Perspectives on productivity and business cycles in Europe

Inklaar, R.

Publication date:
2006

Chapter 4 Productivity growth and ICT use[86]

4.1 Introduction

Oer the past decade, labour productivity growth in Europe has fallen behind growth rates in the United States, reversing the pattern of growth since the Second World War. Much has been written about why U.S. productivity growth accelerated and whether the pace of growth is sustainable.[87] However, by now the U.S. has outpaced European productivity growth for nearly a decade since 1995 and U.S. growth shows little sign of letting up.

Among the potential explanations for this growth gap, a prominent candidate is the slower uptake and less productive use of Information and Communication Technologies (ICT) in Europe. Over the past few decades, ICT has become increasingly pervasive in modern societies. Two main developments have spurred this uptake of new technology. First of all, rapid technological progress has driven down the cost of ICT goods and second, the number of applications of ICT has multiplied over the years, enabled by this technological progress. These twin developments have reinforced each other, making ICT a general purpose technology like steam and electricity.[88]

As a result of these characteristics, one would expect ICT to have an impact on labour productivity growth. Indeed, there are three channels through which an ICT impact may occur, namely from the production of ICT goods and services, investment in ICT and spillovers from the use of ICT. Total factor productivity (TFP) growth in ICT producing industries will quite naturally contribute to aggregate TFP growth and hence labour productivity growth. In a neo-classical framework, the contribution from ICT investment is also well defined: firms will invest in ICT up to the point where further output gains are equal to the marginal cost of the investment. This way the

---

[86] This chapter builds on van Ark, Inklaar and McGuckin (2003a, b) and Inklaar, O'Mahony and Timmer (2005). See the acknowledgements for further details.
[87] See, for example, Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) for relatively optimistic early assessments, Gordon (2000) for a more sceptical argument, and Gordon (2003) and The Economist (2003) for a retrospective on some of these arguments.
[88] For an economic growth model along these lines, see Bresnahan and Trajtenberg (1995).

contribution from growth in ICT capital per hour worked to labour productivity growth can be quantified. The final channel is the hardest to measure and also raises conceptual issues. The underlying idea is that ICT enables the introduction of new organizational models and other innovations. So although new ICT investment goods are standard products, they enable firms to innovate and accumulate firm-specific capital (see e.g. Brynjolfsson and Hitt, 2000 and OECD, 2004). For example, a network of off-the-shelf computers, scanners and databases can be combined into a system that tracks and replenishes inventories and gives insight into patterns of customer purchases. Insofar as these innovations yield additional output gains, they will show up as additional total factor productivity growth in ICT using industries and may be labelled as spillovers. To be precise, if the organizational and other intangible investments were properly accounted for, these 'spillovers' should disappear.

The main question this chapter poses is to what extent Europe has failed to exploit the growth potential of ICT. Specifically, slower ICT investment could be a reflection of a time lag relative to the U.S. or indicate a more structural failure to exploit new technologies. A time lag may be due to the more fragmented nature of the European market. The greater scale of the U.S. market can make certain investments more profitable early on, while ICT prices have to fall further before it is profitable in Europe too. On the other hand, ICT investment in Europe might permanently lag the U.S., because regulations hold back the diffusion of complementary innovations. For example, young, innovative firms may face obstacles to fast growth, such as restrictive land-use regulations. This in turn reduces the incentives for incumbent firms to innovate too.

With the availability of industry data on ICT and productivity growth for the U.S. and several European countries, the link between productivity and ICT can be investigated in detail. This chapter argues that the declining rate of productivity growth in Europe may be a reflection of a slow transition process towards so-called "soft savings" from ICT usage, in particular in market services. These follow the earlier "hard savings" which could be immediately obtained from ICT investment. For example, the earliest application of barcode scanning in supermarkets was to speed up check-out. Along the lines of the literature on general purpose technologies, the results suggest that "soft savings" require investments in intangible capital and organizational innovations, which are most likely to be important in market services. The market services sector is the biggest investor in ICT and is also most dependent on additional innovations to produce new ICT-related services. For example, in addition to speedier check-out, barcodes can be used reorganize the supply chain to take advantage of the increased information on customer purchases, but this is much less straightforward. The European institutional environment, reflected in its labour and product market institutions, tends to hold up the structural adjustment process in Europe and inhibits the reallocation of resources to their most productive uses. The European economic environment creates too little room for good firms to excel and for failing firms to exit the market.

This chapter begins with a presentation of the macroeconomic evidence on the contribution of ICT to productivity growth, using a growth accounting approach. Next, the labour productivity growth gap between the EU-15 and the U.S. is examined at the industry level. This analysis shows that the key to understanding the difference in growth between both economies can be found in the differential growth performance of market services (Section 4.3). Section 4.4 shows that market services is also the most intensive ICT using sector in both the American and European economies. Due to the scarcity of data on ICT investment for individual industries, a more detailed analysis of ICT intensity and TFP growth at the industry level is restricted to four major European countries (France, Germany, the Netherlands and the UK) and the U.S. (Section 4.5). This section delves more deeply into the evidence and implications of the relationship between ICT and TFP growth. The concluding section focuses on the concepts of “hard” and “soft” savings from ICT, on the one hand, and the relation to the competitive market environment in Europe and the U.S. on the other hand.

4.2 ICT and aggregate growth

Economists have been looking for an impact of ICT on growth for almost two decades, but until recently, these researchers spent most of their time explaining why this impact was lacking.[89] It was only with the work of Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) that the impact of ICT on growth in the United States showed up strongly in the data, although at that time Gordon (2000) argued that part of the effect reflected cyclical instead of structural factors. In earlier years, part of the

[89] This is exemplified by Solow’s (1987) quote that computers can be seen everywhere except in the productivity statistics. See also Oliner and Sichel (1994) and Triplett (1999).

reason why ICT contributed little to labour productivity growth was that ICT capital was only a small percentage of the total capital stock (Oliner and Sichel, 1994). Improvements in the measurement of computer and semiconductor prices have also been important in revealing the effects of ICT on labour productivity growth (Jorgenson, 2001). Since the work of Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) it has become an established fact that a significant part of the acceleration in labour productivity growth after 1995 in the United States can be attributed to the production and use of ICT.[90]

The United States is not the only country where ICT is thought to have played an important role in stimulating productivity growth. Indeed, from the mid-1990s onwards, labour productivity growth in Australia also accelerated strongly, with important contributions from faster ICT investment and TFP growth (see Parham, Roberts and Sun, 2001). Australia is an interesting case since it does not have an important ICT producing sector, so productivity gains from ICT can mostly be traced to either the investment or the spillover channel.

In Europe, evidence on the impact of ICT on productivity has been much harder to come by, see for example the review of van Ark (2000). Early work by Schreyer (2000) and Daveri (2000, 2002) relied heavily on private data sources to estimate ICT investment. The consistency of these sources with investment data from the National Accounts was quite questionable though. Colecchia and Schreyer (2002) were the first to collect genuine ICT investment data for a limited number of countries, but it was not until the work of van Ark *et al.* (2002) that ICT investment data was collected for nearly all EU member countries.[91]

Data sources and methods

To analyze the contribution of ICT to growth, a theoretical framework is needed. Assume that gross domestic product (Y) is produced from factor inputs X, consisting of ICT capital services (K_{ICT}), non-ICT capital services (K_N) and labour services (L).

[90] In extensions of their earlier work, Jorgenson, Ho and Stiroh (2005) and Oliner and Sichel (2002) broadly confirm their findings. Gordon, one of the most vocal academic critics a few years ago in his 2000 article, has also come round to this position in more recent work (Gordon, 2003). It should be noted though that recent revisions by the U.S. Bureau of Economic Analysis (BEA) have reduced U.S. GDP growth before 2000, making the 1995-2000 less exceptional in retrospect.

[91] In addition, a number of studies have looked at the impact of ICT investment in individual countries. See van Ark (2002) for an overview.

Total factor productivity (A) is represented as a Hicks-neutral augmentation of the aggregate inputs. The aggregate production function has the following general form:

$$Y = AX(L, K_N, K_{ICT}). \quad (4.1)$$

In this framework, total factor productivity measures technical change and is equal to output growth after accounting for the contributions of all inputs. These contributions can be estimated econometrically, but a common (non-parametric) method to analyze the sources of growth is the growth accounting framework (Solow 1957, Jorgenson and Griliches, 1967). Under the assumption of cost-minimizing producers, competitive factor markets, well-measured inputs and output, and constant returns to scale, total factor productivity (TFP) growth also measures technical change and can be calculated non-parametrically.

However, it is unlikely that all assumptions are fully satisfied and growth accounting has often been criticized because of this. In general, as for example Hulten (2001) argues, TFP is a residual that measures shifts in the production function. These shifts can occur for a variety of reasons, such as technical change, but it can also capture, for example, returns to scale. The main advantage of growth accounting is that it provides a simple and consistent method to account for the contributions from factors that can easily be identified, namely capital and labour.[92] This greatly simplifies the task of testing for deviations from the standard assumptions and dissecting the TFP residual into harder to measure components such as measurement errors, scale economies or spillovers from research and development (R&D). Later in this chapter and in Chapter 5, some of the key growth accounting assumptions will be tested and based on those results, no clear alternative assumptions seem warranted.

The growth accounts are implemented by assuming a translog production function, which only mildly restricts the production function of equation (4.1).[93] As Diewert (1976) showed, the (non-parametric) Törnqvist index can be used to represent such a translog function.[94] A Törnqvist index for the growth of aggregate factor inputs from t to t+1 is equal to the weighted average of the growth in each of the individual inputs, where the weight is equal to the share of each input in total

[92] At the industry level, intermediate inputs also become important; see Chapter 5.
[93] Specifically, the translog function is a second order approximation to an arbitrary, twice continuously differentiable linearly homogenous function; see Christensen, Jorgenson and Lau (1973).
[94] Or to be precise, the Törnqvist index is exact for the translog function.

income, averaged over periods t and t+1. TFP growth can then be derived as the growth of output minus the growth of aggregate inputs:

(4.2) $$\Delta \ln A = \Delta \ln Y - \bar{v}_L \Delta \ln L - \bar{v}_N \Delta \ln K_N - \bar{v}_{ICT} \Delta \ln K_{ICT},$$

where Δ refers to first differences and $\bar{v}$'s denote the two-period average shares in total factor income. Because of constant returns to scale: $\bar{v}_L + \bar{v}_N + \bar{v}_{ICT} = 1$, when calculating these shares as a percentage of GDP. By rearranging equation (4.2), average labour productivity growth, defined as $y = Y/L$, can be decomposed into the ratio of capital services to hours worked, $k = K/L$, and TFP growth. Another useful distinction can be made between TFP originating in manufacturing industries producing ICT goods (A_{prod}) and other industries (A_{other})

(4.3) $$\Delta \ln y = \bar{v}_N \Delta \ln k_N + \bar{v}_{ICT} \Delta \ln k_{ICT} + \Delta \ln A_{prod} + \Delta \ln A_{other}.$$

The estimates on the comparative growth performance of the EU-15 and the U.S. presented here are an update from earlier work by Timmer *et al.* (2003) and Timmer and van Ark (2005). The estimates on investment, capital services, labour input and GDP are updated from 2001 to 2004.[95] Data on investment, GDP and labour compensation are typically derived from the national accounts. However, substantial additional work was required to construct separate investment time series for three ICT assets (office and computing equipment, communication equipment, and software) as well as three non-ICT assets (non-ICT equipment, transport equipment and non-residential structures).[96]

To obtain separate TFP estimates at the macro level for ICT-production industries, the assumption is made that TFP growth rates for ICT-production (office, accounting and computing equipment, communication equipment and electronic components manufacturing) in the U.S. also apply to the European countries. To measure the ICT industry contributions to total factor productivity growth, Domar weights for the individual countries were used.[97]

---

[95] Many thanks go to Gerard Ypma, who constructed much of the data used in this section.

