend captures the extent to which country-specific policies and institutions affect the economy. In turn, the inclusion of the sector time trend captures sector-specific advances in technology and efficiency, assuming that these advances have the same long-run effect on all countries in the sample, *i.e.*, innovations and best practice are allowed to flow across borders in the long run. Unlike Spiezia (2011), we do *not* interact the two sets of time trends, which would allow for maximum flexibility but requires estimating some 300 coefficients. Therefore, to the extent that our assumption of international technology transfer is violated and national policy settings have a differential impact across sectors, our trend TFP estimates might match the data less than perfectly.

Taking into account the sub-aggregates of the production factors, the Cobb-Douglas production function in log-linearized form and our time-, country- and sector-dependent specification of TFP growth, Equation (B1) can be rewritten:

$$(B2) \quad \ln Y_{jt} = \beta_1 \ln K_{jt}^I + \beta_2 \ln K_{jt}^N + \beta_3 \ln L_{jt}^H + \beta_4 \ln L_{jt}^L + \alpha_i \text{time}_{it}^c + \alpha_j \text{time}_{it}^s + \varepsilon_{jt}$$

where  $\text{time}_{it}^c$  denotes the country-specific time trend,  $\text{time}_{it}^s$  the sector-specific time trend and  $\varepsilon_{jt}$  is the error term. The coefficients  $\alpha_i$  and  $\alpha_j$  can be interpreted as the annual growth rates of TFP within each country  $i$  and sector  $j$ , respectively, *relative* to the one country (Austria) and the one sector (food-processing) dropped from the estimation.

**Specification issues.** Two econometric problems arise in estimating Equation (B2): endogeneity (production planning concerns inputs and outputs jointly); and heteroskedasticity, *i.e.*, the error term might not be independently and identically distributed as its variance may vary across countries/sectors/years. The first problem is commonly addressed by instrumental variables (IV) estimation, using lagged values of the endogenous variables as instruments. This technique often leads to an efficiency-size trade-off: satisfactory instrument quality requires long lags, which reduce sample size. To address endogeneity and heterogeneity concerns, we use the Arellano-Bover (1995)/Blundell-Bond (1998) system-GMM estimator, which is suitable for panels (as ours) with a low number of time periods and higher number of individual groups. It estimates a stacked system of first-difference and level equations using two sets of instruments – lagged levels in the first-differenced equation and lagged first differences in the level equation. The Sys-GMM circumvents the efficiency-size trade-off by employing “GMM-style” instruments (one for each variable and time period), resulting in a significantly higher instrument count. To avoid “over-fitting” problems (Roodman 2006), we keep the number of instruments far below the number of groups. Sys-GMM is also able to solve the second problem: it produces a robust estimator of the parameter covariance matrix, with standard errors consistent under heteroskedasticity and within-group autocorrelation (albeit not cross-sectional autocorrelation).

**Data and variables.** The data source is EUKLEMS, 2009 release. Quantity indices (1995=100) are derived from all output and input variables, then their log is taken. For real value-added, we directly take the EUKLEMS



quantity index of real value added. For capital, the underlying time series is the real stock of ICT and non-ICT capital, respectively (in euros at 1995 prices). For high-skilled labour, it is total hours worked times the share of high-skilled labour in total hours (taken from the 2008 EUKLEMS release). For low-skilled labour, it is total hours worked minus high-skilled hours worked. Hence, the quantity indices on the input side are based on “physical units” for each sub-category rather than on capital or labour services measures (as *e.g.* in Spiezia 2011). The reason is that these aggregate services concepts weigh together different types of labour (capital) by using observed differentials in average wages (rental prices) that might not adequately reflect true productivity differences due to *e.g.* productivity and learning spillovers from high- to low-skilled workers. The Annex shows average levels of the (non-logged) output and input indices.

