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THE ECONOMIC IMPACTS OF ICT – A EUROPEAN PERSPECTIVE

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1. Introduction

Information and communications technology (ICT) has proven to be the key technology of the past decade. The widespread diffusion of the Internet, of mobile telephony and of broadband networks all demonstrate how pervasive this technology has become. But how precisely does ICT affect economic growth and the efficiency of firms? How important is its contribution? And what are the conditions under which ICT can become a technology that is effective in enhancing growth and productivity? Why have some countries and regions thus far benefited more from ICT than others? To what extent do measurement issues still pose a problem in quantifying the impacts of ICT? What have we learned thus far about these questions and what are some of the puzzles that still need to be resolved?

Despite the downturn of the economy over the past few years and the passing of the Internet bubble, these questions remain important to academics and policy makers. This is because ICT has become a fact of economic life in all OECD economies. Almost all firms now use computers and most of them have an Internet connection. Moreover, a large share of these firms use computer networks for economic purposes, such as the buying, selling and outsourcing of goods and services. But despite the widespread diffusion of ICT, questions remain about the impact of the technology on economic performance. Thus far, only few countries, including Australia, Canada and the United States, have clearly seen an upsurge in productivity growth in those sectors of the economy that have invested most in the technology, notably services sectors such as wholesale trade, financial services and business services. In many countries, including much of the European Union, these impacts have yet to materialise. Improving the understanding of the ways in which ICT affects economic performance and the factors that influence the potential impacts of ICT thus remains important.

In empirical analysis of economic growth, three effects of ICT are typically distinguished. First, investment in ICT contributes to capital deepening and therefore helps raise labour productivity. Second, rapid technological progress in the production of ICT goods and services may contribute to growth in the efficiency of capital and labour, or multifactor productivity (MFP), in the ICT-producing sector. And third, greater use of ICT throughout the economy may help firms increase their overall efficiency, thus raising MFP. Moreover, greater use of ICT may contribute to network effects, such as lower transaction costs and more rapid innovation, which should also improve MFP.

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These impacts can be examined at different levels of analysis, *i.e.* with macro-economic data, with industry data or with data at the level of individual firms or establishments. Several studies have already examined the impact of ICT at the macro-economic level (*e.g.* Colecchia and Schreyer, 2001; Van Ark, *et al.*, 2003; Jorgenson, 2003; Schreyer, *et al.* 2003). These studies show that ICT investment contributed to capital deepening and growth in most OECD countries in the 1990s, though with considerable variation across countries.[3]

Several studies have also been undertaken at the industry level (Van Ark, *et al.*, 2002; Pilat, *et al.*, 2002; O'Mahony and Van Ark, 2003; Inklaar, *et al.*, 2003; Pilat and Wölfl, 2004). These show that the ICT-producing manufacturing sector contributed substantially to labour productivity and MFP growth in certain OECD countries such as Finland, Ireland and Korea, and that the United States benefited more from the ICT-producing manufacturing sector than the European Union (O'Mahony and Van Ark, 2003). They also showed that ICT-using services in the United States and Australia experienced an increase in productivity growth in the second half of the 1990s, which seems partially associated with their use of ICT.[4] Few other countries have thus far experienced similar productivity gains in ICT-using services (OECD, 2003*a*). Moreover, most studies show that the European Union lags behind the United States in experiencing an increase in productivity growth in ICT-using services (O'Mahony and Van Ark, 2003; OECD, 2004).

The aggregate and industry-level evidence provides helpful insights in the impacts of ICT on productivity, but also raises new questions, notably as regards the conditions under which ICT investment becomes effective in enhancing productivity.[5] Moreover, the aggregate and industry-level evidence points to very limited productivity impacts of ICT in many countries, despite substantial investment in ICT. Firm-level data may help in understanding why investment in ICT has not yet led to greater productivity impacts, as it can point to factors influencing the impacts of ICT that can not be observed at the aggregate level, *e.g.* organisational factors or the availability of skills.[6] Firm-level data can also point to dynamic and competitive effects that may accompany the spread of ICT, such as the entry of new firms, the exit of firms that failed, and changes in market share of existing firms. Confronting firm-level and more aggregate evidence may thus enhance our understanding of the ways in which ICT affects productivity and can contribute to solving some of the questions that still surround the impacts of ICT on productivity.

Firm-level evidence on the uptake of ICT is now available for many OECD countries. This is because over the past years, much progress has been made in developing statistics on the use of various ICT technologies in the economy (OECD, 2002).[7] Most OECD countries now collect information at the

3 . A large number of studies of ICT investment and impacts at the industry level are also available at the national level. These are not examined here; several are summarised in OECD (2003*a*).

4 . Gretton, *et al.* (2004) discuss the evidence for Australia in more detail, whereas Bosworth and Triplett (2003) provide a detailed account of the industry-level evidence for the United States.

5 . The impacts of ICT on productivity can refer to both labour and multi-factor productivity, as discussed above. The literature examines both, as does this paper. Where relevant, a distinction is made in the text.

6 . This section provides references to some of the available firm-level studies. The OECD work has benefited from close co-operation with researchers in 13 countries that were involved in the work with firm-level data. More detail on their work and other firm-level studies is available in OECD (2003*a*) and OECD (2004).

7 . Progress in this area owes much to the efforts of the OECD Working Party on Indicators for the Information Society, a group that was established in 1999 to develop and improve statistics on the information society.

firm level on ICT investment or the uptake of specific technologies. In addition, many countries have developed databases that provide detailed and comprehensive data on the performance of individual firms. Combining these sources can help establish a link between firm performance and their use of ICT. Moreover, providing that these databases cover a large proportion of the economy, or are sufficiently representative for overall performance, they may help link the performance of individual firms to that of the economy as a whole.[8]

This paper summarises some of the findings on the impacts of ICT, and examines results from aggregate, sectoral and firm-level studies, focusing on the experience of different OECD regions, including Europe, Japan and the United States. It does not provide a full overview of the literature, however, and mainly focuses on work that was carried out in the context of a recent OECD project on ICT and economic growth (OECD, 2003*a*, 2004). It also primarily focuses on the impacts of ICT on growth and productivity, partly since these are particularly hard to measure; it does not discuss other economic impacts of ICT, such as effects on wages, employment or trade. The next section briefly examines overall growth patterns in the OECD area, to set the scene for a more detailed analysis of ICT. The third section examines some of the evidence on the economic impacts of ICT at the aggregate and industry level. The fourth section examines the firm-level evidence, while the penultimate section of the paper returns to a key theme of the paper, namely why the spread of ICT may not yet have lead to clear evidence of higher productivity growth in many OECD countries, including much of the European Union, and also why firm-level evidence may lead to different findings from evidence extracted at a more aggregate level. A short final section concludes.

2. Growth patterns in the OECD area

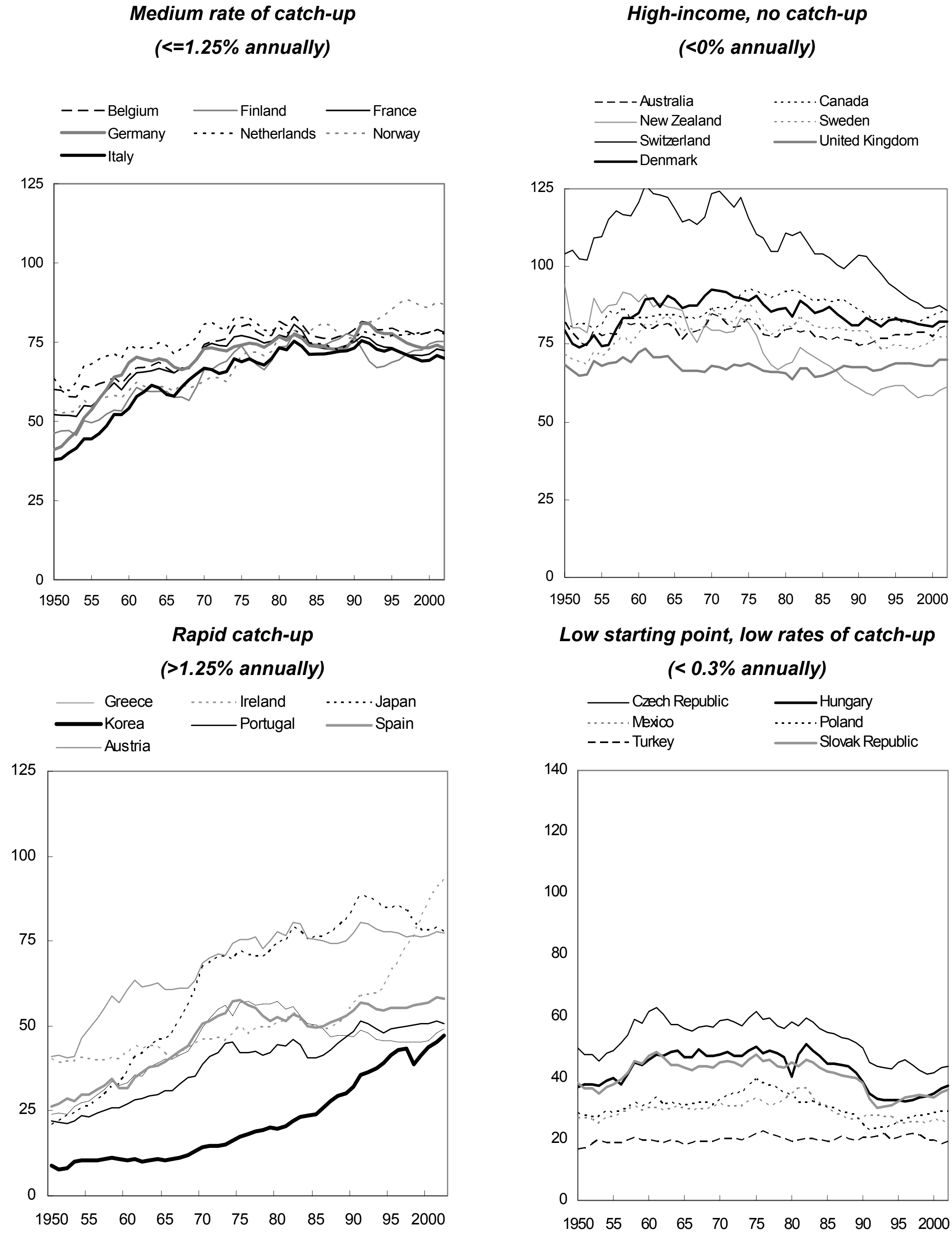
2.1 Growth diverged in the OECD area

The interest of many OECD countries in economic growth over the past years was linked to the strong performance of the United States over the second half of the 1990s and the reversal of the catch-up pattern that had characterised the OECD area over the 1950s and the 1960s. During much of the early post-war period, most OECD countries grew rapidly as they recovered from the war and applied US technology and knowledge to upgrade their economies. For most OECD countries, this catch-up period came to a halt in the 1970s; average growth rates of GDP per capita over the 1973-92 period for much of the OECD area were only half that of the preceding period, and many OECD countries no longer grew faster than the United States (Maddison, 2001).

During the 1990s, a different pattern emerged. Even though the United States already had the highest level of GDP per capita in the OECD area at the beginning of the decade, it expanded its lead on many of the other major OECD countries during the second half of the 1990s. A few other OECD countries, including Australia, Canada, Finland, Greece, Ireland, Portugal and Sweden, also registered markedly stronger growth of GDP per capita over the 1995-2002 period compared with the 1980-1995 period (OECD, 2003*b*; De Serres, 2003). Some of these countries continued to catch up with the United States in the second half of the 1990s. In contrast, the increase in GDP per capita in several other OECD countries, including Japan, Germany and Italy, slowed sharply over the second half of the 1990s, leading to a divergence with the United States (Figure 1).