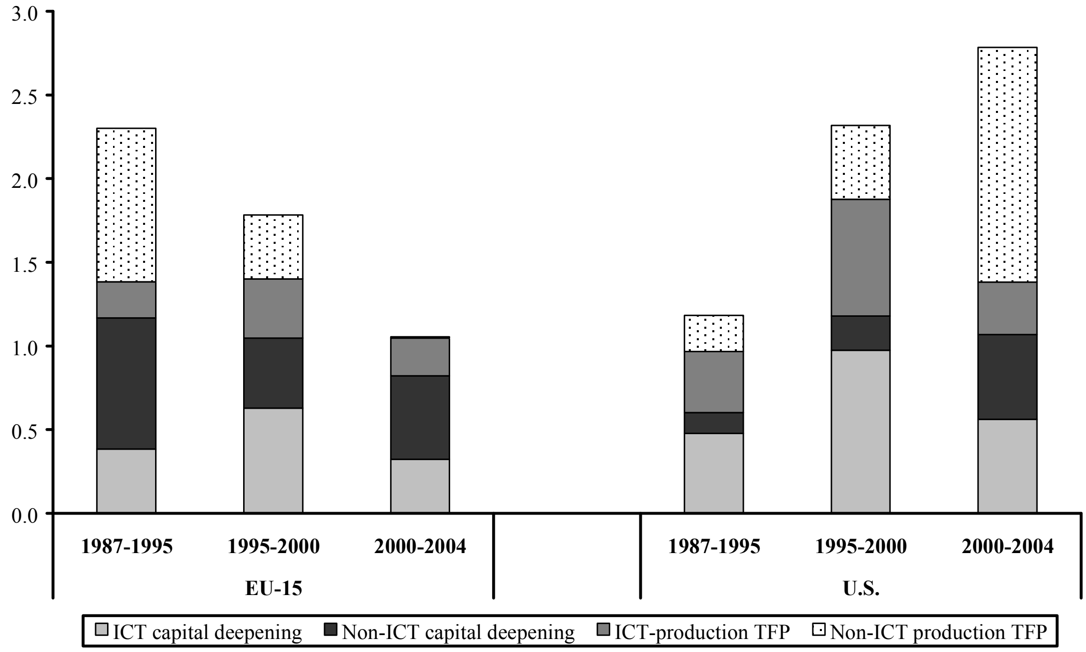
[96] See http://www.ggdc.net/dseries/growth-accounting.html for further details on sources and methods and underlying data. The methodology to obtain the ICT investment series, the deflators for ICT series (which are essentially derived from U.S. hedonic price deflators for ICT) and the capital services method can be obtained from Timmer, Ypma and van Ark (2004) and Timmer and van Ark (2005). Section 4.4 also discusses capital services measurement in more detail.

[97] See Appendix 4.A for further details.

Sources of aggregate labour productivity growth

Figure 4.1 summarizes the main findings for the EU-15 and the U.S. for the periods 1987-1995, 1995-2000 and 2000-2004. The chart shows a decomposition of labour productivity growth into the effects of ICT capital deepening, TFP growth from ICT-producing industries, non-ICT capital deepening and TFP growth other than that from ICT production. The main findings are that the EU-15 as a whole has been lagging behind the U.S. in terms of ICT capital deepening in each period. Both the EU-15 and the U.S. show a strong acceleration in ICT capital deepening during the late 1990s. However, this investment boom was mostly transitory, with ICT capital deepening returning to pre-1995 levels after 2000 in both the EU-15 and the U.S. Since 2000 though, U.S. labour productivity accelerated further, while the EU-15 suffered additional slowdown. This divergence between the Europe and America can mostly be traced to higher TFP growth outside the ICT producing sector. In Europe, TFP growth outside ICT production was effectively zero after 2000, while in the U.S. "non-ICT production" TFP growth added almost 1.5 percentage points to labour productivity growth. This might be because Europe is not generating ICT spillovers, while the U.S. is, but other causes may be important too.[98]

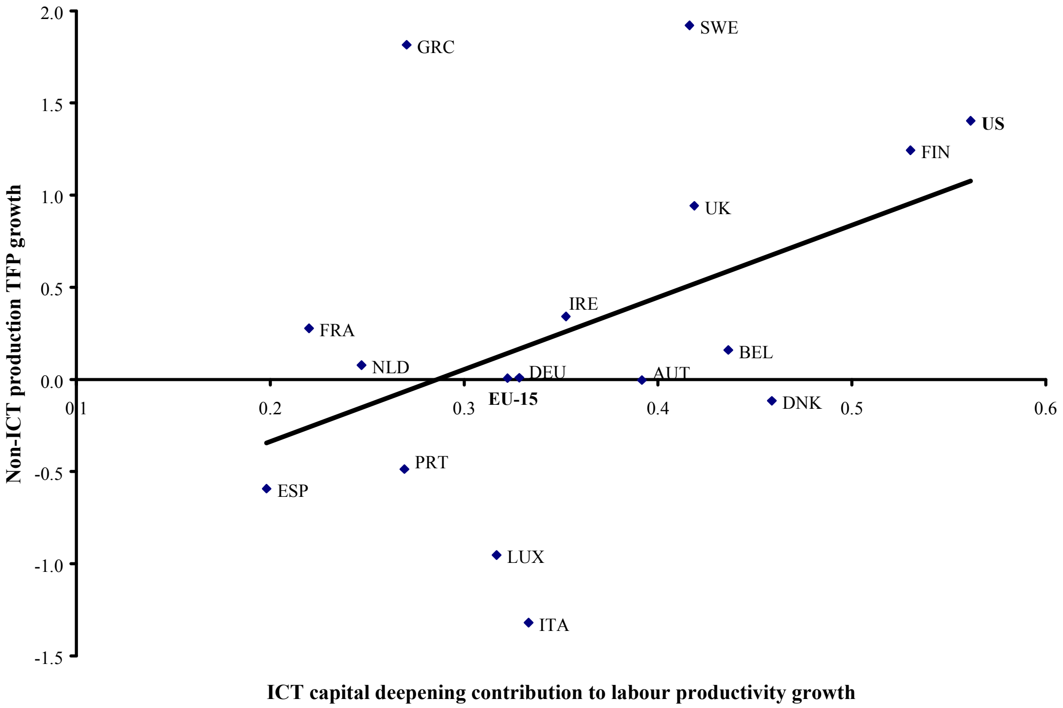
Figure 4.1 Sources of labour productivity growth, EU-15 and U.S., 1987-2004



[98] Estimates for individual countries can be obtained from Timmer, *et al.* (2003). Although there is much variation in TFP not related to ICT, growth is generally slower after 1995, with the exception of Sweden and the United Kingdom. See also http://www.ggdc.net/dseries/growth-accounting.html.

"Non-ICT production" TFP growth may include an element of ICT spillovers. An impressionistic way of getting at possible spillover effects at the macro-level is to relate the contribution from ICT capital deepening to "non-ICT production" TFP growth for the period 2000-2004 (Figure 4.2). This scatter plot shows a very suggestive positive relationship between these two variables, with countries like the U.S., the UK, Finland and Sweden combining high ICT investment and high non-ICT TFP growth, and countries like France, Italy and Spain show the opposite.

Figure 4.2 ICT contribution and non-ICT TFP growth, 2000-2004

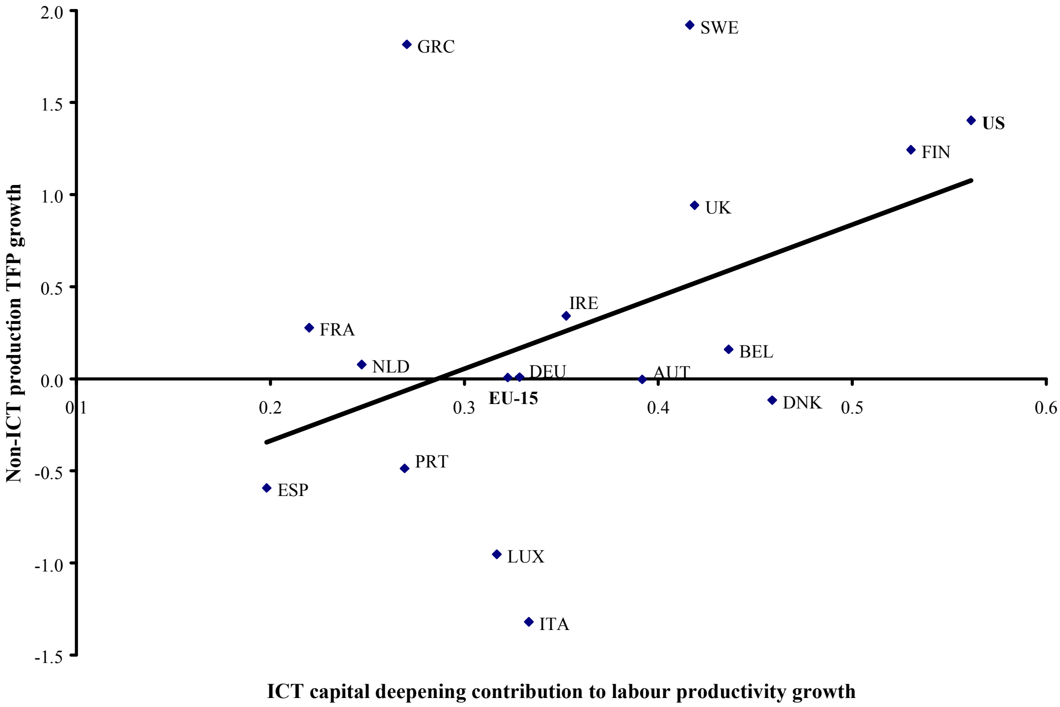


Of course, Figure 4.2 is only a simple, though suggestive, scatter plot. It is therefore useful to test the scope of this finding. The first concern is whether this relationship is stable for different periods and the second is whether the relationship can still be seen when controlling for initial TFP levels.[99] Figure 4.3 already shows that for the period between 1995 and 2000, no relationship can be found. Further answers are provided in Table 4.1, which shows the parameters for the period 1995-2000 in addition to 2000-2004. Furthermore, regressions both with and without the

[99] See Appendix 4.B to this chapter for a description of the construction of these TFP levels.

initial TFP level are shown and with total TFP growth and non-ICT production TFP growth as dependent variables.[100]

Figure 4.3 ICT contribution and non-ICT TFP growth, 1995-2000



As the table shows, a significant positive relationship can only be discerned for the 2000-2004 period and only when the initial TFP level is included as a control variable. The initial TFP level is only significant when non-ICT TFP growth is used as the dependent variable. Most important to note is that for the 1995-2000 period, the ICT coefficient is close to zero, even though U.S. growth had started to accelerate by then. Similar regressions were run for each available starting year, averaging over different numbers of years, but a significant ICT effect appears only for periods that include years after 1998.

[100] The initial level is defined here as the TFP level at the start of the relevant period. So for the 1995-2000 period, the 1995 TFP level is included.

Table 4.1 The cross-country relationship between ICT capital deepening and TFP growth for the EU-15 and the U.S.

	1995-2000		2000-2004	
Dependent variable: TFP growth				
ICT contribution	0.19	0.26	4.79	4.77*
	(1.26)	(1.26)	(2.31)	(2.16)
TFP level		-0.02		-0.02
		(0.02)		(0.01)
Dependent variable: Non-ICT TFP growth				
ICT contribution	-0.14	-0.10	3.91	3.88*
	(0.90)	(0.90)	(2.05)	(1.79)
TFP level		-0.01		-0.03*
		(0.01)		(0.01)

Notes: Cross-country regressions with TFP growth as the dependent variable and the contribution from ICT capital deepening and the initial TFP level as explanatory variables. The initial TFP level is defined as the level at the start of the period, so the 1995 level for the 1995-2000 period. * denotes significantly different from zero at the 5% level. Standard errors are in parentheses.

The results from Table 4.1 show that relying only on aggregate data does not provide robust results. The aggregate analysis severely limits the number of observations, so convincing statistical evidence is difficult to obtain. Another reason for caution is that there are many more variables that potentially affect TFP growth differences between countries such as, for example, differences in market structure and flexibility of product, labour and capital markets between countries. Thirdly, with declining aggregate TFP growth in most European countries it is hard to interpret this evidence as a sign of increased spillovers compared to the period before 2000. Indeed the significant relationship since 2000 has mainly occurred because countries with lower ICT investment, such as Italy, Spain and Portugal, have been showing slower TFP growth rather than from accelerations in countries with rapid ICT investment. This might at best imply that some countries have had more trouble in combining ICT with other growth-enhancing sources than others. Without TFP growth estimates for individual industries there is no good way of identifying such spillovers, as the aggregate TFP residual may include a whole range of unmeasured contributions (or detractions) to output growth which are difficult to distinguish at aggregate level. Hence the remainder of this chapter focuses on industry estimates of labour productivity and total factor productivity growth.