As a result of setting all outputs and inputs equal to 100 in 1995, cross-country differences in size and efficiency (*i.e.* output-to-input ratios) are wiped out. Any existing historical differences in TFP *levels* are thus lost. The interpretation of our results is therefore strictly in terms of (cumulative) growth (within or across countries/sectors) rather than cross-country/sector differences in output and productivity levels. We are thus not concerned by unobserved time-invariant country- and sector-specific effects affecting output and productivity *levels*. To the extent that such unobservables matter for *growth rates*, those effects are captured by the country- and sector-specific time trend variables. Also, the Sys-GMM removes the fixed effects by applying the first-difference transformation to Equation (B2).

**Results.** We implement the one-step Sys-GMM estimation proposed in Bond *et al.* (2001) rather than a two-step procedure because its asymptotically robust standard errors are more reliable in finite samples. We limit the instrument count by “collapsing” GMM-style instruments into columns and *via* economic reasoning. For example, ICT capital is “short-lived”, justifying a low number of lags (we only use the second lag). By contrast, other types of physical capital are longer-lived and thus highly persistent, hence we use all available lags. Further, we use the second to fourth lags for the labour variables. The final instrument count equals 67, much below the number of groups (286).

Table B1 reports estimated coefficients, standard errors and diagnostics for the Sys-GMM model. As discussed in the main text, the output elasticities are sensible. They are all significant at the 1-percent level except for ICT capital, which is significant at the 10-percent level. The sum of input coefficients is close to one and the formal test of constant returns is not rejected at the 5-percent significance level. The lower half of Table B1 reports tests of some of the conditions for the Sys-GMM results to be reliable. The Arrelano-Bond test result suggests freedom of residual autocorrelation. Moreover, the Hansen test indicates that the over-identifying restrictions are valid even though the Sargan test does not. Yet, we primarily rely on the former because, unlike the latter, it is robust to any remaining heteroskedasticity and autocorrelation.

**Table B1. Sys-GMM estimation results and diagnostics**  
Dependent variable: log of real value-added (Index 1995=100)

High-skilled labour	Low-skilled labour	ICT capital	Non-ICT capital	Sum of coeff. [CRS test]	Number of observations
0.135*** (0.047)	0.473*** (0.079)	0.060* (0.036)	0.330*** (0.078)	0.998 [0.096]	3,674
Residual autocorrelation test		Tests for validity of over-identifying restrictions			
Arrelano-Bond (AR(2))		Hansen (robust)		Sargan	
z-value	1.50	Chi2(18)	25.75	Chi2(18)	87.49***

Notes: Robust standard errors in parentheses, p-values in brackets; \*, \*\* and \*\*\* denote significance at the 10, 5 and 1-percent level.

Table 2 provides the estimated results for the country- and sector-specific time trends. The coefficient of a sector-specific time trend may be interpreted as the sector's annual TFP growth relative to that of the omitted sector (Food processing) in a given country. Likewise, the coefficient of a country-specific time trend expresses the country's annual TFP growth relative to that of the omitted country (Austria) in a given sector. Following Inklaar *et al.* (2005), the 22 sectors are grouped into three aggregate categories – ICT-producing sectors, ICT-using sectors and non-ICT-using sectors – for which we calculate a simple average of the estimated coefficients across the constituent sectors.