8 . Although aggregation across industries or firms does not have to lead to consistent findings between aggregate and disaggregated results (Fox, 2004).

Figure 1: **Catch-up and convergence in OECD income levels, 1950-2002, United States = 100**



Source: OECD (2003*c*), Science, Technology and Industry Scoreboard 2003, OECD, Paris.

Even though US growth performance is no longer considered to be as exceptional as was claimed during the "new economy" hype, its strong performance over the second half of the 1990s has increased interest in the analysis of economic growth and the sources of growth differentials across countries. The OECD work suggests that the divergence in growth performance in the OECD area is not due to only one cause, but that it reflects a wide range of factors. These are discussed below in more detail. Differences in the measurement of growth and productivity might also be contributing to the observed variation in performance. A recent OECD study (Ahmad, *et al*, 2003) suggest that such differences do play a role, but that they probably only account for a small part of the variation in growth performance. To reduce the uncertainty of empirical analysis related to the choice of data, OECD has developed a new Productivity Database, which is used in this paper (Box 1). This database is still under development and further methodological adjustments to enhance comparability of productivity estimates will be incorporated in due course.

Box 1. **The OECD Productivity Database**

Productivity comparisons constitute an important focus of OECD work. It includes both efforts to improve the measurement of productivity growth, and efforts to improve the understanding of the drivers of productivity performance and the policies that governments could undertake to strengthen productivity performance. Such analysis reflects a strong interest in many OECD Member countries. The OECD Productivity Database aims at meeting the demand of inside and outside users of OECD statistics by bringing together those series that are judged best suited for productivity analysis. Where possible, data has been complemented with methodological information to facilitate an assessment of its quality and its international comparability.

The productivity database has been developed in co-operation between several parts of the organization to streamline efforts and to bring together relevant expertise. At this point, and concerning measures of *productivity growth*, the database comprises the following series: (i) Measures of output growth (GDP); (ii) labour input growth (index of total hours worked); (iii) labour productivity growth (index of GDP per hour worked); (iv) capital services growth; (v) growth of combined labour and capital inputs; (vi) cost shares of inputs; (vi) multi-factor productivity growth.

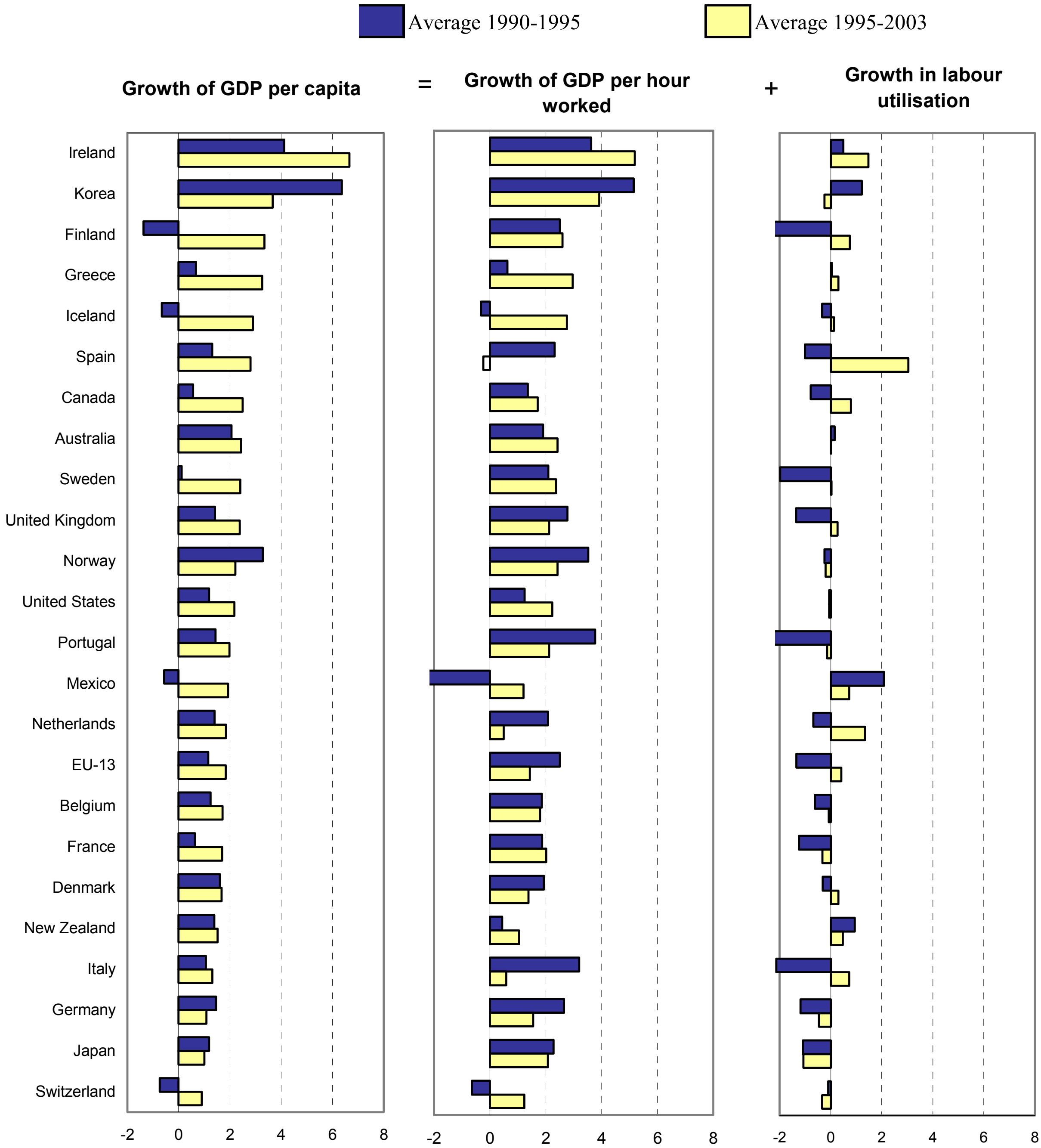
Presently, these data are only available at the level of the total economy. Estimates for the business sector are under development, but these are faced with large-cross country differences in the roles of the market and non-market sector across OECD economies and with data constraints, notably for the estimation of capital services. The productivity estimates for the total economy cover about 28 countries for measures of labour productivity and about 18 OECD countries, including the G7 countries, for capital services and multi-factor productivity. The data for labour productivity typically cover the period 1970-2002, whereas those for capital services and MFP are available for the period 1985-2002 (or the latest year available).

The Productivity database can be accessed from the Statistics Portal of the OECD web pages (http://www.oecd.org/statistics/productivity/). More methodological detail is also available there.

2.2 Labour utilisation plays a key role

The first factor affecting growth differences concerns labour utilisation (Figure 2). In the first half of the 1990s, most OECD countries, in particular many European countries were characterised by a combination of high labour productivity growth and declining labour utilisation. The high productivity growth of these EU countries may thus have been achieved by a greater use of capital or by dismissing (or not employing) low-productivity workers. In contrast, the United States, Australia, Ireland, New Zealand and the Netherlands experienced a combination of productivity growth and stable or growing labour utilisation. In the second half of the 1990s, many European countries improved their performance in terms of labour utilisation, as unemployment rates fell and labour participation increased. However, this was accompanied by a sharp decline in labour productivity growth. In contrast, some other OECD countries, such as Canada, Ireland and the United States experienced a pick-up in both labour utilisation and labour productivity growth from 1990-95 to 1995-2003, showing that there need not be a trade-off between labour productivity growth and increased use of labour.

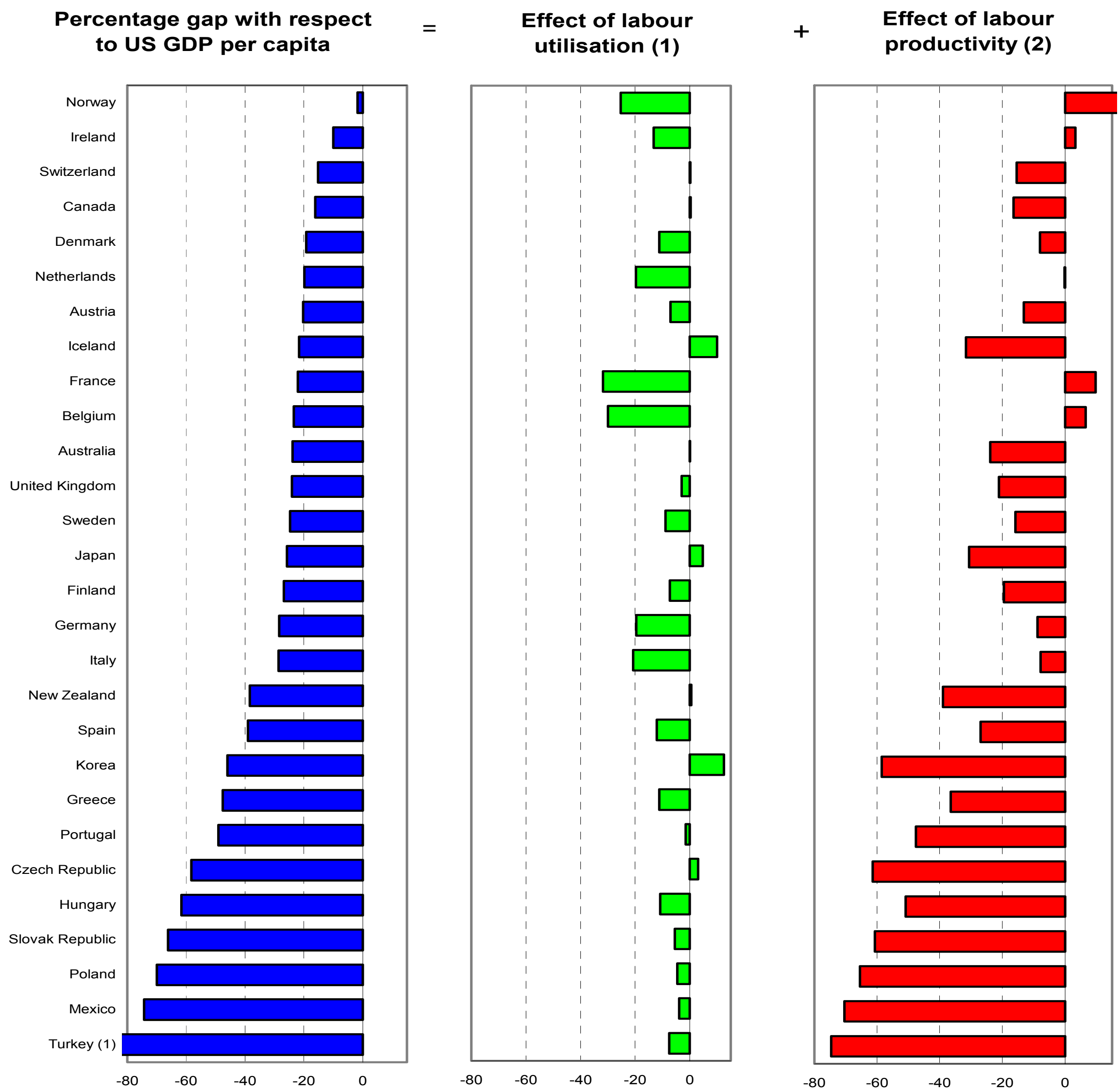
Figure 2: **Changes in labour utilisation contribute to growth in GDP per capita**
Percentage change at annual rates, 1990-95 and 1995-2003



EU-13: Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden and the United Kingdom.
Source: OECD, Productivity Database, September 2004, see De Serres (2003) for cyclically adjusted estimates.