4.3 Industry contributions to labour productivity growth

As discussed in the introduction to this chapter, we would like to supplement the aggregate figures presented above with estimates of TFP growth for individual industries. Only then it becomes possible to see which industries are heavy ICT investors and whether these industries have higher TFP growth. This can help determine whether ICT spillovers are an important source of growth differences between Europe and the United States. At this time such estimates are only available on a comparable basis for 4 major European countries (France, Germany, the Netherlands, the UK) and the U.S., which will be discussed in Section 4.5. In the absence of industry-level growth accounts for all EU-15 countries, it is useful to first look at the labour productivity growth performance by industry for the EU-15.

The 60-industry database of the Groningen Growth and Development Centre (GGDC, 2005b) contains data for the period 1979-2003 on output and employment in 56 industries for all EU-15 countries, the United States and several other OECD countries. This database draws heavily on National Accounts, either as compiled in the OECD STAN database or directly from national sources, supplemented with information from industry censuses and surveys and labour force surveys.[101] For the analysis in the remainder of this chapter, we focus on the market economy, excluding non-market services from the industry data. The measurement of output for non-market services, such as health and education, is very problematic and might affect the aggregate results.[102]

Contribution and decomposition analysis

To determine the contribution of individual industries to aggregate growth, a decomposition method suggested by Stiroh (2002b) is used. This method is akin to the shift-share analysis that was used in earlier work (e.g. van Ark, Inklaar and McGuckin, 2003a). Define labour productivity growth as the difference between the growth of value added at constant prices and the growth of total hours worked:

---

[101] The most recent dataset as well as more extensive documentation can be downloaded from www.ggdc.net. Chapter VII of O'Mahony and van Ark (2003) provides a detailed overview of methodological choices, such as the aggregation procedure and the use of harmonized U.S. deflators for ICT manufacturing industries.

[102] In addition, the real estate industry is excluded as most of the output in this industry consists of imputed housing rents.

(4.4) $$\Delta \ln y = \Delta \ln Y - \Delta \ln H \, .$$

As Stiroh (2002b) shows, aggregate labour productivity growth can be written as:

(4.5) $$\Delta \ln y = \sum_i \overline{w}_i \Delta \ln y_i + \left(\sum_i \overline{w}_i \Delta \ln H_i - \Delta \ln \sum_i H_i \right) = \sum_i \overline{w}_i \Delta \ln y_i + R \, .$$

In equation (4.5), w_i is the share of industry *i* in total value added and a bar over a variable denotes the two-period average.[103] Aggregate labour productivity growth is the weighted sum of industry productivity growth plus a reallocation term *R*. This reallocation term gives the differences between the output-weighted growth of hours and (roughly) the employment-weighted growth of hours (see Appendix 4.C for further discussion). If this term is positive it implies that, industries where the output share is larger than the employment share show faster employment growth than industries where the reverse is true. In other words, the reallocation term is positive if employment shifts towards industries with high productivity levels.

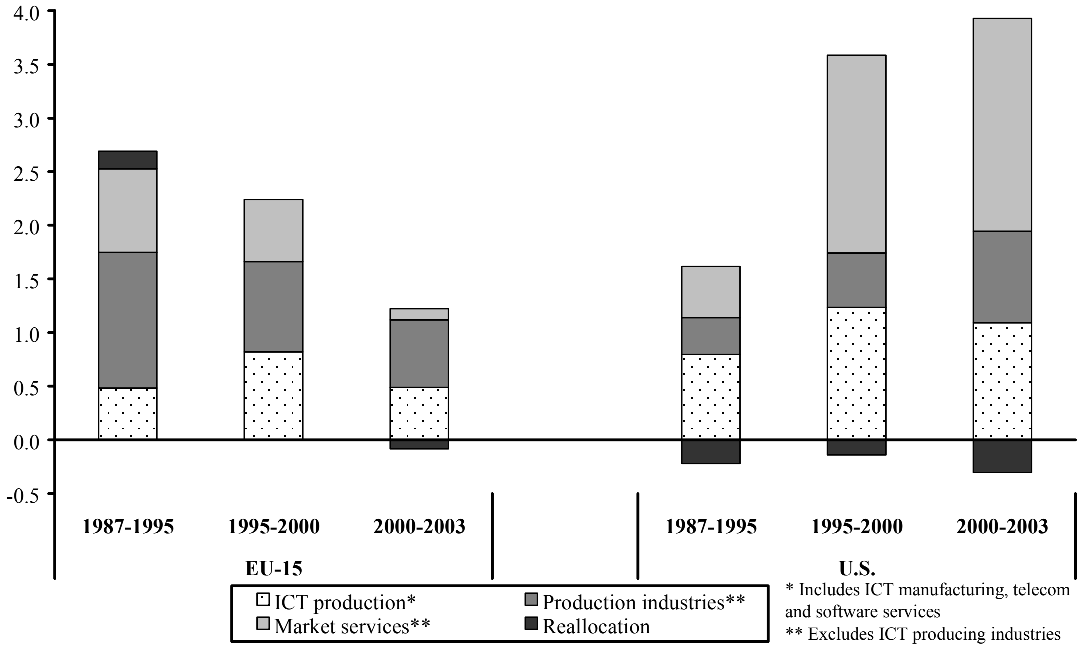
Figure 4.3 shows the contributions to market economy labour productivity growth from the main industry groups for Europe and the U.S.[104] The figure makes clear that the resurgence of U.S. growth after 1995 is not principally due to stronger growth in ICT producing industries. Instead, the performance of market services is the key to understanding the acceleration of U.S. growth.[105] For the 1995-2000 period, it was already quite striking how market services made a much larger contribution to labour productivity growth in the U.S. than in Europe. However, after 2000 the gap widened even more: while in the EU-15 market services added only 0.10 percentage points to growth, in the U.S. this sector made up almost 2 percentage points of overall growth in the market economy.

[103] This is based on a Törnqvist index of industry outputs. Since most statistical offices use different indexes, such as the Laspeyres or Fisher, the aggregate results will not be fully completely comparable to those published in the National Accounts. However, statistical offices are increasingly using so-called 'chained' indexes, with annually changing weights, so the differences will be limited in practice.

[104] The set of ICT producing industries is very close to the OECD (2002b) definition.

[105] Stiroh (2002b) already made a similar argument.

Figure 4.4 Contributions by industry groups to market economy labour productivity growth, EU-15 and U.S. 1987-2003



However, the market services sector is quite heterogeneous, including both florists and accountants, so it is useful to see which industries have mostly contributed to the difference in contribution. A first step is to simply calculate the difference in contribution of each industry: $\overline{w}_i^{US}\Delta\ln y_i^{US} - \overline{w}_i^{EU}\Delta\ln y_i^{EU}$. Summing across industries and adding the difference in the reallocation term then gives the difference in aggregate productivity growth. It can be interesting though to move beyond this straightforward expression and decompose the difference in industry contributions into an effect due to different output shares between the two regions and an effect due to different productivity growth rates:[106]

(4.6) $\frac{1}{2}\left(\Delta\ln y_i^{US} + \Delta\ln y_i^{EU}\right)\left(\overline{w}_i^{US} - \overline{w}_i^{EU}\right) + \frac{1}{2}\left(\overline{w}_i^{US} + \overline{w}_i^{EU}\right)\left(\Delta\ln y_i^{US} - \Delta\ln y_i^{EU}\right).$

The first term in equation (4.6) weighs the difference in value added shares by the average productivity growth rates and is referred to as the *share effect (share_eff)*. The second term weighs the difference in labour productivity growth rates by the average value added share and is the *productivity growth effect (prodty_eff)*. The difference in aggregate productivity growth rates can then be written as:

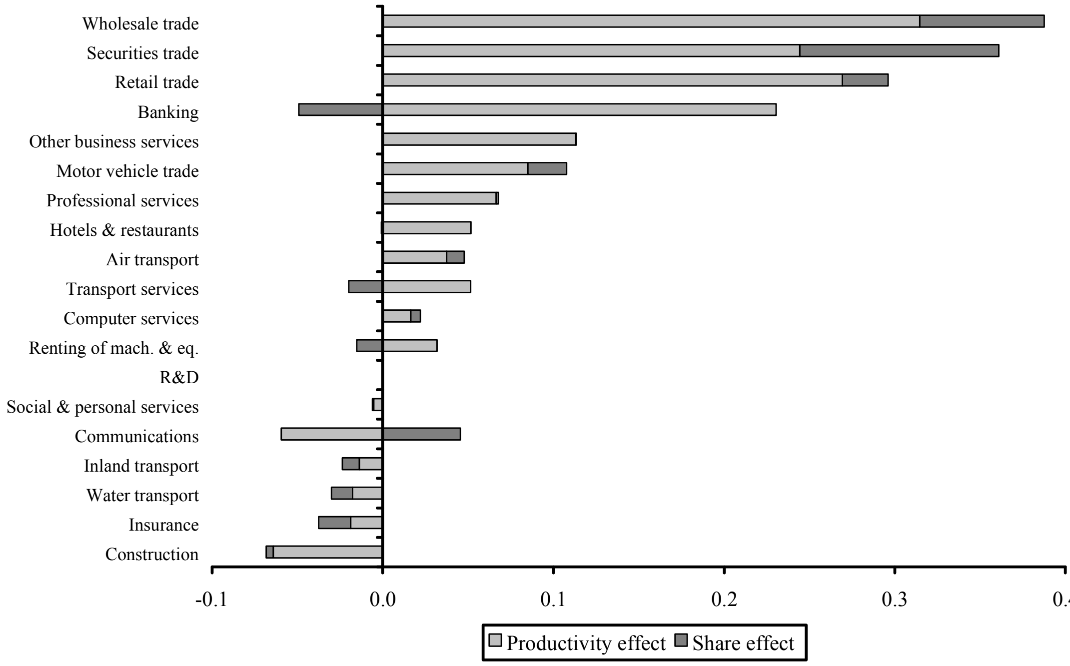
[106] This decomposition is very similar in spirit to the one presented in van Ark, Inklaar and McGuckin (2003a), except that the decomposition there was based on a shift-share decomposition of labour productivity growth.

$$(4.7)\quad \Delta\log y^{US} - \Delta\log y^{EU} = \sum_i prodty\_eff_i + \sum_i share\_eff_i + R^{US} - R^{EU} .$$

By applying equation (4.7), the market services that have contributed most to the growth differential with the U.S. after 1995 can be identified and the cause of this difference can be traced to either faster productivity growth or a larger output share.[107]

To examine this issue, Figure 4.5 shows the difference in contribution of individual market services to labour productivity growth between the U.S. and Europe. It is immediately apparent that most of the difference in contribution can be traced to only a limited number of services industries, mostly industries involved in trade and finance. The chart also separates the overall difference into the productivity growth effect *(prodty_eff)* and the share effect *(share_eff)* from equation (4.7). This makes clear that most of the differences are due to faster productivity growth, although in securities trade and wholesale trade, the larger size of the industry in the U.S. also had a sizeable effect.

Figure 4.5 Difference in labour productivity contributions of market services, U.S. minus EU-15, 1995-2003



[107] Not much attention is devoted here to the reallocation term since it is quantitatively less important. However, it does provide an interesting insight into the impact of structural change in Europe and the U.S. Appendix 4.C shows some of the results.

Measurement issues

One issue that has not been dealt with in much detail so far are measurement problems. Adequately accounting for quality changes of manufactured products can be problematic, particularly for products undergoing rapid changes such as ICT (see e.g. Gordon (1990) and van Ark (2000)). In many service industries the main difficulty is to define a quantity concept that separates price changes from changes in output value. Triplett and Bosworth (2004) discuss the main measurement problems for many important services industries. Here the focus is on some of the questions that have been raised about the strong performance of the industries at the top of Figure 4.5.

In the securities trade industry, very rapid productivity growth rates in the U.S. have been questioned by, among others, Stiroh (2002b) because it is based on the volume of shares traded instead of the margins earned on these trades by the stockbrokers. Recently, statistical practices in this area have improved in the U.S.[108] McKinsey (2001) also shows that after refining and extending BEA output measures, labour productivity growth in this industry in the U.S. remains strong.