**Table 2. Relative trend TFP growth across sectors and countries**  
Estimated coefficient

Sector	Coefficient	Standard error	Country	Coefficient	Standard errors
<b>ICT-using sectors</b>	<b>(0.012)</b>		<b>EU-15</b>	<b>(-0.006)</b>	
Paper and Publishing (21-22)	0.013**	0.005	Austria	—	—
Other machinery (29)	0.012**	0.005	Denmark	-0.018**	0.006
Other manufacturing (36-37)	0.008*	0.005	Finland	0.013*	0.007
Sale of motor vehicles and fuel (50)	0.004	0.008	Germany	-0.003	0.006
Wholesale trade (51)	0.021***	0.006	Italy	-0.018**	0.006
Retail trade (52)	0.012*	0.006	Spain	-0.018**	0.006
Financial services (J)	0.03***	0.007	Sweden	0.001	0.008
Business services excl. real estate (71-74)	-0.002	0.005	Netherlands	-0.002	0.006
<b>ICT-producing sectors</b>	<b>(0.052)</b>		<b>UK</b>	<b>-0.004</b>	<b>0.005</b>
ICT goods production (30-33)	0.057***	0.014	Czech Republic	0.002	0.009
Telecom (64)	0.046***	0.008	Slovenia	0.006	0.011
<b>Non-ICT-using sectors</b>	<b>(0.010)</b>		<b>Japan</b>	<b>-0.005</b>	<b>0.007</b>
Food processing (15-16)	—	—	US	0.003	0.006
Textiles and footwear (17-19)	0.005	0.005			
Wood and cork (20)	0.011**	0.005			
Chemicals (24)	0.026***	0.005			
Rubber and plastics (25)	0.016**	0.008			
Other non-metallic minerals (26)	0.016***	0.005			
Metals (27-28)	0.008	0.005			
Transport equipment (34-35)	0.024**	0.008			
Electricity, gas, water (E)	0.022**	0.007			
Construction (F)	-0.01*	0.006			
Hotel (H)	-0.013*	0.007			
Transport (60-63)	0.004	0.005			

Notes: Robust standard errors in parentheses; \*, \*\* and \*\*\* denote significance at the 10, 5 and 1-percent level, respectively. Cells in bold indicate sector or country groupings for which the reported relative TFP growth is a simple average of the estimated coefficients of the component sectors or countries.

The trend coefficient estimates reveal the following results. For one thing, the values confirm the stellar TFP growth performance of the ICT-goods and ICT-service-producing sectors (annual growth by 5.2 pp. in excess of TFP growth in food-production). For another, it suggests that TFP growth is indeed higher in ICT-using sectors (1.2 percent faster than in food production) than in sectors that use ICT less intensively (1 percent).

The difference is, however, surprisingly small. This is partly because even within the group of ICT-users, sectors are still quite heterogeneous. While Trade displays strong TFP gains, the business services sector – already identified as a weak performer in Sections 2.2 and 3.1 – is found to have a negative (if insignificant) trend coefficient. The financial industry, by contrast, has a significantly positive trend coefficient of 3 percent. Given the much greater size of the business services compared with the financial services sector, the two coefficients taken together are roughly consistent with the growth accounting result of positive but weak TFP growth in the period 1995-2007 (see Figure 7). At the same time, the average trend TFP growth in non-ICT-using sectors is pulled up by two R&D-intensive sectors: Chemicals and Transport equipment.

Further, the results suggest that the average annual TFP growth has been higher in the US and the new EU member states (Slovenia and Czech Republic) than in Japan and the EU-15. Within the EU-15, the only countries with significant country trend coefficients are Denmark and Finland (positive TFP growth) on the one hand and Italy and Spain (negative TFP growth) on the other.

All in all, Section 3 shows, first, that TFP growth and ICT capital-deepening are linked in time as productivity effects of ICT take several years to materialize. Second, our empirical analysis suggests that the marginal productivity of ICT capital and non-ICT capital is larger than their respective shares in factor income, and that skilled labour is substantially more productive than what is reflected in the share of the high-skilled in domestic income. Finally, our estimates show that trend TFP growth varies substantially across sectors and countries.

#### **4. Conclusions and policy implications**

ICT capital is an important driver of productivity growth. Using data from the EUKLEMS growth accounts, this paper has shown that ICT has made smaller contributions to labour productivity growth in the EU-15 than in the US, both at the macro level and at the level of individual sectors. At the same time, progress in productive efficiency – as measured by total factor productivity (TFP) growth – sharply declined in Europe and has remained weak since the mid-1990s whereas the US has seen acceleration in TFP. The near-stagnant TFP in market services in the EU-15 is particularly worrying. In both the EU-15 and the US, the growth contributions from ICT have been found to be smaller than those from TFP.