Achieving a combination of labour productivity growth and growing labour utilisation requires well-functioning labour markets that permit and enable reallocation of workers. This is particularly important during times of rapid technological change. Labour market institutions have to ensure that affected workers are given the support and the incentives they need to find new jobs and possibly to retrain. In many countries, institutions and regulations hinder the mobility of workers and prevent the rapid and efficient reallocation of labour resources (OECD, 1999). In most of the countries characterised by a combination of increased labour utilisation and labour productivity, reforms over the 1980s and 1990s improved the functioning of labour markets, effectively enabling more rapid growth. Despite the progress in enhancing labour utilisation that has been made in many OECD countries over the 1990s, further improvements will be needed, in particular as the population in many OECD countries is ageing rapidly. Moreover, for several OECD countries, notably many European countries, there is still a large scope for improvement in labour utilisation, as it accounts for the bulk of the gap in GDP per capita with the United States (Figure 3).

Figure 3: **Income and productivity levels, 2002**
Percentage point differences with respect to the United States



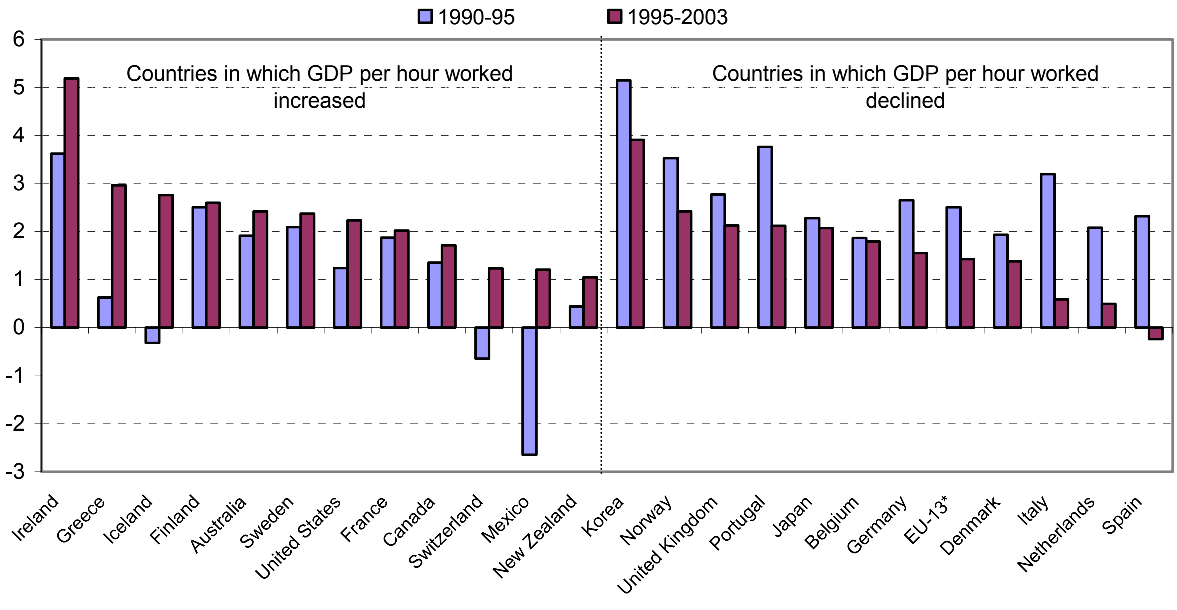
1. Based on hours worked per capita.
2. GDP per hour worked.
3. GDP estimates for Turkey are based on the 1968 System of National Accounts (SNA).
Source: OECD estimates, September 2004. See www.oecd.org/statistics/productivity for methodological details.

A range of policies may be beneficial to increase labour utilisation, and should not just focus on reducing unemployment, but also on increasing participation in the labour force, notably from women and older workers (De Serres, 2003; OECD, 2003*d*). The key influences on labour utilisation include tax and benefit systems as well as regulations in labour and product markets (OECD, 2003*e*). Reform in these areas may help enhance both the incentives for firms to hire workers and for would-be workers to take up work. Efforts to enhance labour utilisation should also include policies to make work pay. For example, schemes under which in-work benefits such as tax reductions are conditional on employment, or where employers are exempt from social security charges if they hire low-skilled workers have been effective when properly targeted (OECD, 2003*d*). It is also important to increase the opportunities for women to participate in the labour market, for example by enhancing access to child-care facilities and enabling greater flexibility in working time for family workers. Improving prospects for older workers will also require a range of measures, including the removal of incentives for early retirement.

2.3 Labour productivity

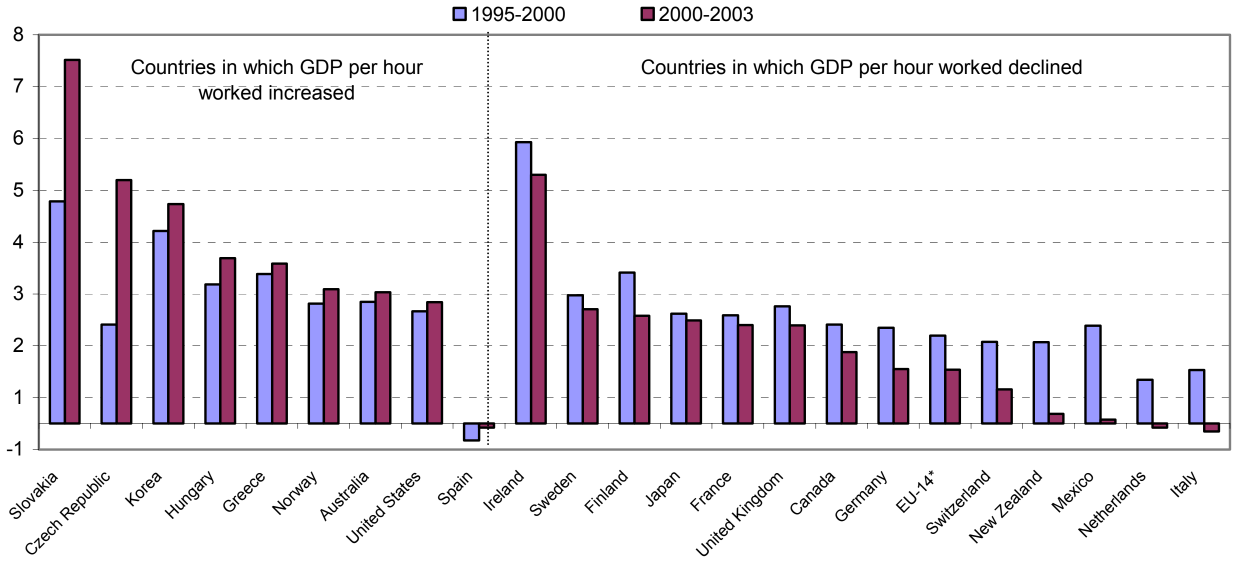
Labour productivity is the other main driver of GDP per capita shown in Figure 2. It is also the key determinant of the gap in income levels between the United States and other OECD countries (Figure 3). As shown above, labour productivity growth accelerated in a number of OECD countries in the second half of the 1990s; including Australia, Canada, Greece, Ireland and the United States (Figure 4). In contrast, it declined in a large number of other OECD countries. With the slowdown of the world economy since 2000, most OECD countries have experienced a marked slowdown in labour productivity growth, Australia, Korea, the United States and some small European countries being the main exceptions (Figure 5).

Figure 4: **Growth in GDP per hour worked, 1990-95 and 1995-2003**
(annual compound growth rates, in per cent)



Source: OECD, Productivity Database, September 2004.

Figure 5: **Growth in GDP per hour worked, 1995-2000 and 2000-2003**
(annual compound growth rates, in per cent)

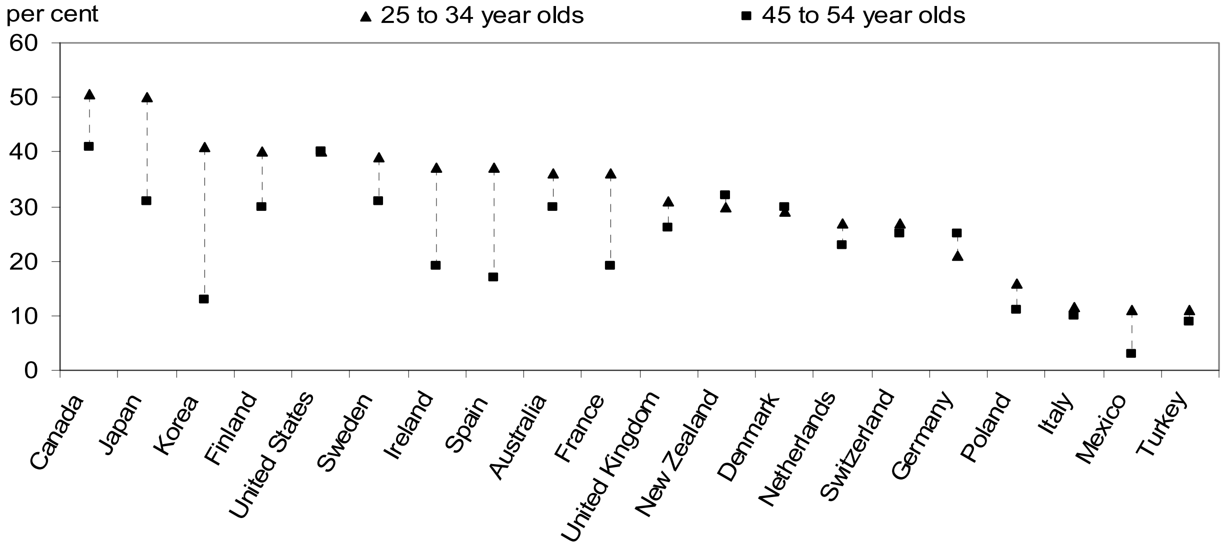


Source: OECD, Productivity Database, September 2004.

2.4 The impact of human capital

Labour productivity growth can be increased in several ways: by improving the composition of labour used in the production process, increasing the use of capital and improving its quality, and attaining higher multi factor productivity (MFP). The composition of labour is the first of these, and plays a key role in labour productivity growth. This is partly because in all OECD countries, educational policies have ensured that young entrants on the jobs market are better educated and trained on average than those who are retiring from it. For example, in most OECD countries, more 25-34 year olds have attained tertiary education than 45 to 54 year olds (Figure 6).