There has also been a debate whether rapid U.S. productivity growth in wholesale trade and retail trade reflects true productivity gains, or whether it is driven by measurement problems. The European Commission (2004) and Gordon (2004) stress that U.S. growth in the trade sector may be overstated. The main problem is that the volume of trade services is proxied by the volume of sales. For many goods, this assumption seems plausible: if twice as many cars are sold, car dealers will have delivered about twice as many services to customers. The assumption becomes more problematic if the volume of sales increases because of quality improvement of the goods, such as in the case of ICT goods. Although a Pentium computer represents much more computing power than a 286, the trade services needed to sell these computers are probably not much different.[109]

However, there is little concrete evidence on how important this issue is. Timmer and Inklaar (2005) show that real output growth in U.S. wholesale trade suffers from a noticeable upward bias. The bias in European wholesale trade is probably smaller, but not entirely absent either. The growth figures for retail trade are

[108] See McCahill and Moyer (2002).
[109] Most of these arguments can be found in Triplett and Bosworth (2004).

much less affected by such measurement problems, and the productivity growth gap in retail trade between Europe and the U.S. is not much reduced by measurement refinements. Although any adjustment to growth in wholesale trade would lower the contribution of this industry to aggregate growth, it would do little to detract from the overall importance of market services in explaining the U.S. productivity advantage.

4.4 Patterns of ICT use in the U.S. and Europe

ICT intensity measures

The next step of the analysis is to see whether there is a relationship between the strong performance of the industries in Figure 4.5 and the intensity of ICT use. To compare the intensity of ICT use across industries, it is necessary to have a good metric for ICT use such as the expenditure on ICT relative to the expenditure on other inputs. Other measures are, for example, the number of firms using the Internet for sales or purchases or the penetration of network technologies (OECD, 2002b, 2003). However, these measures are much harder to compare across industries or to the other input choices of a firm. However, since ICT is a general purpose technology, it seems more illuminating to focus on the ICT inputs than looking at specific uses.

Given the use of a production framework, the focus here is on investment-based measures. Specifically, let $P_t^i I_t^i$ stand for investment in current prices in asset *i* at time *t*. The simplest measure of ICT intensity is then $\sum_{ICT} P_i^i I_t^i \Big/ \sum_i P_i^i I_t^i$, or the share of ICT investment in total investment.[110] If investment series are available for a sufficiently long period of time, capital stocks can be calculated using the perpetual inventory method (PIM):

(4.8) $$K_t^i = (1-\delta^i)K_{t-1}^i + I_t,$$

where K_t^i is the capital stock at constant prices of asset *i* at time *t* and δ^i is the geometric depreciation rate of capital good *i*. The second measure of ICT intensity can then be calculated as the share of ICT capital in the capital stock at current prices, or $\sum_{ICT} P_i^i K_t^i \Big/ \sum_i P_i^i K_t^i$. In general, the ICT investment share will be larger than the ICT capital share because non-ICT assets such as structures have a much longer service life and hence, a lower depreciation rate (around 3-10%) than ICT assets (10-

[110] The group of ICT assets consists of computers, communication equipment and software.

30%). However, the capital stock share neglects the fact that ICT assets deliver more capital services because of a higher user cost. To take this into account, the ICT share in capital compensation is required. The ICT capital compensation share is defined as:

(4.9) $$\sum_{ICT} r_t^i P_i^i K_t^i \Big/ \sum_i r_t^i P_i^i K_t^i \ .$$

Similar to labour compensation, $\sum r_t^i P_i^i K_t^i$ gives the income that capital assets have to generate to cover their user cost. The gross real rate of return on a capital asset, $r^{i,}$ is calculated as:

(4.10) $$r_t^i = R_t + \delta_t^i - \dot{p}_t^i \ .$$

The gross return is determined by the internal rate of return R_t at time t, the depreciation rate of asset i and its rate of price change $\dot{p}_t^i$.[111] ICT assets demand a higher return than other assets because of a higher depreciation rate and rapid price declines. As a result, the ICT share of capital compensation will be higher than the ICT share of the capital stock.

We can also look at the share of ICT capital compensation in value added:

(4.11) $$\sum_{ICT} r_t^i P_t^i K_t^i \Big/ P_t^Y Y_t \ .$$

The main advantage of this last expression is that given cost minimization and constant returns to scale it is equal to the output elasticity of ICT for a general production function:[112]

(4.12) $$Y = f\left(L, K_{ICT}, K_{Non-ICT}\right).$$

Furthermore, equation (4.11) takes into account that some industries are more labour intensive than others as the productive impact of a given ICT share in capital compensation is likely to be smaller for a labour intensive than for a capital intensive industry. One problem with these intensity measures is that they are all input measures, while we are ultimately interested in the impact of ICT on output and productivity. Of course, as mentioned before, in a neo-classical framework, the output impact of ICT will be equal to the ICT share in value added as given in equation (4.11). However, this assumes away spillover effects from ICT reflected in TFP

[111] Usually a term reflecting corporate taxes and investment credits is also included in equation (4.10). However, as Erumban (2004) shows, taxes have only a limited effect on capital input growth, so these terms are omitted here. The internal rate of return is in this case taken as the return which equates total economy capital compensation with the observed capital stock at current prices.

[112] In general, the industry production function is specified in terms of gross output instead of value added and intermediate inputs are included amongst the inputs. Given separability of intermediate inputs, the equality of cost shares and output elasticities will hold.

growth. In reality, however, there is a lot of case-specific evidence of spillovers from ICT. One example is the retail-case as discussed by McGuckin et al. (2005) (see Section 4.5). Another example is from Olewiler (2002), who discusses how a relatively small ICT investment by the oil industry has fundamentally changed oil exploration methods. But although the impact of ICT may not be well captured by the intensity measures described here, the intensities should be useful as a first approximation.

To get some idea about the magnitude of the various ICT intensity measures, Table 4.2 shows the various measures discussed above for two broad sectors of the U.S. economy, production industries and market services, as well as the market economy as a whole in 1995. These estimates are based on a dataset containing investment and output data for 47 U.S. industries.[113] ICT investment consists of all investment in computers (IT hardware), communication equipment and software.

Table 4.2 ICT intensity measures for major U.S. sectors in 1995

	ICT investment share	*ICT capital stock share*	*ICT capital compensation share*	*ICT capital compensation in value added*
Production industries	15.3	3.2	11.8	4.7
Market services	33.3	13.0	32.1	8.5
Market economy	26.1	8.2	23.2	7.2
Rank correlation				
Investment share		0.97	0.97	0.81
Capital stock share			0.96	0.83
Capital compensation share				0.80

Sources: BEA, 1997 Capital Flow Table, extrapolated using BEA, Estimates of nonresidential fixed assets, detailed industry by detailed type, 1987-2003 (NAICS-based) and 1901-2001 (SIC-based). GGDC (2005) 60-Industry database (value added). Notes: Production industries includes agriculture, mining, manufacturing and utilities. Market services covers the other market industries. The (Spearman) rank correlation is calculated using data for 47 U.S. industries covering the market economy.

As the table shows, the services sector invests most strongly in ICT according to all intensity measures. Indeed, the services sector owns more than 85 percent of ICT assets in the U.S. economy.[114] The high ICT intensity of the services sector is not

[113] The basic source is the 1997 Capital Flow Table from the U.S. BEA (see Meade *et al.*, 2002) on the basis of which nearly all industries from the 60-industry database can be distinguished. The benchmark figures are extrapolated using detailed investment series by industry and asset from the BEA.
[114] As Inklaar, O'Mahony and Timmer (2005) show, this pattern is similar in Europe.

just due to the fact that services are less capital-intensive overall, since the ICT intensity is highest of the sectors even as a share of value added. The four intensity measures vary considerably in magnitude, but as the bottom panel of the table shows, the ranking of industries is very similar across measures. The average rank correlation between the four measures is 0.89. The rank correlation among the first three measures (investment, capital and capital compensation share) is even higher at about 0.97. Differences in capital intensity between industries explain why the ICT share in value added has a lower rank correlation with the other measures. Still, the various ICT intensity measures give a largely similar picture of which industries are intensive ICT users and which are less so. In the remainder, the ICT capital compensation share is used as the main measure of ICT intensity.

Can a distinct group of ICT users be identified?

In earlier work we have extensively focused on ways to distinguish between industries that are intensive users of ICT and industries that are less intensive users. Van Ark, Inklaar and McGuckin (2003a) looked at the share of ICT capital in total capital compensation to distinguish between intensive ICT-using and less-intensive ICT-using industries. An arbitrary cut-off point, namely the median, was used to distinguish ICT using industries from non-intensive users.

Of course, this typology can be criticized on grounds of the arbitrariness of the cut-off point between more intensive and less intensive ICT-use.[115] Indeed the literature on general purpose technologies suggests that the spectrum of ICT intensity will be much more gradual as technological opportunities only differ gradually across industries. Gradualism is confirmed in Figure 4.6, which ranks industries in the United States on the basis of the share of ICT capital compensation in total capital compensation in 1995. As the figure shows, most of the ICT producers and market services are on the left side of the chart whereas most of the production industries are on the right side.

An alternative approach to distinguish between intensive and less intensive ICT using industries is to look for a data-determined cut-off point using cluster analysis (see e.g. Peneder, 2003). One such approach to dividing observations into two (or more) groups is the *k-means* approach. Starting from an arbitrary grouping of

[115] See, for example, Daveri (2004).

industries, the absolute difference with the mean of each group is calculated. New groups are then formed by allocating industries to the group with the nearest mean. This process is repeated until no industries change between groups. This way, the intra-group variability is minimised.

Another clustering method is *hierarchical* cluster analysis. In this method, the distance (for example, the squared difference) between all observations is calculated. The two observations that are closest together are grouped into a cluster and the distance from this cluster to all other observations is calculated. This process is repeated until there is only one cluster left containing all observations. To get two groups of industries, one can simply go to the point in the hierarchy where all observations are part of either of two clusters. The distance from the cluster to all other observations can be calculated in a number of ways. Three commonly used methods are the average link, single link, and complete link methods. *Average link* uses the average ICT intensity of a cluster to calculate distances to all other observations. *Single link* uses the minimum distance from any cluster member to the other observations. *Complete link* uses the maximum distance.

Table 4.3 Number of U.S. industries classified in high ICT intensity cluster and correlation between ICT intensity measures

	ICT share in capital compensation			*ICT share in value added*		
	1987	1995	2003	1987	1995	2003
Number of industries in high intensity cluster						
K-means	14	9	15	10	7	8
Hierarchical						
Average link	8	9	8	2	4	3
Single link	2	9	1	1	4	1
Complete link	2	9	13	4	4	3
Rank correlation between ICT intensity measures						
	1987	1995	2003	1987	1995	2003
1987		0.83	0.78		0.72	0.64
1995			0.97			0.90

Notes: Average link uses the average ICT intensity of a cluster to calculate distances to all other observations. Single link uses the minimum distance from any cluster member to the other observations, complete link uses the maximum distance.