Our empirical analysis at the sector level has suggested that weak ICT capital accumulation may impair labour productivity growth by more than is suggested by growth accounting. For one thing, TFP growth and ICT capital-deepening are linked in time as many of the benefits from ICT adoption only materialize with a time lag and are thus recorded as TFP. For another, the marginal productivity of ICT capital is larger than its share in total factor income.

The policy implications of this paper are as follows. As suggested by our brief discussion of the determinants of ICT investment (see Box 1) and the conspicuous connection between (past) ICT capital deepening and medium-term TFP growth, policies that foster productive efficiency would most likely boost economy-wide ICT diffusion, too. Accordingly, competition-friendly product market reforms and a high-quality education system are key in stimulating productivity growth both directly and *via* ICT capital deepening. Public action to build innovation-friendly societies by stimulating entrepreneurship and experimentation and by removing barriers to mobility and resource reallocation would give an additional impetus to productivity growth in Europe (see Strauss 2011b for a summary).

***Policies to foster productive efficiency – product market reform, better education and fewer barriers to mobility – would boost economy-wide ICT diffusion, too.***

By contrast, we do not see a role for specific sector policies targeting the use of ICT. That being said, it is in the government's responsibility to ensure that ICT-enabling infrastructure networks be provided at sufficient size and quality. Over and above a stable, predictable and investment incentive-compatible regulatory framework, this may require targeted public support to network deployment in less profitable geographic areas (see Hätönen 2011).

## Annex

**Table A1. Sectoral levels of real value-added, capital stocks, hours worked and TFP, average 1995-2007**  
Indices (1995=100)

	Sector	Real value-added	High-skilled labour	Low-skilled labour	ICT capital	Non-ICT capital	TFP
ICT-using sectors	Paper and Publishing (21-22)	112	120	92	249	113	106
	Other machinery (29)	116	127	96	247	119	108
	Other manufacturing (36-37)	111	136	95	252	112	108
	Sale of motor vehicles and fuel (50)	120	139	108	280	126	103
	Wholesale trade (51)	131	128	102	314	121	113
	Retail trade (52)	125	126	102	289	124	114
	Financial services (J)	126	129	96	281	105	107
	Business services excl. real estate (71-74)	136	153	128	372	152	93
ICT producers	ICT goods production (30-33)	193	122	98	253	135	164
	Telecom (64)	164	171	98	294	135	122
Non-ICT-using sectors	Food processing (15-16)	103	135	94	218	113	99
	Textiles and footwear (17-19)	87	111	75	192	95	109
	Wood and cork (20)	114	123	94	254	115	110
	Chemicals (24)	126	122	94	231	117	115
	Rubber and plastics (25)	141	132	105	289	129	113
	Other non-metallic minerals (26)	113	119	93	220	108	111
	Metals (27-28)	113	127	100	240	112	105
	Transport equipment (34-35)	137	129	97	246	127	120
	Electricity, gas, water (E)	111	114	85	211	107	108
	Construction (F)	110	132	110	347	127	96
	Hotel (H)	109	146	110	295	117	95
	Transport (60-63)	116	129	104	239	128	102
Country							
	Austria	122	148	98	419	104	117
	Czech Republic	149	114	103	314	141	116
	Denmark	112	132	100	401	113	99
	Finland	126	117	106	238	106	119
	Germany	138	103	92	171	107	110
	Italy	107	126	101	250	117	100
	Japan	109	111	87	154	108	103
	The Netherlands	106	153	99	276	110	111
	Spain	123	185	114	267	133	97
	Slovenia	132	114	97	156	161	117
	Sweden	137	152	97	189	130	121
	UK	117	128	94	297	115	107
	US	124	110	97	286	115	113

Source: EUKLEMS; own transformations based on EUKLEMS (columns 2 to 5)

Notes: The sector (country) numbers reflect simple cross-country (cross sector) cross-time averages of the corresponding sector (country) index. The sample period is 1995-2007 for all countries except for Japan and Slovenia (2006).

Sectors are given short names as in the main text. The NACE code (rev. 1) is provided in parentheses. The table does not provide detail for sectors not used in the regression in Section 3.2, *i.e.* Agriculture (A), Fishery (B), Mining (C), Coke and fuel refinery (23), real estate (70), and social services (L to Q).