Figure 6: **Percentage of the population that has attained tertiary level education, 2002**
(percentage points)



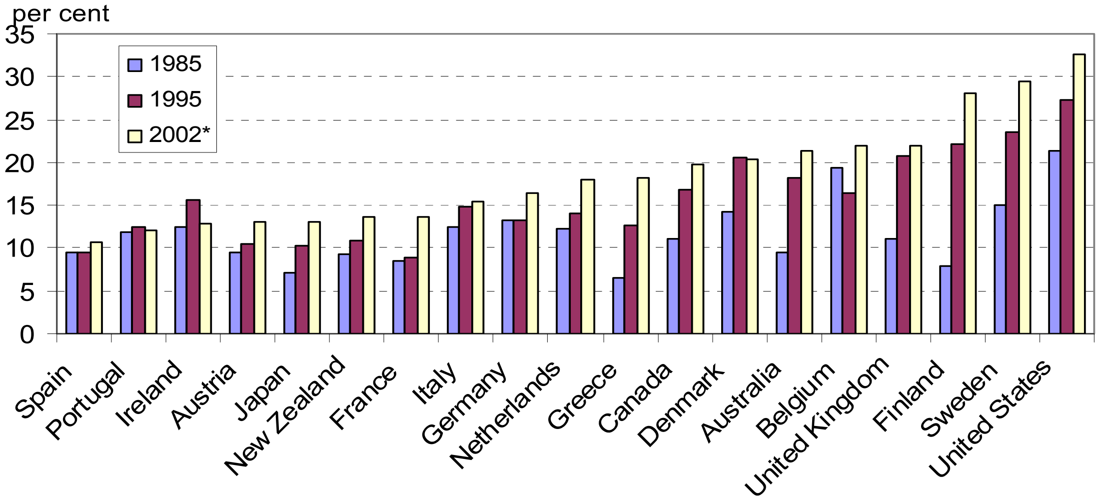
Source: OECD, Education at a Glance, 2004.

The available empirical evidence suggests that improvements in labour composition have directly contributed to labour productivity growth in virtually all OECD countries (Bassanini and Scarpetta, 2001; Jorgenson, 2003). The OECD Productivity Database does not yet include estimates of labour composition, although their inclusion is planned for the future. Estimates of labour composition for the G7 countries are included in a recent study by Prof. Dale Jorgenson, however (Jorgenson, 2003; Colecchia, forthcoming). These suggest that the contribution of labour composition to labour productivity growth has declined in most G7 countries over the second half of the 1990s, Italy being the only exception. This can partly be attributed to the large number of low-skilled workers that were integrated in the labour force in several OECD countries over the second half of the 1990s. Moreover, the contribution of labour composition has also declined over time since the gap in education levels between cohorts of new and retiring workers has become smaller over time. Growth accounting estimates, such as those presented by Prof. Jorgenson, point to the important contribution of human capital to economic growth. They typically only take account of changes in educational attainment, however; increases in the level of post-educational skills may also help enhance labour composition, but few hard measures are available.

2.5 The role of investment in fixed capital

Investment in physical capital is the second factor that plays an important role in labour productivity growth. Capital deepening expands and renews the existing capital stock and enables new technologies to enter the production process. While some countries have experienced an overall increase in the contribution of capital to growth over the past decade, ICT has typically been the most dynamic area of investment. This reflects rapid technological progress and strong competitive pressure in the production of ICT goods and services and a consequent steep decline in prices (Jorgenson, 2001). This fall, together with the growing scope for application of ICT (including the impact of Y2K), has encouraged investment in ICT, at times shifting investment away from other assets. The available data show that ICT investment rose from less than 15 per cent of total non-residential investment in the business sector in the early 1980s, to between 15 and 30 per cent in 2002 (OECD, 2003*a*; Figure 7).

Figure 7. **ICT investment in selected OECD countries, 1985-2002**
(As a percentage of non-residential gross fixed capital formation, total economy)



* 2002 for Australia, Canada, France, Germany, Japan, New Zealand and the United States, 2001 for other countries.

Note: Estimates of ICT investment are not yet fully standardised across countries, mainly due to differences in the capitalisation of software in different countries. See Ahmad (2003).

Source: OECD, Database on capital services, September 2004.

Growth accounting estimates show that the pace of investment and its impact on growth differed widely (see Box 2 for methodological details). For the G7 countries and Australia, ICT investment accounted for between 0.3 and 0.85 percentage points of growth in GDP per capita over the 1995-2002 period (Table 1).[9] The United States and the United Kingdom received the largest boost; Australia, Canada and Japan a sizeable one; and Germany, France and Italy a much smaller one (OECD, 2003*a*).[10]

In some OECD countries, *e.g.* Australia, France, Germany and Japan, the growing contribution of ICT capital was accompanied by a decline in the contribution of non-ICT capital (Table 1). In these countries, ICT investment partly substituted for investment in other assets. In the United Kingdom and the United States, on the other hand, capital deepening in the 1990s was a broad phenomenon as the contribution of non-ICT capital increased too. For France, Germany and Japan, the declining contribution of non-ICT capital has been attributed to weaknesses in domestic demand (Jorgenson, 2003).

Box 2: **Capital input in the OECD Productivity Database**

The appropriate measure for capital input within the growth accounting framework is the flow of productive services that can be drawn from the cumulative stock of past investments in capital assets (see OECD, 2001*a*). These services are approximated by the rate of change of the 'productive capital stock' – a measure that takes account of wear and tear, retirements and other sources of reduction of the productive capacity of fixed assets. Flows of productive services of an office building, for instance, are the protection against rain or the comfort and storage services that the building provides to personnel during a given period (Schreyer *et al.*, 2003). The price of capital services per asset is measured as their rental price. If there are markets for capital services, as is the case for office buildings, for instance, rental prices could be directly observed. For most assets, however, rental prices have to be imputed. The implicit rent that capital good owners 'pay' themselves contributes to the terminology 'user costs of capital'.

Capital input (S) is measured as the volume of capital services, assumed to be in a fixed proportion to the productive capital stock (see Schreyer, *et al.*, 2003 for a more extensive explanation and for details of the computation of capital services). The productivity database publishes capital services data with calculations based on the perpetual inventory method (PIM) The PIM calculations are carried out by OECD, using service lives for different assets that are common across countries and correcting for differences in deflators for information and communication technology assets. Sources for the investment series by type of asset underlying the capital services series are national statistical offices[11] and the *Groningen Growth and Development Centre Total Economy Growth Accounting Database*[12] (http://www.ggdc.net).

9 . These estimates are based on official data on ICT investment from individual countries' national accounts. They are based on a harmonised deflator for ICT investment, which adjusts for cross-country differences in the measurement of ICT prices (see Colecchia and Schreyer, 2001 and Schreyer, *et al.* 2003). Methodological differences in the measurement of software investment may affect the results, however (Ahmad, 2003), and are particularly likely to affect the results for Japan and the United Kingdom.

10 . A recent study by Jorgenson and Motohashi (2004) shows that the modest contribution of ICT investment in Japan is linked to the underestimation of software investment in Japan's official statistics. Adjusting for this underestimation leads to a much more sizeable contribution of ICT investment in Japan, comparable to that of the leading OECD countries in this area.

11 For Australia, Canada, France, Japan, Italy, Germany, New Zealand, United States.

12 For Austria, Belgium, Denmark, Finland, Greece, Ireland, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Table 1: **Contributions of growth to GDP, 1990-95 and 1995-2002**[1]
In percentage points, based on cost shares and harmonised hedonic prices

	Australia	Canada	France	Germany	Italy	Japan	United Kingdom	United States
1990-95								
Labour input	0.82%	0.27%	-0.54%	-0.71%	-1.39%	-0.55%	-0.79%	0.88%
ICT capital, of which	0.36%	0.33%	0.13%	0.26%	0.13%	0.31%	0.38%	0.51%
ICT hardware	*0.22%*	*0.17%*	*0.07%*	*0.16%*	*0.08%*	*0.21%*	*0.22%*	*0.25%*
Software	*0.11%*	*0.11%*	*0.03%*	*0.05%*	*0.00%*	*0.06%*	*0.14%*	*0.18%*
Communications equipment	*0.03%*	*0.05%*	*0.03%*	*0.05%*	*0.05%*	*0.04%*	*0.03%*	*0.08%*
Non-ICT capital	0.26%	0.63%	0.69%	0.65%	0.58%	0.92%	0.59%	0.22%
MFP	1.76%	0.47%	0.77%	1.09%	1.94%	0.82%	1.46%	0.75%
GDP growth	3.20%	1.70%	1.06%	1.29%	1.26%	1.50%	1.65%	2.36%
1995-2002[1]								
Labour input	0.79%	1.40%	0.23%	-0.16%	0.67%	-0.67%	0.61%	0.92%
ICT capital, of which	0.61%	0.60%	0.31%	0.36%	0.43%	0.52%	0.72%	0.84%
ICT hardware	*0.39%*	*0.37%*	*0.15%*	*0.25%*	*0.22%*	*0.34%*	*0.47%*	*0.43%*
Software	*0.14%*	*0.15%*	*0.11%*	*0.07%*	*0.10%*	*0.11%*	*0.17%*	*0.26%*
Communications equipment	*0.08%*	*0.08%*	*0.05%*	*0.04%*	*0.11%*	*0.07%*	*0.08%*	*0.15%*
Non-ICT capital	0.17%	0.61%	0.46%	0.46%	0.63%	0.55%	0.61%	0.36%
MFP	2.07%	1.03%	1.35%	0.76%	0.14%	0.60%	0.99%	1.11%
GDP growth	3.64%	3.64%	2.36%	1.42%	1.88%	1.00%	2.92%	3.22%
Change 1990-95 to 1995-2002[1]								
Labour input	-0.03%	1.13%	0.77%	0.54%	2.06%	-0.13%	1.39%	0.04%
ICT capital, of which	0.25%	0.27%	0.18%	0.11%	0.29%	0.21%	0.34%	0.33%
ICT hardware	*0.18%*	*0.21%*	*0.08%*	*0.09%*	*0.14%*	*0.13%*	*0.26%*	*0.18%*
Software	*0.03%*	*0.03%*	*0.08%*	*0.02%*	*0.09%*	*0.05%*	*0.03%*	*0.08%*
Communications equipment	*0.05%*	*0.03%*	*0.02%*	*-0.01%*	*0.06%*	*0.03%*	*0.05%*	*0.06%*
Non-ICT capital	-0.09%	-0.02%	-0.23%	-0.19%	0.05%	-0.37%	0.01%	0.14%
MFP	0.31%	0.56%	0.58%	-0.33%	-1.80%	-0.22%	-0.47%	0.35%
GDP growth	0.44%	1.94%	1.30%	0.13%	0.61%	-0.50%	1.27%	0.86%

(1) Or latest available year, i.e. 2001 for Italy and the United Kingdom.
Source: OECD, Productivity Database and Database on Capital Services, September 2004.

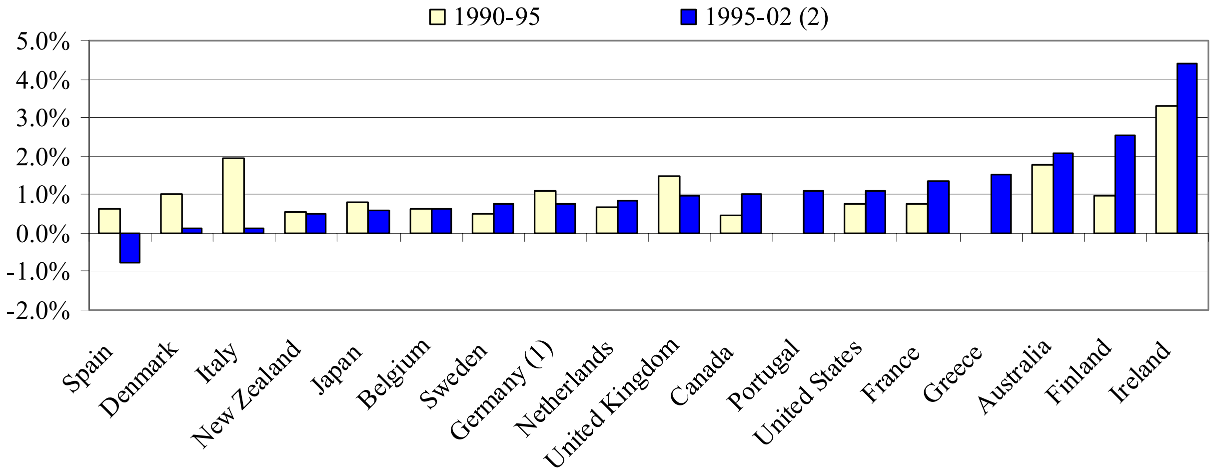
The strength of investment in ICT and non-ICT capital in several OECD economies primarily relies on good fundamentals. Stable macroeconomic policies are critical. Evidence for a wide range of OECD countries shows that fiscal discipline, low inflation rates and the reduction in the variability of inflation over the 1990s have helped to boost national savings, reducing uncertainty and enhancing the efficiency of the price mechanisms in allocating resources (OECD, 2001*b*). This has resulted in an improved environment for decision making and has unleashed resources for private investment.