Figure 4.6 Share of ICT capital in total capital compensation in the United States for 1995

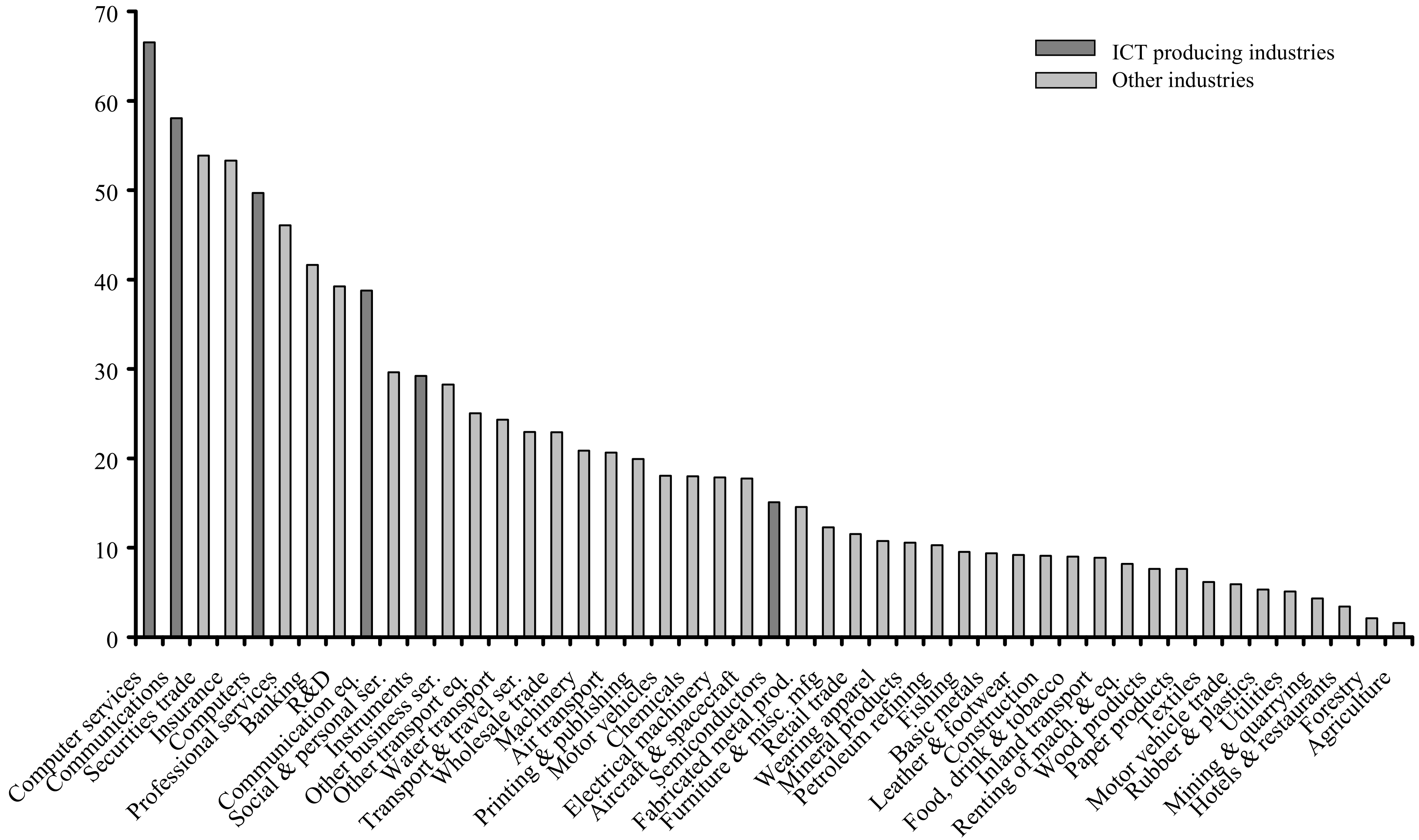


Table 4.3 shows the number of U.S. industries that is classified in the high ICT intensity cluster according to the different cluster analysis methods discussed above for various years.[116] For example, in 1995 the nine industries with the highest ICT share in capital compensation would be clustered into the ICT-using group of industries. Judging by these results, no clear group of ICT users can be identified. There are considerable differences between methods for a single year, between years and between ICT intensity measures. Using these results, one can either defend choosing only the most ICT intensive industry as ICT using or take the top 15 industries. The cluster analysis methods are also remarkably sensitive to small changes in the data: even though the correlation between the 1995 and 2003 shares of ICT in capital compensation is 0.97, the single link method places nine industries in the high intensity cluster in 1995, but only one in 2003. Overall this suggests that no clearly defined group of ICT users exists but instead that the change from highly ICT intensive to less intensive is gradual. Any analysis of the productive impact of ICT by industry should therefore be cautious in making a sharp distinction between ICT using and non-ICT industries.

4.5 Industry-level growth accounts and the contribution of ICT to growth

Growth accounts can provide information that is obscured when looking only at labour productivity growth by providing a framework in which the contribution to growth of different types of physical and human capital can be assessed and compared. However, data on investment by asset at the industry level is still scarce so the analysis is limited to five countries (France, Germany, Netherlands, United Kingdom and United States) and 25 market industries.[117] This section first gives an overview of the growth accounting methodology at the industry level and then moves on to a discussion of some of the data issues. The remainder of the section is devoted to a presentation of the results.

---

[116] For the hierarchical cluster analysis, the squared difference between observations is used as a distance measure. Using the absolute difference does not change the results. For the cluster analysis, all 47 market industries have been used. The results are qualitatively similar if the ICT producing industries, which are mostly near the top of the ranking, are left out.

[117] In addition, there are an increasing number of country-specific studies with industry-level growth accounts and data on ICT investment. Some of these studies are for countries that are covered here (e.g. Oulton and Srinivasan (2005) for the UK, and van der Wiel (2001) for the Netherlands) and others are for other countries (e.g. Mas and Quesada (2005) for Spain).

Growth accounting at the industry level

Calculating capital stocks and rental prices

Capital input is measured by capital service flows, following the methodology pioneered by Jorgenson and Griliches (1967) and more recently implemented in Jorgenson, Ho and Stiroh (2005). Capital stocks are constructed using the perpetual inventory method (PIM) as in equation (4.8). The rental price for each asset is defined as the rate of return *R* at time *t* plus the depreciation rate minus the rate of inflation of the asset in question (see equation (4.10)). Growth in capital input is measured by capital service flows and is derived from the capital stocks by asset type as follows:

(4.13) $$\Delta \ln K_t = \sum_j \bar{v}^K_{j,t} \Delta \ln K_{j,t} \ ,$$

where $\bar{v}^K_{j,t}$ is the two-period average share of asset type *j* in total nominal capital compensation (implementing equation (4.9)). In the results below, the contribution of ICT capital services and non-ICT capital services are separately distinguished. ICT capital services are calculated by weighting each of the ICT capital stocks by the share of the asset in total ICT capital compensation. Non-ICT capital services are calculated analogously.

Aggregation and industry contributions

Section 4.1 provided an overview of the basic growth accounting methodology. Industry-level data adds the complication that results have to be aggregated to get industry contributions to aggregate growth. Jorgenson, *et al.* (2005) distinguish three methods to aggregate output and inputs across industries, namely the aggregate production function, the aggregate production possibility frontier and aggregation over industries. The third method is employed here because it is the most flexible. Specifically, the assumption that the prices of value added and inputs are equal across industries does not have to be made.[118] This means that industry growth rates of output and inputs are weighted by their share in aggregate value added to calculate contributions to aggregate labour productivity growth.

[118] An aggregate production function exists only if gross output prices, and hence value added prices, as well as input prices are equal across industries. For an aggregate production possibilities frontier, input prices need to be equal.

Combining the decomposition of aggregate labour productivity in (4.5) with equation (4.2), the decomposition of aggregate labour productivity growth into industry contributions can be written as:

(4.14) $$\Delta \ln y = \sum_i \overline{w}_i \left(\overline{v}_i^L \Delta \ln q_i^L + \overline{v}_i^{ICT} \Delta \ln k_i^{ICT} + \overline{v}_i^N \Delta \ln k_i^N + \Delta \ln A_i \right) + R .$$

In contrast to equation (4.2), equation (4.14) also includes a term reflecting labour quality, q_i^L. This term is calculated as the difference between the change in an index of labour input and growth of total hours worked. The labour input index is calculated in a similar fashion as capital services growth, but with different types of labour, distinguished by educational attainment.[119] Using this decomposition, the contribution of input and TFP growth from each industry to aggregate labour productivity growth can be calculated.[120] For example, the contribution of ICT-capital deepening in industry *i* to aggregate labour productivity growth is given by:

(4.15) $$ICTContr_i = \overline{w}_i \left(\overline{v}_i^{ICT} \Delta \ln k_i^{ICT} \right),$$

which is defined as the growth of ICT capital per hour worked in industry *i* weighted by the share of ICT capital compensation of industry *i* in aggregate nominal value added. The weight is the product of the share of industry *i* in aggregate value added ($\overline{w}_i$) and the share of ICT capital compensation in industry value added ($\overline{v}_i^{ICT}$). Similar calculations can be carried out for the contributions of non-ICT capital, labour quality and TFP. [121]

Growth accounting results

Table 4.4 shows the growth accounts for the total market economy as well as for the contributions from two industry groups, namely the (broad) ICT production sector and total market services from 1995 to 2003.[122] In addition to the four European countries, a column shows the (weighted) average results for these countries (referred to as EU-

[119] See Inklaar, O'Mahony and Timmer (2005) for more details.

[120] Just as in Section 4.2, value added is used as the measure of output. As long as statistical offices use double deflation to estimate real value added from gross output and intermediate inputs, value added-based TFP is equal to gross output-based TFP divided by the value added to gross output ratio. See OECD (2001) for further discussion.

[121] For a more extensive description of methodology as well as the data sources, see Inklaar, O'Mahony and Timmer (2005). Estimates for recent years follow similar procedures. At this stage, no educational attainment data could be collected for years after 2000, so labour quality growth is assumed to be zero for those years.

[122] The "broad" ICT production sector includes electrical and optical equipment (ISIC 30-33) and telecommunications (64). Investment data is not available to distinguish computer services (72) in all countries.

4) which facilitates the comparisons with the macro-results presented in Section 4.2. The findings for the market economy are similar to those at the macro-level: labour productivity growth in the U.S. is higher than in Europe due to a combination of higher contributions from ICT capital deepening and TFP growth. The EU-U.S. gap in TFP growth from ICT production is somewhat smaller here than for the aggregate level (where the impact of ICT production was subtracted from aggregate growth on the basis of output shares) because the industry data also include telecommunications services, where Europe has a growth edge over the U.S.

Table 4.4 Sources of industry labour productivity growth, 1995-2003

	France	Germany	Netherlands	United Kingdom	EU-4	United States
Market Economy Labour Productivity Growth	***1.80***	***2.08***	***1.41***	***2.59***	***2.12***	***3.51***
of which:						
ICT capital deepening	0.46	0.54	0.81	0.77	0.63	1.27
Non-ICT capital deepening	0.32	0.37	0.71	0.71	0.54	0.60
Labour quality growth	0.21	0.05	0.12	0.23	0.14	0.11
Reallocation of hours	0.01	0.25	-0.35	-0.26	-0.08	-0.26
Total factor productivity growth	0.79	0.88	0.14	1.13	0.89	1.78
Contribution of ICT producing sector	*0.71*	*0.84*	*0.41*	*0.87*	*0.83*	*1.15*
of which:						
ICT capital deepening	0.03	0.06	0.08	0.14	0.09	0.23
Non-ICT capital deepening	0.02	0.07	0.11	0.05	0.05	0.08
Labour quality growth	0.02	0.01	0.03	0.02	0.03	0.01
Total factor productivity growth	0.64	0.69	0.19	0.65	0.67	0.83
Contribution of market services	*0.12*	*0.34*	*0.63*	*1.29*	*0.57*	*2.02*
of which:						
ICT capital deepening	0.33	0.38	0.60	0.53	0.44	0.84
Non-ICT capital deepening	0.00	0.13	0.25	0.40	0.20	0.27
Labour quality growth	0.15	0.02	0.07	0.15	0.07	0.07
Total factor productivity growth	-0.36	-0.19	-0.29	0.21	-0.14	0.85

The industry results bring out some of the earlier findings in sharper perspective. First, market services in both Europe and the U.S. account for between 75 and 80 percent of ICT capital deepening in the total market sector, with much smaller contributions from ICT producing industries. In terms of TFP contributions, however, the ICT producing sector is the most important source of TFP growth in Europe (0.67 percentage-points out of 0.89 percent growth). In the U.S., ICT production also makes a sizeable contribution, but market services are equally important. Indeed in the U.S., this sector generates 0.85 percentage points of growth, or half of market economy TFP growth. For the EU-4, the TFP contribution from market services is negative, -0.14 percentage points. The UK stands out among the four European countries for its relatively strong TFP performance in market services, although it still lags the U.S.

What is the evidence on TFP spillovers?

Table 4.4 suggests that the U.S. has managed to combine strong ICT investment in market services with high TFP growth. There is considerable firm-level evidence for the U.S. that ICT has a larger impact on productivity than suggested by its share in total cost, according to a survey of this literature by Brynjolfsson and Hitt (2000). A recent OECD (2004) collection of studies also shows that this result holds more widely than just for the U.S. In other recent work, Brynjolfsson and Hitt (2003) demonstrate that at the firm level, the benefits from ICT investment increase by a factor 5, up to seven years after the initial investment.