While the first five data columns are based on the indices used in the regressions of Section 3 (see Box 2), the TFP indices in the last column are those from the EUKLEMS growth accounting results discussed in Section 2.

## References

- Acemoglu, D. (2002). "Technical change, inequality and the labour market". *Journal of Economic Literature*, (40:1), pp. 7-72.
- Altomonte, C. and Ottaviano, G.I.P. (2011). "The role of international production sharing in EU productivity and competitiveness". *EIB Papers*, (16:1), pp. 62-89, Issue 1 of this volume.
- Arnold, J., Nicoletti, G. and Scarpetta, S. (2008). "Regulation, allocative efficiency and productivity in OECD countries: Industry and firm-level evidence". OECD Economics Department Working Paper No. 616.
- Arnold, J., Nicoletti, G. and Scarpetta, S. (2011). "Regulation, resource reallocation and productivity growth". *EIB Papers*, (16:1), pp. 90-115, Issue 1 of this volume.
- Arrelano, M. and Bover, O. (1995). "Another look at the instrumental-variable estimation of error-component models". *Journal of Econometrics*, (68:1), pp. 29-52.
- Basu, S. and Fernald, J. (2007). "Information and Communications Technology as a General-Purpose Technology: Evidence from US Industry Data". *German Economic Review*, (8:2), pp. 146-173.
- Blundell, R. and Bond, S. (1998). "GMM estimation with persistent panel data: An application to production functions". Institute for Fiscal Studies Working Paper No. W99/4.
- Bond, S., Hoeffler, A. and Temple, J. (2001). "GMM estimation of empirical growth models". CEPR Discussion Paper No. 3048.
- Brynjolfsson, E. and Hitt, L.M. (2000). "Beyond Computation: Information Technology, Organizational Transformation and Business Performance". *Journal of Economic Perspectives*, (14:4), pp. 23-48.
- Brynjolfsson, E., Hitt, L.M. and Yang, S. (2002). "Intangible Assets: Computers and Organizational Capital". *Brookings Papers on Economic Activity*, (2002:1), pp. 137-199.
- Brynjolfsson, E. (2011). "ICT, innovation and the e-economy". *EIB Papers*, (16:2), pp. 60-76, in this issue.
- Corrado, C., Hulten, C. and Sichel, D. (2005). "Measuring Capital and Technology: An Expanded Framework", in Corrado, C., Haltiwanger, J. and Sichel, D. (eds.), *Measuring Capital in the New Economy*, National Bureau of Economic Research, Studies in Income and Wealth volume 65, pp. 11-45, The University of Chicago Press, Chicago and London.
- Corrado, C., Hulten, C. and Sichel, D. (2009). "Intangible Capital and US Economic Growth". *The Review of Income and Wealth*, (55:3), pp. 661-685.
- Dupont, J., Guellec, D. and Oliveira Martins, J. (2009). "Recent productivity growth in the OECD: Sectoral patterns and the effect of innovation". OECD Department of Science, Technology and Industry, DSTI/EAS/IND/WPIA(2009)6, mimeo.
- EUKLEMS (2009). "EU KLEMS Growth and Productivity Accounts: November 2009 Release". <http://www.euklems.org/>
- Guerrieri, P., M. Luciani and V. Meliciani (2010). "The determinants of investment in information and communication technologies". College of Europe, Bruges European Economic Research Paper No. 16.
- Haskel, J. and Pesole, A. (2011). "Within-country analysis of intangible assets and investments at sector-level", in COINVEST Project Report, Deliverable D 10, pp. 93-132. [http://www.ceriba.org.uk/pub/CoInvest/CoInvestProjects/COINVEST\\_217512\\_D10.pdf](http://www.ceriba.org.uk/pub/CoInvest/CoInvestProjects/COINVEST_217512_D10.pdf)
- Hätönen, J. (2011). "The economic impact of fixed and mobile high-speed networks". *EIB Papers*, (16:2), pp. 30-59 in this issue.