At the same time, the way public finances are improved influences growth. In particular, government is a direct investor in the economy. Although the volume of this investment may be small compared with that of the private sector, it can be a crucial importance. For example, public investment in R&D, transport, communication and infrastructure, to the extent it is of high quality and generates high economic and social returns, can help to create an environment conducive to entrepreneurship, innovation and private sector activity. Similarly, efficient government spending on education should improve the stock of human capital. The pursuit of fiscal consolidation will remain a priority in many OECD countries, particularly in view of population ageing, but neglecting public spending in high-return physical and human capital investments can lead to negative economic effects in the medium-term. Investment in these areas should thus be given due consideration in public budgets.

2.6. The pick-up in MFP growth

The final component that accounts for some of the pick-up in labour productivity growth in the 1990s in certain OECD countries is the acceleration in multi factor productivity (MFP) growth (Figure 8). MFP growth rose particularly in Australia, Canada, Finland, France, Greece, Ireland, and the United States. In other countries, including Germany, Italy, Japan, the United Kingdom, Denmark and Spain, MFP growth slowed down over the 1990s.[13]

Figure 8: **MFP growth, 1990-95 and 1995-2002[2]**
Total economy, in percentage points



(1) 1992-1995 instead of 1990-95. (2) Or latest available year, i.e. 2001 for Spain, Denmark, Italy, Belgium, Sweden, United Kingdom, Netherlands, Portugal, Greece, Finland and Ireland.
Source: OECD Productivity Database, September 2004.

The improvement in MFP in some countries reflects a break with slow MFP growth in the 1970s and 1980s and may be due to several sources. Better skills and better technology may have caused the blend of labour and capital to produce more efficiently, organisational and managerial changes may have helped to improve operations, and innovation may have led to more valuable output being produced with a given combination of capital and labour. ICT-induced changes may be among these factors and its impacts are discussed in the following sections in more detail.

3. The impacts of ICT at the aggregate level

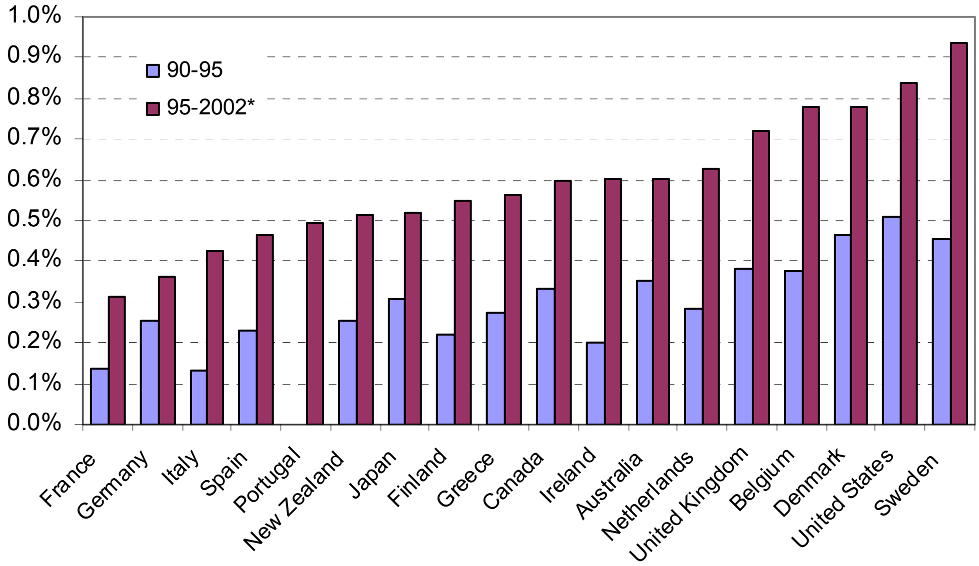
3.1 The role of ICT capital

The role of ICT investment has primarily been examined at the macroeconomic level, *e.g.* by Jorgenson (2001), Colecchia and Schreyer (2001), Van Ark, *et al.* (2002), Schreyer, *et al.* (2003) and Jorgenson (2003). All of these studies and the estimates presented in Table 1 show that ICT has been a very dynamic area of investment, due to the steep decline in ICT prices over the past decades which has encouraged investment in ICT, at times shifting investment away from other assets. Growth

13 . The MFP estimates in Figure 8 are not adjusted for labour quality. Moreover, for some countries, software investment may be underestimated (Ahmad, 2003). Adjusting for both factors would lead to a smaller contribution of MFP to total GDP growth in OECD countries.

accounting estimates show that ICT investment typically accounted for between 0.3 and 0.9 percentage points of growth in GDP per capita over the 1995-2002 period (Figure 9). Sweden, the United States, Denmark, Belgium and the United Kingdom received the largest boost; Japan a more modest one,[14] and Germany, France and Italy a much smaller one.[15]

Figure 9: **The contribution of investment in ICT capital to GDP growth**
Percentage points contribution to annual average GDP growth, total economy



Note: * 1995-2002 for Australia, Canada, France, Germany, Japan, New Zealand and the United States, 1995-2001 for other countries.
Source: OECD estimates based on Database on Capital Services, September 2004. See Schreyer, et al. (2003).

The measurement of the economic impacts of ICT investment is relatively straightforward and has been outlined in detail in Colecchia and Schreyer (2001) and Schreyer, *et al.* (2003). It is based on growth accounting, which involves the estimation of the productive capital stock, followed by the estimation of the capital services flowing from that stock (Box 2). The method can be applied at both the macro-economic and industry level, providing the appropriate data are available.[16] One important element in this respect is having the appropriate deflators for ICT investment that adjust for quality change, i.e. so-called hedonic deflators. France and the United States, for example, use such deflators for computer equipment: these deflators adjust prices for key quality changes induced by technological progress, like higher processing speed and greater disk capacity. They tend to show faster declines in computer prices than conventional price indexes. As a result, countries that use hedonic indexes are likely to record faster real growth in investment and production of information and communications technology (ICT) than countries that do not use them. This faster real growth will translate into a

14 . Though measurement problems for Japan may underestimate the role of ICT investment, see Jorgenson and Motohashi (2004).

15 . The estimates in Figure 9 differ from those released in prior OECD work (notably Colecchia and Schreyer, 2001), due to data revisions in OECD countries, updates to the series, the change from estimates for the business sector to those for the economy as a whole, as well as some minor methodological changes that are discussed in Schreyer, *et al.* (2003).

16 . Some studies have also examined the role of ICT investment at the firm level, *e.g.* Crepon and Heckel (2000).

larger contribution of ICT capital to growth performance. The method used in Figure 9 and in the work by Colecchia and Schreyer (2001) and Van Ark, et al. (2002) adjusts for these differences.

Estimates of ICT investment point to considerable differences in the uptake of ICT. Countries such as the United States, Japan, Canada, New Zealand, Australia, the Nordic countries and the Netherlands typically have the highest share of ICT investment in GDP. Several large European countries have low investment rates in ICT. The question that follows is why the diffusion of ICT differs so much across countries? All OECD countries have been faced with a rapid decline in ICT prices and with growing opportunities for efficiency-enhancing investment in ICT. However, previous studies have shown that having the equipment or networks may not be enough to derive economic impacts. Other factors play a role and countries with equal rates of diffusion of ICT will not necessarily have similar impacts of ICT on economic performance. In addition, it is possible to invest too much in ICT and some studies suggest that firms have sometimes over-invested in ICT in an effort to compensate for poor performance. Previous work points to several factors affecting the diffusion of ICT (and the rate of investment in ICT), namely (Gust and Marquez, 2002; Pilat and Devlin, 2004):

- Factors related to competition and the regulatory environment. A competitive environment is more likely to lead a firm to invest in ICT, as a way to strengthen performance and survive, than a more sheltered environment. Moreover, competition puts downward pressure on the costs of ICT. Excessive regulation in product and labour market may also make it more difficult for firms to draw benefits from investment in ICT.

- Factors related to the direct costs of ICT, *e.g.* the costs of ICT equipment, telecommunications or the installation of an e-commerce system.

- Costs and implementation barriers related to enabling factors and the ability of the firm to absorb new technologies. These factors include the availability of know-how and qualified personnel, the scope for organisational change and the capability of a firm to innovate.

- Factors related to risk and uncertainty, *e.g.* the security of doing business online or the uncertainty of payments, delivery and guarantees online.

- Factors related to the nature of the businesses. ICT is a general purpose technology, but is more appropriate for some activities than for others. ICT may not fit in all contexts and specific technologies, such as electronic commerce, may not be suited to all business models.

Some of these factors may help explain why several large European countries, such as France, Germany and Italy have not invested to the same degree in ICT than the United States, Japan or many smaller European Union countries. These countries face more stringent regulatory environments than the United States or Japan, which may reduce competitive pressures to invest in ICT, lower the ability of firms to make complementary organisational changes and increase the costs of ICT.

One limitation of the work on ICT investment discussed above is that most of the work in this area has been based on growth accounting. Fairly few studies have thus far been undertaken at the aggregate level to estimate the impact of ICT investment on economic growth through econometric procedures, *e.g.* estimating of production functions including ICT capital, or estimates of the impacts of ICT capital on labour productivity growth. Such work would provide a useful complement to the growth accounting studies that have been carried out in many OECD countries.

3.2 The role of the ICT-producing sector

The second impact of ICT derives from the ICT-producing sector. This sector is of interest for several countries, as it has been characterised by high rates of productivity growth, providing a considerable contribution to aggregate performance. The sector has been defined in official statistics (Box 3). Examining the contribution of this sector to aggregate productivity is relatively straightforward.