However, as the overview of literature in Stiroh (2002a) shows, the evidence at the industry-level or economy-wide is much less convincing. His finding for the total economy was confirmed in Section 4.2 and Stiroh's (2002a) own estimates show little or no evidence of spillovers from ICT capital accumulation to TFP growth at the industry level. Others, such as Basu, Fernald, Oulton and Srinivasan (2004) find more support, especially for the hypothesis that it takes time for firms to accumulate sufficient organizational capital to productively use ICT. O'Mahony and Vecchi (2005) also report findings that point towards spillovers.[123]

To more fully explore this issue for the industry data for Europe and the U.S., the following regression is estimated:

$$\Delta \ln A_{it} = \alpha + \beta\left(\bar{v}_{it}^{ICT} \Delta \ln K_{it}^{ICT}\right) + \varepsilon_{it} . \tag{4.16}$$

Using equation (4.16), the productive impact of ICT capital can be evaluated. Specifically, if β is not significantly different from zero, ICT capital makes a "normal" contribution to growth, given by its cost share and the entire productive impact of ICT is accounted for in the calculation of TFP growth. This equation is similar to one of the equations estimated in the more extensive study of Stiroh (2002a) for U.S. manufacturing.[124]

Equation (4.16) is estimated using ordinary least squares (OLS). The standard errors of the parameters have been corrected for autocorrelation and heteroscedasticity

---

[123] In general, see Stiroh (2003) for a survey of studies estimating the output elasticity of ICT capital.

[124] Stiroh also simultaneously estimates the impact of the other inputs on TFP, but these are omitted here to facilitate the focus on ICT capital.

using the procedure of Newey and West (1987). The estimates in Table 4.5 are shown with only a single constant term as well as with fixed effects, with a dummy included for each country/industry pair. The regressions with only a single constant show whether higher ICT contributions are related to higher TFP growth. The fixed effects models establish whether a rise in the contribution from ICT capital, in a particular industry in a specific country, is related to higher TFP growth. These fixed effects models may be relevant if certain unmeasured industry- and country-specific factors are important. For example, it could be the case that the regulatory environment of an industry in a country influences TFP growth, but not ICT investment. Eliminating this unobserved heterogeneity through a fixed effects model may be important to identify the impact of ICT on TFP growth (see e.g. Griliches and Mairesse, 1998).[125]

Table 4.5 The impact of ICT on TFP growth, annual growth rates for 1979-2003 in Europe and the U.S.

*TFP=a+b*ICT+e*	*All countries*	*France*	*Germany*	*Netherlands*	*UK*	*U.S.*
Single constant	-1.01*	-0.99	-1.43	-1.25*	-0.78	-0.96*
	(0.27)	(0.90)	(0.81)	(0.48)	(0.66)	(0.42)
Fixed effects	-1.47*	-1.98	-3.14*	-1.49	-0.71	-1.11
	(0.45)	(1.39)	(1.50)	(0.89)	(0.50)	(0.69)

Notes: * denotes significantly different from zero at 5% level. Heteroscedasticity and autocorrelation-consistent standard errors are shown in parentheses. Dependent variable is industry TFP growth between 1979 and 2001. Independent variable is the contribution of ICT capital to output growth. In the fixed effects estimates, a dummy is introduced for each country/industry pair. Estimates for all market industries and all countries include 2875 observations (23 years, 25 industries, 5 countries), the other columns include 575 observations.

Table 4.5 shows the estimates of equation (4.16) for all market industries. When pooling across countries, a higher (or rising) ICT contribution actually leads to lower TFP growth. Most of the country estimates are insignificantly different from zero or negative too.[126] Overall, these results are in line with those reported in Stiroh (2002a), who also reports a number of significantly negative estimates of ICT on TFP growth, although he manages to trace these to the ICT producing industries.

One reason why no positive relationship between ICT and TFP is found in the industry data may be that the effect of ICT on TFP occurs only with a lag, for example, because complementary investments in organizational change must be made

[125] Experiments with demand-side instruments to take further endogeneity problems into account, show comparable results.

[126] Removing the ICT producing manufacturing industry from the sample does not change the qualitative results. Estimates for only services industries are also not noticeably different. The fixed effects estimates are mostly larger, in absolute sense, than the single constant estimates. The reason for this is not immediately clear since this result also shows up for individual countries. However, in a statistical sense the two sets of estimates do not differ, so the issue is of limited importance.

first. Basu *et al.* (2004) build a theoretical model and present some results that suggest this may be important. In their empirical exercise, they explain TFP growth in each industry, averaged over 1995 to 2000, by the ICT contribution to growth for 1980-1990, 1990-1995 and 1995-2000. For the U.S. they find a negative effect of ICT for 1995-2000 on TFP and positive effects for the first two periods. This suggests that lags may be important. The analysis of Basu *et al.* (2004) however, is strictly cross-sectional and the choice of periods and lags is somewhat arbitrary.

Brynjolfsson and Hitt (2003) test a similar hypothesis of possible time lags using firm-level data, arguing that the best way to pick up the effects of earlier ICT investment on current TFP is by taking longer differences of the data. so instead of 1-year growth rates, they look at growth rates over 2, 3 and more years. Their main finding is that the ICT impact on TFP growth rises as longer differences are taken, with the 7-year difference showing an impact of ICT that is 5 times as large as the 1-year difference.

Other methods have also been used to distinguish short-run and long run effects of ICT use. O'Mahony and Vecchi (2005) apply the pooled mean group (PMG) estimator of Pesaran *et al.* (1999) to estimate the output contribution of ICT capital.[127] With this methodology, O'Mahony and Vecchi (2005) find a long-run effect of ICT on output that is higher than is expected on the basis of cost shares. This implies evidence of spillovers from ICT use. While their result is useful and interesting, the link to firm-level studies such as Brynjolfsson and Hitt (2003) is somewhat lost. The first goal here is to use similar methods as Brynjolfsson and Hitt (2003) to see whether the firm-level results hold up at the more aggregate industry level. A secondary goal is to gauge the robustness of the Basu *et al.* (2004) results to different lag lengths and periods.

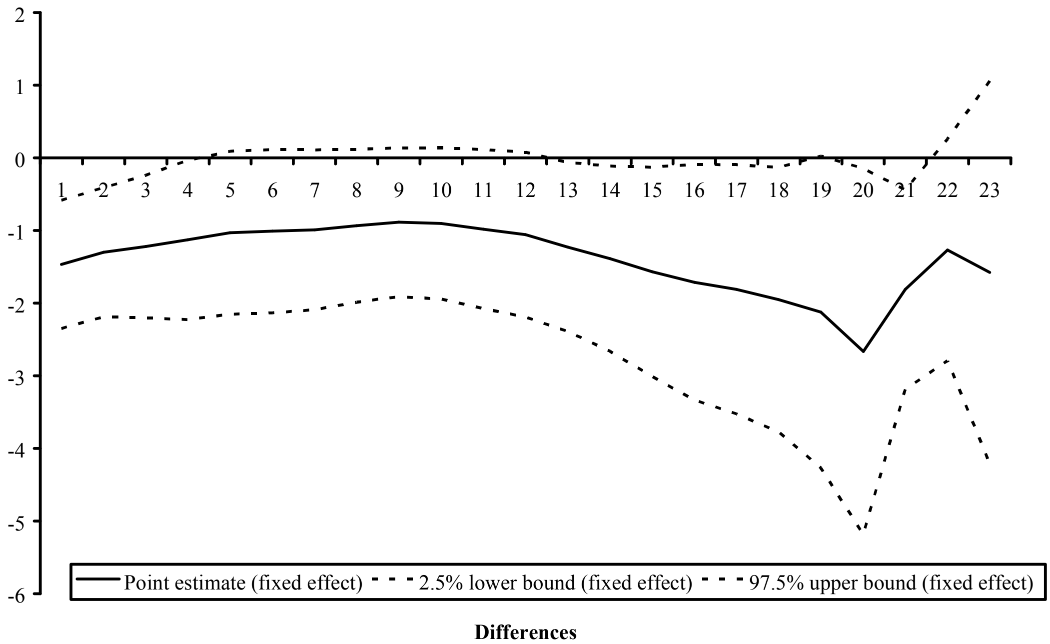
It is not immediately clear which method (using long differences or including lagged ICT investment) best captures the idea of a long-run effect of ICT on TFP. A priori, the lagged specification would seem to capture the idea of complementary investments better. If a firm starts an ICT investment project at time *t*, it might be that for example the largest TFP benefits accrue at time *t+5*. However, by that time a new ICT investment project (perhaps in a different part of the organization) may have

[127] The PMG estimator allows short-run dynamics to differ across industries and countries, but constrains the long-run effect to be the same.

commenced. Also, summing TFP contributions over the years would include the years in which the peak TFP impact was not yet reached as well. However, it is straightforward to test both methods. Furthermore, they both have the added advantage that measurement errors become less prominent, since these errors are unlikely to be highly correlated across years.

As a first step, ever longer differences are calculated following the same procedure as Brynjolfsson and Hitt (2003). When increasing the difference length, their approach is to use overlapping periods. So for three-year differences, they first calculate the difference from year 1 to year 4, next from year 2 to year 5, etc. This procedure does build in a certain amount of autocorrelation, since any measurement error in for example year 3 is included in the first, second and third observation. The Newey-West procedure should correct for this, however, and the results are qualitatively similar if no overlapping periods are used. Figure 4.7 shows the parameter as well as confidence bands for fixed effects estimates, ranging from 1-year to 23-year differences.[128]

Figure 4.7 Effect of ICT on TFP growth in the EU-4 and U.S. at the industry level, 1-year to 23-year difference



The estimate for 1-year differences is the same as shown for OLS with fixed effects from Table 4.5. This estimate is significantly negative at the 5% level. From 5-

[128] To estimate fixed effects, at least two observations per industry are needed, so a 23-year difference is the maximum possible.

year differences to 12-year differences, the coefficient is insignificantly different from zero and after the 12th year, the upper bound fluctuates around zero.[129] Hence, Figure 4.6 suggests that a rising ICT contribution in an industry does not have a significant impact on TFP growth over differences longer than four years and a negative effect for the first four years. In any case, a strong positive relationship is certainly not supported by these data.[130]

The other possibility that needs to be explored is whether the ICT contribution in one year has an impact on TFP growth in the next year or years after that. For this exercise, only one-year differences are used, although experiments with combinations of lags and longer differences suggest a similar story as increasing lags in combination with one-year differences. Figure 4.8 shows the estimated impact of ICT on TFP growth, from the contemporaneous effect up to a 22 year lag. As before, fixed effects estimates are presented.

Figure 4.8 Effect of ICT on TFP growth in the EU-4 and U.S. at the industry level, contemporaneous effect to 22-year lag

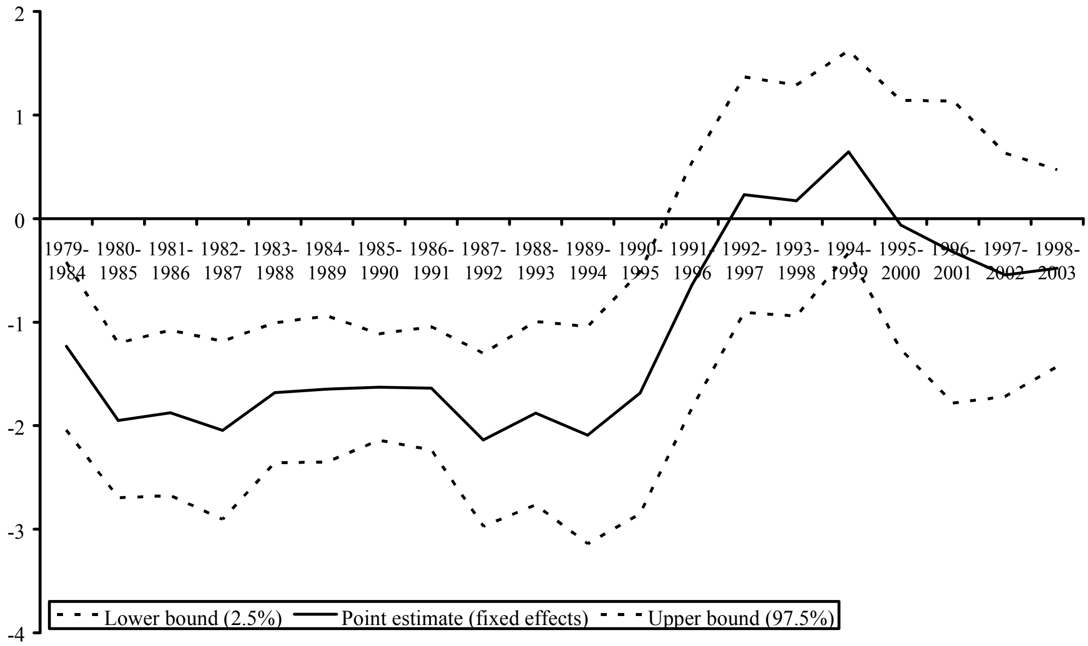
The contemporaneous effect and at the effect of a one-year lag are significantly negative but from two years onwards, the estimated effect is not significantly different

[129] If only a single constant is used, the coefficient remains significantly negative, even for very long differences. This is mainly the result of tighter confidence intervals and not so much lower point estimates. As the fixed effects model removes certain unobserved heterogeneity, it seems preferable.
[130] The individual country results are not shown, since no country shows consistently positive or negative effects.

from zero. Estimates with a single constant are significantly below zero up to a lag of five years, and insignificant afterwards, which can again mostly be traced to tighter confidence intervals. As before, the country-specific results do not diverge noticeably from the overall pattern of Figure 4.8.