- Inklaar, R., O'Mahony, M. and Timmer, M. (2005). "ICT and Europe's Productivity Performance: Industry-Level Growth Account Comparisons with the United States". *Review of Income and Wealth*, (51:4), pp. 505-536.
- Inklaar, R. and Timmer, M. (2007). "Of yeasts and mushrooms: Patterns of industry-level productivity growth". *German Economic Review*, (8:2), pp. 174-187.
- Inklaar, R., Timmer, M. and van Ark, B. (2008). "Market services productivity". *Economic Policy*, (23:53), pp. 139-194.
- Jorgenson, D.W. and Stiroh, K. (2000). "Raising the Speed Limit: U.S. Economic Growth in the Information Age". *Brookings Papers on Economic Activity*, (2000:1), pp. 125-211.
- Oliner, S.D. and Sichel, D.E. (2000). "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?". *Journal of Economic Perspectives*, (14:4), pp. 3-22.
- Oliner, S.D., Sichel, D.E. and Stiroh, K.J. (2007). "Explaining a productive decade". *Brookings Papers on Economic Activity*, (2007:1), pp. 81-152.
- O'Mahony, M., Robinson, C. and Vecchi, M. (2008). "The impact of ICT on the demand for skilled labour: A cross-country comparison". *Labour Economics*, (15:6), pp. 1435-1450.
- O'Mahony, M. and Timmer, M. (2009). "Output, Input and Productivity Measures at the Industry Level: The EUKLEMS Database". *The Economic Journal*, (119:538), pp. F374-F403.
- Roodman, D. (2006). "How to do xtabond2: An introduction to "Difference" and "System" GMM in Stata". Center for Global Development Working Paper No. 103.
- Samkharadze, B. and Strauss, H. (2011). "ICT, human capital and output: Sectoral evidence for 13 OECD countries". EIB Economics Department, mimeo.
- Spiezia, V. (2011). "ICT investments and productivity: Measuring the contribution of ICTs to growth". OECD, Directorate for Science, Technology and Industry. DSTI/ICCP/IIS(2011)9, mimeo.
- Stiroh, K. (2002). "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?". *American Economic Review*, (92:5), pp. 1559-1576.
- Stiroh, K. (2004). "Reassessing the Impact of IT in the Production Function: A Meta-Analysis and Sensitivity Tests". Working Paper (updated from 2002), Federal Reserve Bank of New York.
- Strauss, H. (2011a). "ICT capital and productivity growth". Presentation held at the EIB Conference in Economics and Finance. European Investment Bank, 27 October.  
[http://www.eib.org/attachments/general/events/luxembourg\\_27102011\\_07\\_strauss.pdf](http://www.eib.org/attachments/general/events/luxembourg_27102011_07_strauss.pdf)
- Strauss, H. (2011b). "Productivity and growth in Europe: Editor's Introduction". *EIB Papers*, (16:1), pp. 8-17, Issue 1 of this volume.
- Timmer, M., Inklaar, R., O'Mahony, M. and van Ark, B. (2010). *Economic Growth in Europe – A comparative Industry Perspective*, Cambridge University Press, Cambridge (UK).
- Timmer, M., van Moergastel, T., Stuivenwold, E., Ypma, G., O'Mahony, M. and Kangasniemi, M. (2007). "EU KLEMS growth and productivity accounts, version 1.0. Part I: Methodology". [www.euklems.org](http://www.euklems.org)
- Uppenberg, K. and Strauss, H. (2010). "Innovation and productivity growth in the EU services sector". European Investment Bank. [www.eib.org/efs](http://www.eib.org/efs)
- Uppenberg, K. (2011). "Economic growth in the US and the EU: a sectoral decomposition". *EIB Papers*, (16:1), pp. 18-51, Issue 1 of this volume.
- van Ark, B., Hao, J., Corrado, C. and Hulten, C. (2009). "Measuring intangible capital and its contribution to economic growth in Europe". *EIB Papers*, (14:1), pp. 63-93.