Box 3. **OECD definition of ICT-producing industries**

In 1998, OECD countries reached agreement on an industry-based definition of the ICT sector based on International Standard Industry Classification (ISIC) Revision 3. The principles are the following: for *manufacturing* industries, the products of an industry must be intended to fulfil the function of information processing and communication including transmission and display, or must use electronic processing to detect, measure and/or record physical phenomena or control a physical process. For *services* industries, the products must be intended to enable the function of information processing and communication by electronic means. The following industries were included:

Manufacturing

3000	Manufacture of office, accounting and computing machinery
3130	Manufacture of insulated wire and cable
3210	Manufacture of electronic valves and tubes and other electronic components
3220	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy
3230	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods
3312	Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment
3313	Manufacture of industrial process control equipment

Services

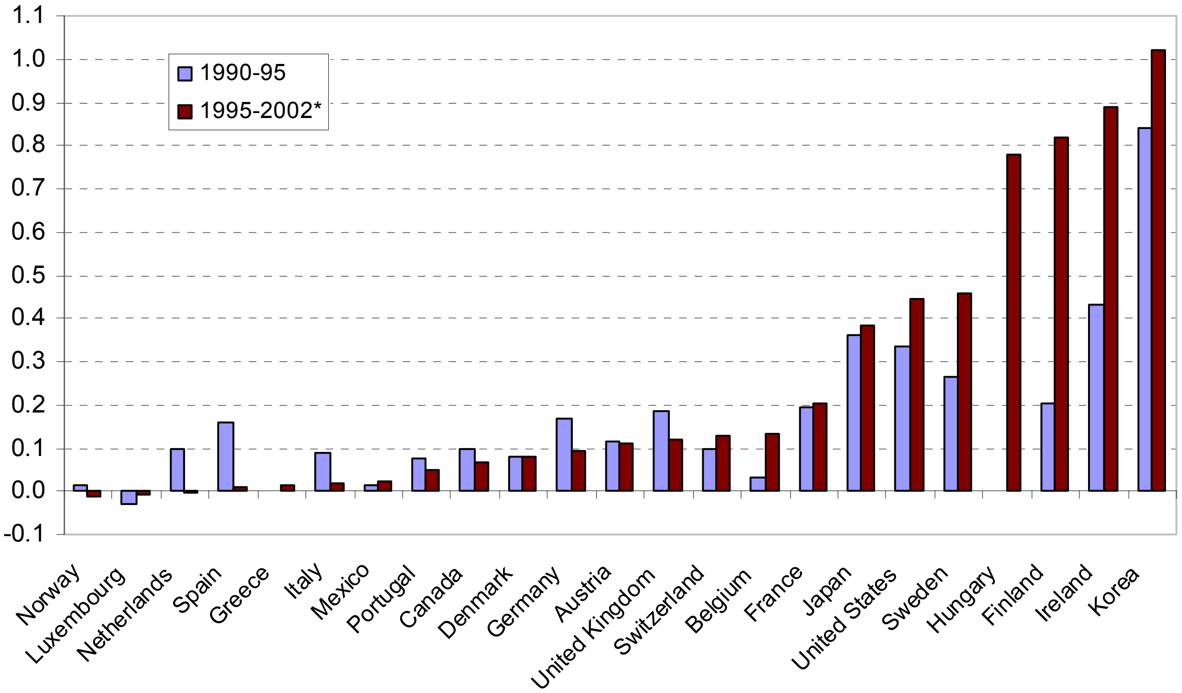
5150	Wholesale of machinery, equipment and supplies
7123	Renting of office machinery and equipment (including computers)
6420	Telecommunications
7200	Computer and related activities (hardware consultancy, software consultancy and supply, data processing, database activities, maintenance and repair of office, accounting and computing machinery, other)

Source: OECD (2002).

Figure 10 shows the contribution of ICT manufacturing to labour productivity growth over the 1990s, distinguishing between the first half of the decade and the second half of the decade. In most OECD countries, the contribution of ICT manufacturing to overall labour productivity growth has risen over the 1990s. This can partly be attributed to more rapid technological progress in the production of certain ICT goods, such as semi-conductors, which has contributed to more rapid price declines and thus to higher growth in real volumes (Jorgenson, 2001). However, there is a large variation in the types of ICT goods that are being produced in different OECD countries. Some countries only produce peripheral equipment, which is characterised by much slower technological progress and consequently by much less change in prices.[17]

17 . The large product variety also affects productivity comparisons. Some countries, such as the United States, use hedonic price indexes to capture rapid quality changes in the ICT-producing sector. This typically raises productivity growth for these sectors compared to countries that do not use these methods. However, the US hedonic price index can not simply be used (or adapted) for other countries, as the quality changes that are implicit in the US price index for ICT manufacturing may not be

Figure 10: **The contribution of ICT manufacturing to aggregate labour productivity growth**
Contribution to annual average labour productivity growth, percentage points



Note: 1991-1995 for Germany; 1992-95 for France and Italy and 1993-1995 for Korea; 1995-99 for Korea and Portugal, 1995-2000 for Ireland, Spain and Switzerland, 1995-2001 for France, Germany, Hungary, Japan, Mexico, the Netherlands, Norway, Sweden, the United Kingdom and the United States.

Source: Estimates on the basis of the OECD STAN database, September 2004. See Pilat and Wölfl (2004) for details.

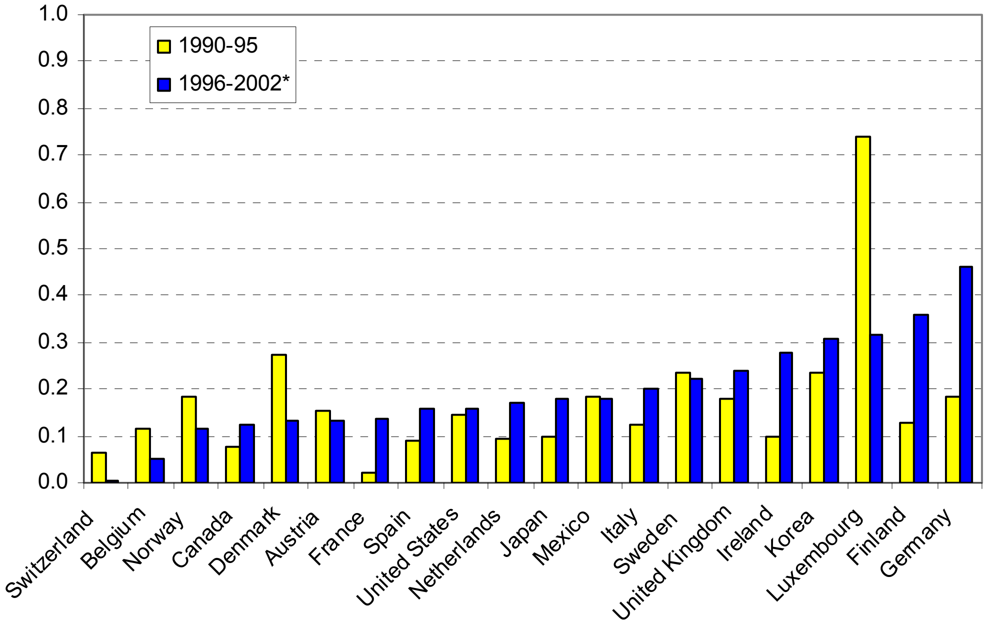
ICT manufacturing made the largest contributions to aggregate productivity growth in Finland, Hungary, Ireland, Japan, Korea, Sweden and the United States. In Finland, Hungary, Ireland and Korea, between 0.7 and 1 percentage point of aggregate productivity growth in the 1995-2002 period is due to ICT manufacturing. The contribution of this sector to labour productivity growth in the large EU countries was typically less than 0.2 percentage points in the late 1990s.

The ICT-producing services sector (telecommunications and computer services) plays a smaller role in aggregate productivity growth, but has also been characterised by rapid progress (OECD, 2003*a*; Figure 11). Partly, this is linked to the liberalisation of telecommunications markets and the high speed of technological change in this market. The contribution of this sector to overall productivity growth increased in several countries over the 1990s, notably in Canada, Finland, France, Germany and the Netherlands. Some of the growth in ICT-producing services is due to the emergence of the computer services industry, which has accompanied the diffusion of ICT in OECD countries. The development of these services has been important in implementing ICT, as the firms in these sectors offer key advisory and training services and also help develop appropriate software to be used in combination with the ICT hardware.

appropriate for a country producing only computer terminals or peripheral equipment. See Pilat, *et al.* 2002, for details.

Figure 11. **Contribution of ICT-producing services to aggregate labour productivity growth**

(Total economy, value added per person employed, contribution in percentage points)



Note: See Figure 10 for period coverage.

Source: Estimates on the basis of the OECD STAN database, September 2004.

Some of the growth of labour productivity in the ICT-producing sector may be linked to capital deepening. Adjustment for this factor leads to estimates of multi-factor productivity growth that are available for a limited number of countries at the industry level (OECD, 2004). This shows that ICT-producing manufacturing has had very rapid labour and MFP growth in several countries, but with considerable variations. Out of the countries for which data was available, productivity growth was highest in Finland, followed by France and Japan. It was also in these countries that the ICT-producing sector provided the largest contribution to aggregate labour and multi-factor productivity growth. In Finland, about 0.8 percentage points of the total aggregate MFP growth of 3.3% over the 1995-2000 period was accounted for by ICT-producing manufacturing, i.e. about one quarter of total MFP growth.

The OECD STAN database does not yet include capital stock estimates for the United States, which implies that the United States can not be included in the estimates discussed above. However, several studies for the United States have distinguished the role of ICT production in MFP growth (e.g. Oliner and Sichel, 2002; Gordon, 2002; CEA (2001), Jorgenson, Ho and Stiroh (2002). The results show considerable variation in the contribution of the computer sector to MFP growth, ranging between almost 0.5% to less than 0.2%.[18]

There are some issues related to the ICT producing sector that would benefit from further analysis. For example, what is the link between having an ICT-producing sector and benefiting from ICT investment and use? The experience of a country such as Australia suggests that having a large ICT manufacturing sector might not be necessary. However, this would benefit from more research as there could be spill-overs associated with have a manufacturing sector. Moreover, perhaps it might be even

18. The differences between the various US studies are partly due to the data sources and methodology used, as well as the timing of various studies.

more important in benefiting from ICT use to have a well developed domestic industry providing software and computer services to firms using the technology. This issue might also benefit from further analysis.

3.3 The role of ICT use

Much of the current interest in ICT is linked to the potential economic benefits arising from its use in the production process. If the rise in MFP growth due to ICT were only a reflection of rapid technological progress in the production of computers, semi-conductors and related products and services, there would not be effects of ICT use on MFP in countries that are not already producers of ICT (although there would still be impacts on labour productivity from ICT capital deepening). For ICT to have benefits on MFP in countries that do not produce ICT goods, the use of ICT would need to be beneficial too. ICT use may have several economic impacts. For example, the effective use of ICT may help firms gain market share at the cost of less productive firms. In addition, the use of ICT may help firms expand their product range, customise the services offered, or respond better to client demand; in short, to innovate. Moreover, ICT may help reduce inefficiency in the use of capital and labour, *e.g.* by reducing inventories.