So far, only the full sample of observations for all years has been analyzed. One might argue, however, that the relationship between ICT and TFP growth has changed over time. To investigate this possibility, equation (4.16) is also estimated for each 5-year period in the sample.[131] Figure 4.9 shows the regression coefficient for 1979-1984, then the 1980-1985 coefficient up to the 1998-2003 coefficient. Throughout the 1980s, the ICT effect remains significantly negative, but starting with the 1991-1996 period, the coefficient becomes indistinguishable from zero. So during the 1990s, ICT capital generated productivity effects in line with the cost of ICT capital, suggesting normal returns.

Figure 4.9 The relation between ICT contributions and TFP growth for subsequent sets of 5-year differences, 1979-1984 to 1998-2003



[131] Five-year differences were chosen since Figure 4.6 shows that on average over the full period, the ICT effect is not significantly different from zero. Using differences of other lengths does not alter the qualitative results. Including a single constant instead of fixed effects also does not affect the pattern. If similar rolling estimates are made using lags instead of long differences, the coefficients fluctuate more from period to period, but the pattern of significantly negative in the 1980s to indistinguishably different from zero in the 1990s is unchanged.

The analysis so far suggests that the significantly negative results, shown in Table 4.5, paint a picture that is too pessimistic about ICT's impact on TFP growth. Taking longer differences or allowing for lags between the ICT investment and the impact on TFP, mostly eliminates the significant negative results, although the point estimates remain predominantly negative. These results seem to cast some doubt on the estimates shown by Basu *et al.* (2004), who find a significant positive impact of the 1990-1995 U.S. ICT contribution on 1995-2000 TFP growth. In the setting of this study, they find a positive impact of the 5-year lagged ICT contribution with (roughly) 5-year differences. Although their specification is not separately reported, the more comprehensive set of specifications that were tested here shed some doubt on the robustness of their findings. Figure 4.9 shows that some of the point estimates for the 1990s are positive, but never significantly so.

It might also be argued that the U.S. and UK are ahead of the Continental European countries, as suggested by Table 4.4. Figure 4.10 therefore takes the use of sub samples one step further by carrying out the 5-year regressions separately for the three continental European countries (France, Germany and Netherlands) and the two Anglo-Saxon countries (UK and U.S.) in the dataset.

Figure 4.10 The relation between ICT contributions and TFP growth for subsequent sets of 5-year differences, Continental Europe vs. Anglo-Saxon countries

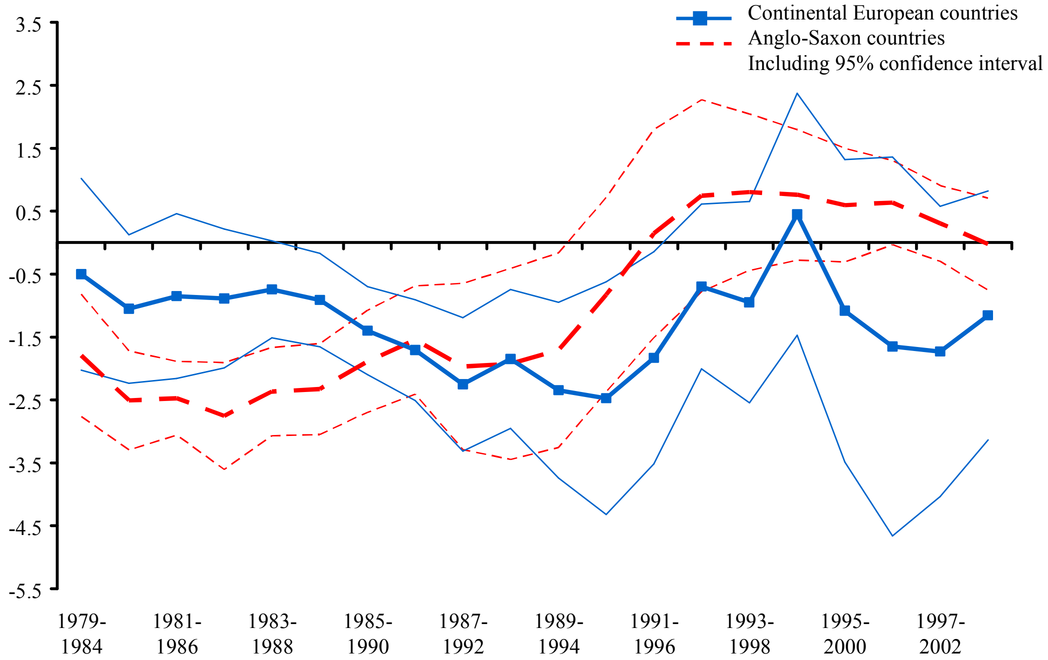


Figure 4.10 shows that the effect of ICT on TFP growth is U-shaped for the Continental European countries: ICT capital has no significant impact on TFP growth up to the mid-1980s, a significantly negative effect up to the 1991-1996 period and from the 1991-1996 period onwards there is again no significant effect. There is some suggestion that a similar U-curve might exist for the Anglo-Saxon countries, but as it is located a couple of years earlier, the left tail of the U-shape cannot be directly observed because of lack of data. It should be stressed once again, however, that ICT has at best no effect on TFP growth in both the Continental European and Anglo-Saxon countries. The main change from the 1980s is that ICT is no longer a drag on TFP growth in the 1990s.

Some complementary evidence for the U-curve hypothesis can be found in Morrison (1997), who shows that high tech capital in U.S. manufacturing earned its marginal cost from the early 1970s until about 1980 and again from around 1990 onwards. During the 1980s though, the marginal returns from ICT fell short of the marginal cost. In other words, it seems likely that the U-curve exists in all countries in our sample. This pattern may be indicative of relatively straightforward, direct, 'hard' savings from ICT investment that can be realized quickly. However, before further savings can be realized, new organizational forms need to be developed and experimented with. In addition a strong competitive process is needed to weed out failing experiments with investment in organizational innovations.

Compared to the many firm-level studies on the impact of ICT capital on productivity, the results presented here are still puzzling. Brynjolfsson and Hitt (2003) estimate a number of long differences models and find a normal return to computer investment already at one-year differences, while at longer differences the return becomes five times as high. The results here show that even with very long differences, only a normal return can be observed at the industry level. Furthermore Brynjolfsson and Hitt (1996) find that after accounting for fixed firm effects, the impact of ICT on growth decreases. They take this as evidence of important firm-specific effects, possibly related to the strength and flexibility of the organization. The industry estimates here show little difference in point estimates, which can be taken as evidence that these firm effects are mostly a within-industry phenomenon. In other words, industries may have strong performers, but at the industry-level this averages out. Brynjolfsson and Hitt (2000) also point out that within-industry variation in ICT investment and productivity can lead to a lower correlation between these measures at the industry level due to the averaging out process described above.

4.6 Concluding remarks

This chapter has provided some new perspectives on the relationship between ICT and productivity growth from an international comparative perspective. First of all, estimates up to 2004 show that the EU-U.S. growth gap, which opened up around 1995, grew even larger after 2000. The gap can mostly be attributed to the sharp acceleration of total factor productivity growth in the U.S., which appears to be located mainly in market service industries. European growth has declined further, and in particular, market services have performed quite poorly in recent years. This evidence gives support to the hypothesis that the European Union is presently not on a track to realize the same productivity gains from ICT as the U.S.

Further analysis focused on the possibility that there is a difference in timing of the productivity effects of ICT between Europe and the U.S. The argument would then go that many European countries are still in a transition process towards a new phase of productivity gains from ICT usage, which the United States have already realized. To this end the direct relationship between ICT use and TFP growth at the industry level has been estimated, to identify any productivity spillover effects of ICT use. The results suggest that, at the industry level, ICT does not earn super-normal returns, even when taking longer differences or lags into account. The analysis did establish a pattern suggesting that ICT earned its normal returns in the early phase of ICT investment (1970s, early 1980s), followed by a period of negative effects from ICT on productivity (late 1980s) with a return to normal returns after several years. This U-shaped pattern of returns on ICT shows up clearly for the three continental European countries (France, Germany and the Netherlands), and there is also evidence for a similar pattern in the UK and the U.S. several years earlier.

These results might be better understood when relating them to the literature on general purpose technologies and, more specifically, to the idea that the pervasiveness of technologies, such as ICT, involves a significant amount of time before its productivity effects are exploited (see, for example, Bresnahan and Trajtenberg, 1995). One might speculate that the early normal returns on ICT are the result of the direct productivity effects of ICT production and ICT investment (called “hard savings” here). The “negative spillover”-period may be related to a phase of investments in human capital and knowledge capital as well as organizational innovations which do not immediately result into an acceleration of productivity growth. It takes time before the combination of ICT investment and intangible investments and innovations (here called the "soft savings"), have an effect on productivity. This interpretation of the results is also in line with the firm-level evidence which emphasizes the importance of human capital and organizational innovations (Brynjolfsson and Hitt, 2000, 2003; OECD, 2004).

The idea that ICT can generate 'hard' and 'soft' savings with an impact that is phased over time is consistent with detailed studies of individual industries. For example, McGuckin, Spiegelman and van Ark (2005) show that in retail trade, ICT investment had an immediate impact on productivity growth through hard savings. For example, the introduction of barcode scanning allowed for more efficient check-out systems without much further investment. However, the same barcode technology has enabled a reorganization of the supply chain and the introduction of new shopping concepts. These soft savings not only require heavy investment in ICT, but also investments in new complementary technologies (RFID, transportation technology) and organizational changes (new shopping concepts, supplying shops more often).

These findings also have methodological implications. The econometric analysis of the ICT impact provided new insights compared to the growth accounts, especially by showing a U-curve of the productive impact of ICT investment. However, the growth accounting framework did provide a consistent framework that defines the normal returns from ICT investment. Furthermore, the output elasticity of the other capital inputs and labour did not need to be estimated, but could be assumed equal to their cost share.

This leaves open the question why firm-level studies find positive spillovers whereas the industry estimates show neutral effects. A plausible explanation is that within an industry, some leading firms invest heavily in ICT and organizational change and reap the accompanying productivity gains. But there are also laggards with lower productivity growth. These laggards may have also invested heavily in ICT, but were less successful in realizing soft savings. Although in time these laggards are likely to either exit or catch-up due to competitive pressures, this inevitably takes time. In the meantime, industry performance will reflect both leading and lagging firm performance. To find out whether this explanation holds in practice, further firm-level research into these aggregation effects is needed.

The most relevant issue for policy is why Continental European countries are slower in realizing the effects from soft savings than the UK and the U.S. One possible line of argumentation is that the process of realizing soft savings involves much trial-and-error. It therefore requires an entrepreneurial environment and competitive labour and product markets that allow efficient firms to grow and weed out inefficient ICT users. There is substantial evidence from industry level studies on regulation (e.g., Nicoletti and Scarpetta, 2003) as well from firm-level studies on the dynamics of firm performance (e.g, Bartelsman, *et al.*, 2005) that confirm the need for a conducive regulatory environment to generate productivity growth. Many of the continental European institutions, in particular in the area of labour and product markets, inhibit the reallocation of resources to the most productive companies. The European economic environment creates too little room for good firms to excel and for failing firms to exit the market so as to free up resources for the much-needed transition. This may particularly affect investments in firm-specific resources, such as human and organizational capital, which unlike ICT are not easily transferred on markets and may stay for too long in firms that are not productive. This direct link between regulation and soft savings is an important area for further research.

Appendix 4.A ICT-production TFP

Section 4.2 presented estimates of ICT-production TFP. Similar estimates were also presented in Timmer *et al.* (2003), but a number of changes were made to the methodology. The main idea is to 'back-out' TFP growth that can be traced to ICT producing industries and is different from the 'bottom-up' industry approach from Section 4.5. The starting point is TFP growth of ICT producing industries in the United States. These growth rates are assumed to be equal across countries because there are few countries that account for quality changes as thoroughly as the U.S. Although a growing number of countries now use constant-quality (hedonic) prices for computers, few do so for telecommunications and semiconductor manufacturing.

The definition of ICT-production is limited here to the manufacturing of computers (ISIC 30), semiconductors (321) and telecommunications equipment (322). This definition is narrower than those used in Sections 4.3 and 4.5. Section 4.3 closely follows the OECD (2002) classification and also includes insulated wire and cable (ISIC 313), part of the instruments industry (331), telecommunication services (64) and computer services (72). The definition in Section 4.5 is coarser due to the limits of the capital data and covers the entire electrical and optical equipment industry (ISIC30-33) and telecommunications (64). The reason for choosing a more narrow definition is that U.S. TFP growth rates in those three industries are most likely to be applicable to other countries. For example, Inklaar *et al.* (2005) report large differences in TFP growth rates in telecommunications between the four European countries and the U.S. and similarly, there are considerable differences in labour productivity growth between countries in insulated wire and cable and instruments.

U.S. labour productivity growth in computers, semiconductors and telecom equipment is available from the GGDC (2005) 60-industry database. Capital deepening estimates are based on the 1997 Capital Flow Table, which provides investment by asset data for each of the three industries. Investment trends are only available at a more aggregate level. Next, TFP growth is changed from a value added-basis to gross output basis by multiplying by the value added to gross output ratio. This way, cross-country differences in the value added to gross output ratio can be taken into account.

Domar weights are used to estimate the contribution of ICT production to TFP growth in both the U.S. and the European countries. These weights are defined as industry gross output divided by aggregate value added and were originally suggested by Domar (1961). When summed across all industries, the weights will generally exceed one to account for the fact that TFP growth in any industry will also have effects on downstream industries through cheaper intermediate inputs. For the European countries, value added for each of the ICT industries is taken from the 60-industry database. Input-output tables, mostly from Eurostat, give data on value added to gross output ratios for a number of years in the late 1990s. For earlier and later years, these ratios are assumed to have remained constant. Multiplying value added and the value added to gross output ratios gives estimates of gross output for the ICT producing industries and this is used to calculate Domar weights.

Appendix 4.B Estimating TFP levels

In the literature on growth convergence, controlling for initial levels of GDP per capita or per hour worked is common practice (see e.g. Baumol, 1986). In these cases, only the relative price (PPP) of GDP is needed to make income or labour productivity comparable across countries. However, to estimate TFP levels, a correction also has to be made for differences in capital levels. Once those are available, TFP levels can be calculated in analogous fashion to TFP growth rates:

$$\log\left(\frac{A^X}{A^U}\right) = \log\left(\frac{Y^X}{Y^U}\right) - \bar{v}^L \log\left(\frac{L^X}{L^U}\right) - \left(1-\bar{v}^L\right)\log\left(\frac{K^X}{K^U}\right). \tag{4.B1}$$

In equation (4.B1), superscripts X and U denote the countries. Analogous to growth accounting, the relative TFP level can be calculated as the relative GDP level minus the weighted relative labour input level and relative capital input level (Caves, Christensen and Diewert, 1982).

GDP levels in U.S. dollars are available from the GGDC/TCB Total Economy Database (2005). Relative labour input is from the same source and calculated as the ratio of total hours worked. For comparisons of capital input across countries, we need an estimate of the rental price in one country relative to another, the so-called capital service PPP (PPP^K):

$$PPP^K_{k,m,j} = \frac{r_{k,j}}{r_{m,j}} = \frac{\left(R_{k,t} + \delta_j - \dot{p}_{k,j,t}\right)}{\left(R_{m,t} + \delta_j - \dot{p}_{m,j,t}\right)} PPP^I_{k.m,j}\,. \tag{4.B2}$$

Equation (4.B2) gives an expression for the rental price of asset j in countries k and m, using the same variables as in equation (4.10) (since the same depreciation rate are used across countries, no country subscript is attached). Most elements of equation (4.B2) are readily available, since these are inputs for the calculation of the gross rate of return. The only missing element is the investment PPP (PPP^I). Expenditure PPPs for 35 assets for 1999 from the OECD (2002a) are used here. The investment PPPs for the 35 assets are aggregated to investment PPPs for each of the six assets in this study using a multilateral (EKS) aggregation procedure. The resulting capital service PPPs are used to convert capital compensation to U.S. dollars. Summing over the assets gives total capital input in U.S. dollars for each country.

Appendix 4.C The reallocation effect

Although the reallocation effect is quantitatively less important for labour productivity growth than growth within industries, it provides useful insight into the impact of structural change. Recall from equation (4.5) that the reallocation effect is defined as follows:

(4.C1) $$R = \sum_i \overline{w}_i \Delta \ln H_i - \Delta \ln \sum_i H_i \ .$$

There is no exact decomposition of this expression into industry contributions, but the following approximation comes very close:[132]

(4.C2) $$R \approx \sum_i \overline{w}_i \Delta \ln H_i - \sum_i \overline{s}_i \Delta \ln H_i = \sum_i \left(\overline{w}_i - \overline{s}_i\right) \Delta \ln H_i \ .$$

In equation (4.C2), $\overline{s}_i$ denotes the two-period average employment share, $H_i \big/ \sum H_i$. In other words, the contribution of an industry to the aggregate reallocation of hours is determined by its growth in total hours worked and the difference between the industry output share and employment share. This difference is large when the industry labour productivity level is higher than the aggregate productivity level.

[132] The approximation is due to the substitution effect, whereby the employment shares of each industry change over time. The squared difference between the exact measure and the approximation is roughly 1000 times smaller than the standard deviation of the exact measure over time.

Figure 4.C1 Contributions by industry groups to market economy reallocation of hours, EU-15 and U.S., 1987-2003

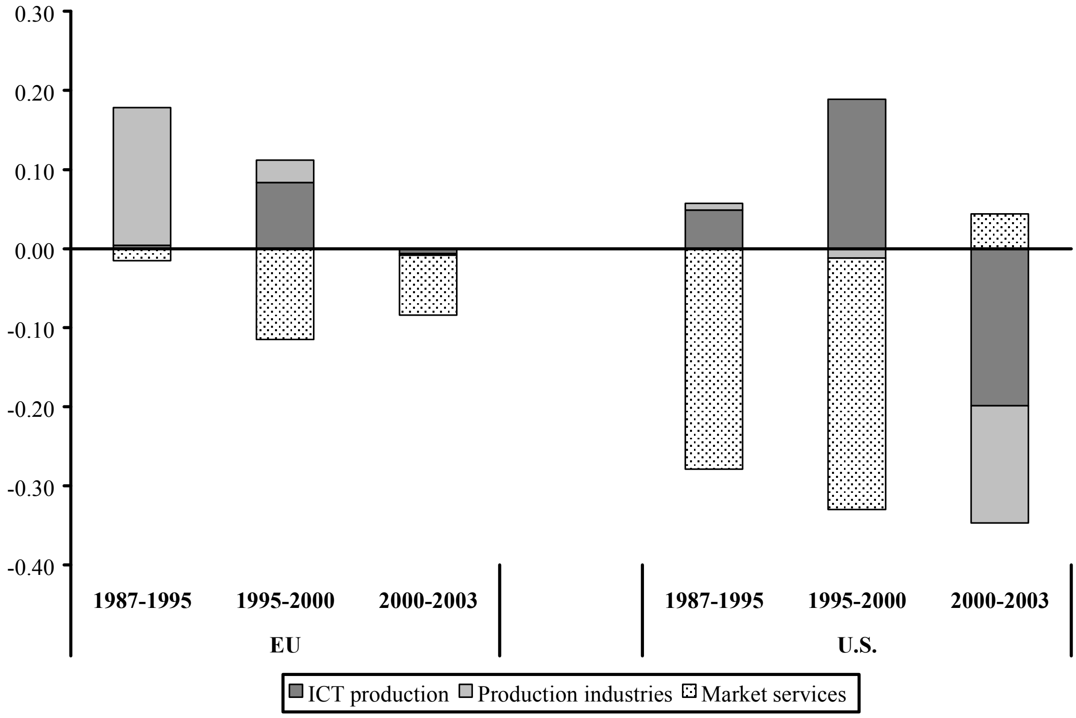


Figure 4.C1 shows the (approximate) industry contributions to the market economy reallocation effects by industry group. A first observation is that the size of the reallocation effects is larger in the U.S. than in the EU-15. The industry pattern is also different. In Europe, the production sector contributed positively to aggregate reallocation, and hence to labour productivity growth, while in the U.S., the main effects from this industry group are negative. Also interesting is that after 2000, market services contributed positively in the U.S., while in earlier periods the contribution was negative. In Europe, the contribution from market services was negative throughout the period.

First of all, these results suggest that the degree of structural change is much higher in the U.S. than in Europe. Indeed, when averaging the absolute reallocation contributions over the full period, U.S. reallocation is more than 40 percent higher than EU-15 reallocation. This does not seem implausible, judging by for example the lower degree of employment protection in the U.S. (Nicoletti, *et al.*, 2000). But to establish this, we would need to know whether this difference is due to larger employment changes at the industry level or possibly due to a greater dispersion in labour productivity levels. Although a similar decomposition as in the main text is possible, the resulting effects are hard to interpret.[133]

It makes more sense to find direct measures of productivity level dispersion and gross employment change. A measure for productivity level dispersion is the standard deviation of productivity levels relative to the aggregate. To avoid overstating the importance of small sectors, industries are weighted by their employment share. Gross employment change is measured here as the absolute growth of total hours worked, again weighted using industry employment shares.[134] Table 4.C1 shows these two summary measures for the EU-15 and U.S. There is no large difference in the dispersion of productivity levels, but the difference in gross employment change is substantial. This suggests that the difference in the size of the reallocation effects can be traced to larger employment flows.

Table 4.C1 Summary measures of productivity level dispersion and gross employment change, EU-15 and U.S., 1987-2003

	1987-1995	1995-2000	2000-2003
Labour productivity dispersion			
EU-15	0.32	0.36	0.38
U.S.	0.32	0.37	0.41
Gross employment change			
EU-15	2.46	2.20	1.51
U.S.	3.04	3.08	2.56

Note: Labour productivity dispersion is defined as the standard deviation of labour productivity levels relative to the aggregate, weighted by employment share. Gross employment change is defined as the absolute growth in total hours worked, weighted by employment share.

This leaves the different industry pattern of the reallocations to be explained. As discussed above, the most notable differences can be seen between 2000 and 2003. However, given that the post-2000 period includes a recession in the U.S. and slow growth in Europe too, this finding should not be overstated. The negative contribution from market services for most of the period can, to an important extent, be traced to non-professional business services in both Europe and the U.S. In the U.S., this can be

[133] See also van Ark, *et al.* (2003a).
[134] At the industry level, only the net change in employment is available, so this measure understates true gross job flows.

further traced to strong employment growth of employment agencies.[135] After 2000, U.S. employment in this industry declined by about 5 percent per year. However, as persons employed by employment agencies work in other parts of the economy, it is hard to give an economic interpretation to developments after 2000. The most that can be said is that a notable part of the reallocation term is probably due to an increased importance of employment agencies to increase labour input flexibility.

[135] In Europe, this information is usually not available, although for the Netherlands, similar observations can be made.