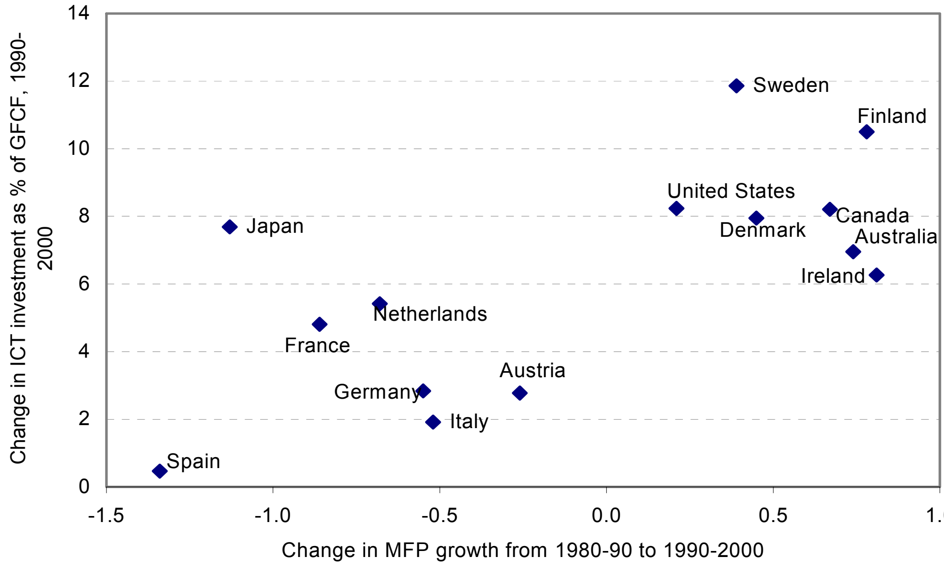
The diffusion of ICT may also have impacts that go beyond individual firms as it may help establish ICT networks, which produce greater benefits (the so-called spill-over effects) the more customers or firms are connected to the network. For example, the spread of ICT may reduce transaction costs, which can lead to a more efficient matching of supply and demand, and enable the growth of new markets that were not feasible before. Increased use of ICT may also lead to greater scope and efficiency in the creation of knowledge, which can lead to an increase in productivity (Bartelsman and Hinloopen, 2002). These spill-over effects would drive a wedge between the impacts of ICT that can be observed at the firm level and those at the industry or aggregate level, which implies that spill-over effects can only be observed at the industry or the aggregate level. The remainder of this section briefly examines some approaches that have been followed to analyse the impacts of ICT use.

Few studies have thus far examined the impacts of ICT use at the aggregate level. Simple correlations show that the link between ICT use and MFP growth is visible at the aggregate level; countries that have invested most in ICT in the 1990s have often also seen the largest increase in MFP growth over the 1990s (Figure 12). More formal regression approaches could, in principle, also be followed at the aggregate level to examine the economic impacts of ICT. However, these are still somewhat scarce, since long time series of ICT use and ICT investment have only recently become available.

While few studies are available at the aggregate level, a considerably larger number of studies have examined the impacts of ICT use with sectoral data. Several of these studies have distinguished an ICT-using sector, composed of industries that are intensive users of ICT (McGuckin and Stiroh, 2001; Pilat, *et al.* 2002; Van Ark, *et al.*, 2002*b*; O'Mahony and Van Ark, 2003). Examining the performance of these sectors over time and with sectors of the economy that do not use ICT may help point to the role of ICT in aggregate performance.[19] Services sectors such as finance and business services are typically the most intensive users of ICT. Figure 13 shows the contribution of the key ICT-using services (wholesale and retail trade, finance, insurance and business services) to aggregate productivity growth over the 1990s.

19. A more satisfactory method involves examining the link between ICT use and productivity performance by industry. However, estimates of ICT capital by industry are currently only available for some countries.

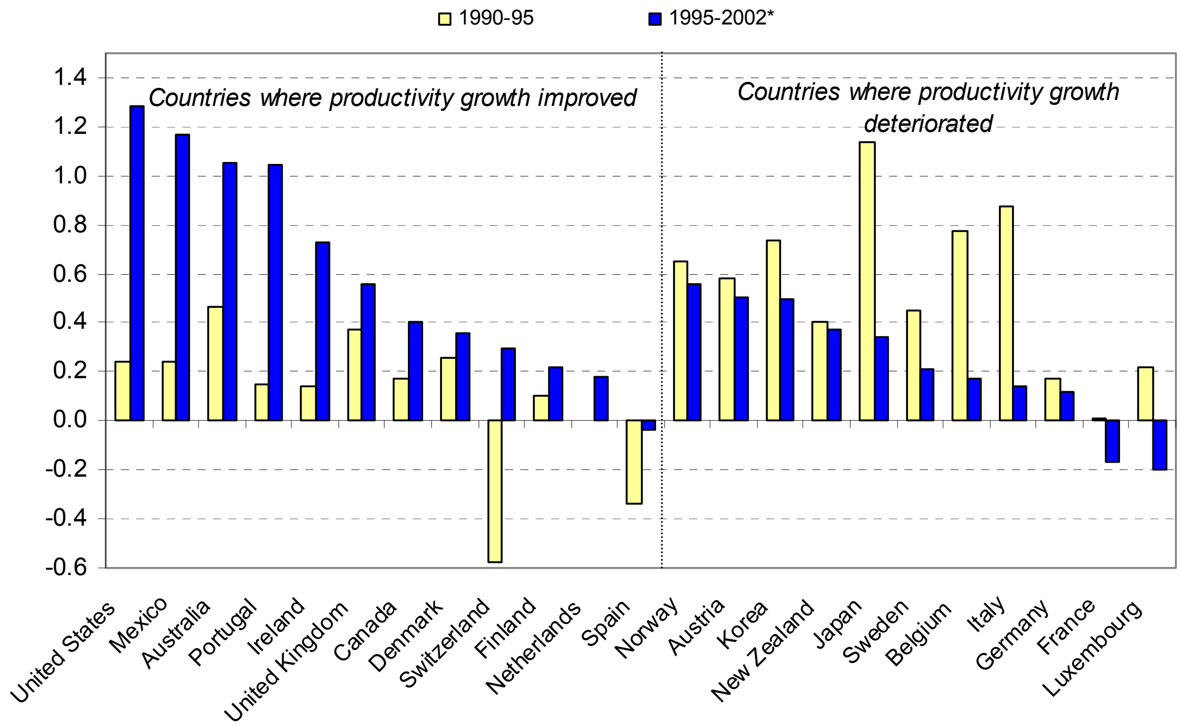
Figure 12. **Pick-up in MFP growth and increase in ICT investment**



Correlation coefficient = 0.66; T-statistic = 3.03.
Source: OECD (2003*a*).

Figure 13. **Contribution of ICT-using services to aggregate labour productivity growth, 1990-95 and 1995-2002**

(Total economy, value added per person employed, contributions in percentage points)



Note: ICT-using services are defined as the combination of wholesale and retail trade (ISIC 50-52), financial intermediation (ISIC 65-67) and business services (ISIC 71-74). See Figure 2 for period coverage. Data for Australia are for 1995-2001.
Source: Estimates on the basis of the OECD STAN database, September 2004. See Pilat and Wölfl (2004) for detail.

The graph suggests small improvements in the contribution of ICT-using services in Finland, the Netherlands and Sweden, and substantial increases in Australia, Canada, Ireland, Mexico, Portugal, the United Kingdom and United States. The strong increase in the United States is due to more rapid productivity growth in wholesale and retail trade, and in financial services (securities), and is confirmed by several other studies (*e.g.* McKinsey, 2001; Bosworth and Triplett, 2003). The strong increase in productivity growth in Australia has also been confirmed by other studies (Gretton, *et al.*, 2004). In some countries, ICT-using services made a negative contribution to aggregate productivity growth. This is particularly the case in Switzerland in the first half of the 1990s, resulting from poor productivity growth in the banking sector.[20]

More detailed examination have been undertaken for some countries and broadly confirm the role of ICT use. For the United States, for example, Bosworth and Triplett (2003) find that MFP growth in wholesale trade accelerated from 1.5% annually to 3.1% annually from 1987-95 to 1995-2001. In retail trade, the jump was from 0.2% annually to 2.9%, and in securities the acceleration was from 3.1% to 6.6%. Several other service sectors also experienced an increase in productivity growth over this period. On average, Bosworth and Triplett estimate that the contribution of service producing industries to aggregate MFP growth increased from 0.27% over the 1987-95 period to 1.2% over the 1995-2001 period, with the largest contributions coming from the sectors mentioned above.

Other studies suggest how these productivity changes due to ICT use in the United States could be interpreted. For example, a considerable part of the pick-up in productivity growth can be attributed to retail trade, where firms such as Wal-mart used innovative practices, such as the appropriate use of ICT, to gain market share from its competitors (McKinsey, 2001). The larger market share for Wal-mart and other productive firms raised average productivity and also forced Wal-mart's competitors to improve their own performance. Among the other ICT-using services, securities accounts also for a large part of the pick-up in productivity growth in the 1990s. Its strong performance has been attributed to a combination of buoyant financial markets (*i.e.* large trading volumes), effective use of ICT (mainly in automating trading processes) and stronger competition (McKinsey, 2001; Baily, 2002).

The United States is not the only country where ICT use may already have had impacts on MFP growth. Studies for Australia (Gretton, *et al.* 2004), suggest that a range of structural reforms have been important in driving the strong uptake of ICT by firms and have enabled these investments to be used in ways that generate productivity gains. This is particularly evident in wholesale and retail trade and in financial intermediation, the sectors accounting for most of the Australian productivity gains in the second half of the 1990s.

A number of measurement problems affect the measurement of productivity in ICT-using services, however (Wölfl, 2003). First, output measures are not straightforward. There is little agreement, for example, on the output of banking, insurance, medical care and retailing. In addition, some services are not sold in the market, so that it is hard to establish prices. In practice, these constraints mean that output in some services is measured on the basis of relatively simple indicators. Several series are deflated by wages or consumer prices or extrapolated from changes in employment, sometimes with explicit adjustment for assumed labour productivity changes. Second, best practices in measuring services output have not yet spread widely. With better measurement, potential productivity gains may become visible. Fixler and Zieschang (1999), for example, derive new output measures for the US financial services industry (depository institutions). They introduce quality adjustments to capture the effects of improved service characteristics, such as easier and more convenient transactions, *e.g.* use of

20 . Poor measurement of productivity in financial services may be partly to blame. The OECD is currently working with its member countries to improve methods in this sector.

ATMs, and better intermediation. Their output index grows by 7.4% a year between 1977 and 1994, well above the official measure for this sector of only 1.3% a year on average. The recent revisions of GDP growth for the United States also incorporate improved estimates of banking output, notably on the real value of non-priced banking services, which better capture productivity growth in this industry. While some new approaches to measurement in these sectors are being developed (Triplett and Bosworth, 2003), only few countries have thus far made substantial changes in their official statistics. Work is currently underway at OECD in some areas, e.g. finance and insurance.

Further analytical work with industry-level data would be helpful. For example, industry-level data on ICT investment or ICT uptake are becoming available for more countries and could be used for more formal regression analysis on the impacts of ICT in different sector or for the estimation of production functions. More sector-specific studies, as have been undertaken for some industries, e.g. for trucking (see Chakraborty and Kazarosian, 1999), would also be of interest as they could help point to the ways in which ICT is applied and made effective in different sectors of the economy.

4. The impacts of ICT at the firm level

4.1 Firm-level data and methods

Most of the early work with firm-level data on ICT and productivity was based on private data. For example, Brynjolfsson and Hitt (1997) examined more than 600 large US firms over the 1987-94 period, partly drawing on the Compustat database, while Bresnahan, Brynjolfsson and Hitt (2002) examined over 300 large US firms from the Fortune-1000 database. Similar studies with private data exist for other countries. Studies based on such private data have helped to generate interest in the impacts of ICT on productivity and have given an important impetus to the development of official statistics on ICT. However, private sources suffer from a number of methodological drawbacks. First, private data are often not based on a representative sample of firms, which may imply that the results of such studies are biased. For example, studies based on a limited sample of large firms may be biased since large firms may benefit more from ICT than small firms. Moreover, studies based on a limited sample of firms will tend to ignore dynamic effects, such as the entry of new firms or the demise of existing firms, which may accompany the spread of ICT. Second, the quality and comparability of private data are often not known, since the data do not necessarily confirm with accepted statistical conventions, procedures and definitions.

Over the past decade, the analysis of firm-level impacts of ICT has benefited from the establishment of longitudinal databases in statistical offices. These databases cover much larger and statistically representative samples than private data, which is important given the enormous heterogeneity in plant and firm performance (Bartelsman and Doms, 2000). These data allow firms to be tracked over time and can be linked to many surveys and data sources. Among the first of these databases was the Longitudinal Research Database of the Center of Economic Studies (CES) at the US Bureau of the Census (McGuckin and Pascoe, 1988). Since then, several other countries have also established longitudinal databases and centres for analytical studies with these data. Examples include Australia, Canada, Finland, France, the Netherlands and the United Kingdom. The data integrated in these longitudinal databases differ somewhat between countries, since the underlying sources are not the same. However, many of the basic elements of these databases are common. The basic sources for such databases are typically production surveys or censuses, *e.g.* the US Annual Survey of Manufactures. These data typically cover the manufacturing sector, although longitudinal databases increasingly cover (parts of) the service sector as well.

In recent years, longitudinal databases have increasingly been linked to data on firm use of ICT; the linked data can subsequently be explored in analytical studies. Firm-level studies of ICT's impact on economic performance require that researchers and statisticians link data for the same firms derived from different statistical surveys, e.g. data from a production survey and from a survey on ICT use. Other types of data can be integrated too, which is important since empirical studies suggest that the impact of ICT depends on a range of complementary investments and factors, such as the availability of skills, organisational factors, innovation and competition (OECD, 2003*a*).

Unlike the analysis of economic impacts of ICT at the aggregate and sectoral level, analysis at the firm-level is characterised by a wide range of data and methods (Table 2). This variety is partly linked to differences in the basic data, but also reflects that a wide range of methods can be applied to firm-level data. To some extent, this variety is desirable, since the empirical evidence on impacts is stronger when it can be confirmed by different methods.

Table 2: **Approaches followed in some recent firm-level studies of ICT and economic performance**

Study	Countries	Survey covering ICT	Method	Economic Impacts
Arvanitis (2004)	Switzerland	Survey of Swiss business sector	Labour productivity regressions	Labour productivity & complementarities
Atrostic, et al. (2004)	Denmark, Japan, United States	US Computer Network Usage Survey, Denmark survey of ICT use, Japan survey of IT workplaces	Labour productivity regressions	Labour productivity (United States, Japan), Multi-factor productivity (Japan)
Baldwin and Sabourin (2002)	Canada	Survey of Advanced Technology	Labour productivity & market share regressions	Market share, labour productivity
Clayton, et al. (2003)	United Kingdom	ONS e-commerce survey	Labour productivity and TFP regressions	Labour productivity, TFP, price effects
Crepon and Heckel (2000)	France	BRN employer file	Growth accounting	Productivity, output
Criscuolo and Waldron (2003)	United Kingdom	Annual Respondents Database	Labour productivity regressions	Labour productivity
DeGregorio (2002)	Italy	Structural business survey	Multivariate analysis	IT adoption, e-commerce, organisational aspects
De Panniza, et al. (2002)	Italy	E-commerce survey	Principal components	Labour productivity
Doms, Jarmin and Klimek (2002)	United States	Asset and Expenditure Survey	Labour productivity and establishment growth regressions	Labour productivity, establishment growth
Gretton, et al. (2004)	Australia	Business longitudinal survey, IT Use Survey	Labour productivity regressions	Labour productivity, MFP, IT adoption
Haltiwanger, et al. (2003)	Germany, United States	US Computer Network Usage Survey, German IAB establishment panel	Labour productivity regressions	Labour productivity
Hempell (2002)	Germany	Mannheim innovation panel	Regressions based on production function	Sales, contribution of ICT capital, innovation, labour productivity
Hempell, et al. (2004)	Germany, Netherlands	Innovation surveys, structural business statistics	Regressions based on production function	Value added, contribution of ICT capital, innovation, labour productivity
Hollenstein (2004)	Switzerland	Survey of Swiss business sector	Rank model of ICT adoption	ICT Adoption
Maliranta and Rouvinen (2004)	Finland	Internet use and E-commerce survey	Labour productivity regressions, breakdown of productivity growth	Labour productivity, productivity decomposition
Milana and Zeli (2004)	Italy	Enterprise survey of economic and financial accounts	Malmquist indexes of TFP growth, TFP correlations	TFP growth
Motohashi (2003)	Japan	Basic survey on business structure and activities (BSBSA); ICT Workplace Survey	Production function, TFP regressions	Output, TFP, productivity

Source: See references, OECD (2003*a*; 2004).

On the other hand, cross-country comparisons require common methods and comparable data. Some researchers have recently engaged in cross-country comparisons (e.g. Atrostic, *et al.*, 2004; Hempell, *et al.*, 2004; Haltiwanger, *et al.*, 2003), and the methods used in these studies are increasingly also being adopted by other countries. For example, the approach followed by Atrostic, *et al.* (2004) was also applied by Criscuolo and Waldron (2003), and, to some extent, by Gretton, *et al.* (2004).

4.2. Evidence on the impacts of ICT at the firm level

A number of studies have summarised the early literature on ICT, productivity and firm performance (*e.g.* Brynjolfsson and Yang, 1996). Many of these early studies found no, or a negative, impact of ICT on productivity. Most of these studies also primarily focused on labour productivity and the return to computer use, not on MFP or other impacts of ICT on business performance. Moreover, most of these studies used private sources, since official sources were not yet available. The limited impacts of ICT found in such early studies are often linked to difficulties in isolating the impact of ICT and to the state of diffusion of the technology at the time (Box 4).

Box 4: **Difficulties in identifying the impact of ICT in early work**

Many studies in the 1970s and 1980s showed negative or zero impacts of investment in ICT on productivity, a situation which led economist Robert Solow to state that "computers were everywhere but in the productivity statistics" (Solow, 1987). Many of these early studies focused on labour productivity, which made the findings surprising as investment in ICT adds to the productive capital stock and should thus, in principle, contribute to labour productivity growth. Later studies found some evidence of a positive impact of ICT on labour productivity, however. Some also found evidence that ICT capital had larger impacts on labour productivity than other types of capital, suggesting that there might be spill-overs from ICT investment or that ICT might have positive impacts on MFP growth. More recent work for certain OECD countries, *e.g.* the United States and Australia, has more conclusively shown how ICT may enhance labour and multi-factor productivity (Gretton, *et al.*, 2004; Bosworth and Triplett, 2003).

Studies over the past decade have pointed to several factors that contributed to the productivity paradox. First, some of the benefits of ICT were not picked up in the productivity statistics (Triplett, 1999). The key problem is measuring productivity in the service sector, the part of the economy where most ICT investment occurs. For instance, the improved convenience of financial services due to automated teller machines (ATMs) is only counted as an improvement in the quality of financial services in some OECD countries. Similar problems exist for other activities such as insurance, business services and health services. Progress towards improved measurement has been made in some sectors and in some OECD countries, but this remains an important problem in examining the impact of ICT on performance, notably across countries.

A second reason for the difficulty in finding hard evidence on ICT's impacts is that the benefits of ICT use might have taken a considerable time to emerge, as did the impacts of other key technologies, such as electricity. The diffusion of new technologies is often slow and firms can take a long time to adjust to them, *e.g.* in changing organisational arrangements, upgrading the workforce or inventing and implementing effective business processes. Moreover, assuming ICT raises MFP in part via the networks it provides; it takes time to build networks that are sufficiently large to have an effect on the economy. ICT diffused very rapidly in many OECD countries over the 1990s and recent empirical studies typically find a larger impact of ICT on performance than studies that were carried out with data for the 1970s or 1980s. However, such impacts have not been observed in equal measure in all countries, and are more visible in the United States than in any other country. This may suggest that other countries are still adjusting to the diffusion of ICT.

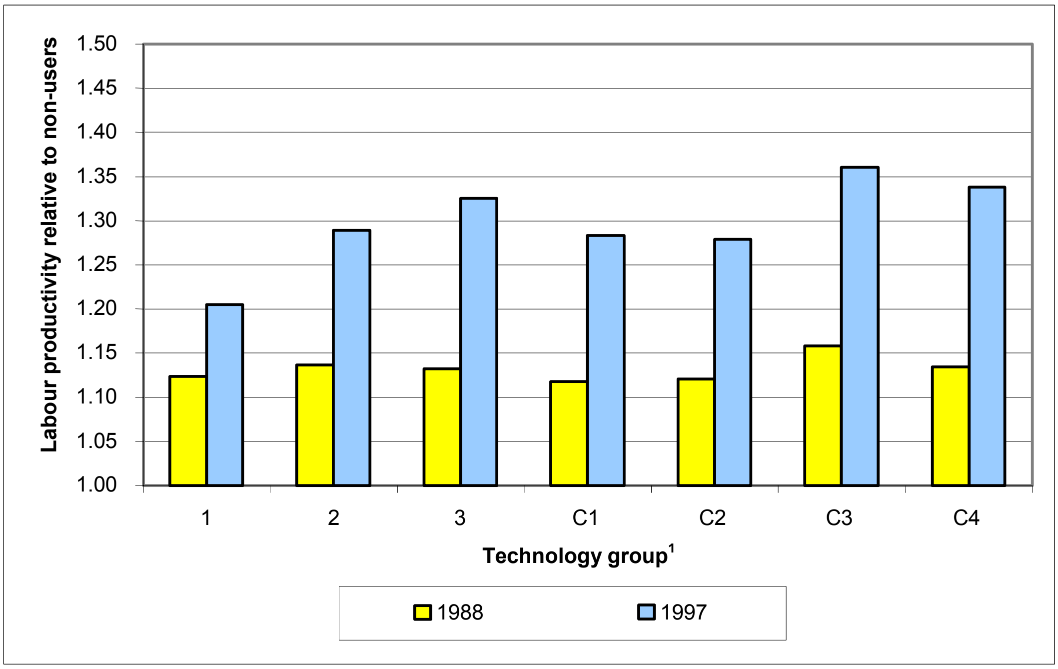
A third reason is that many early studies that attempted to capture the impact of ICT at the firm level were based on relatively small samples of firms, drawn from private sources. If the initial impact of ICT on performance was small, such studies might find little evidence, as it would easily get lost in the econometric "noise". It is also possible that the samples were not representative, or that the data were of poor quality. Moreover, several studies have suggested that the impact of ICT on economic performance may differ between activities, implying that a distinction by activity is important for the analysis. More recent studies based on large samples of (official) data and covering several industries are therefore more likely to find an impact of ICT than earlier studies. Much progress has been made in recent years in measuring ICT investment and the diffusion of ICT technologies, implying that the range of available data is broader, more robust and of greater quality than previous data.

Recent work by researchers and statistical offices, using official data, has gone beyond the early work on ICT and has provided many new insights in the role of ICT. Over the past years, OECD has worked closely with a group of researchers and statisticians from 13 OECD countries to generate further evidence on the link between ICT and business performance (OECD, 2003*a*, 2004). Some of the findings of this group are discussed below.

Links between ICT and firm performance

Recent firm-level studies provide evidence that ICT use can have a positive impact on firm performance. The findings of these studies vary. Figure 14 illustrates a typical finding from several studies showing that ICT-using firms tend to have better productivity performance. It shows that Canadian firms that used either one or more ICT technologies had a higher level of productivity than firms that did not use these technologies.[21] Moreover, the gap between technology-using firms and other firms increased between 1988 and 1997, as technology-using firms increased their relative productivity compared to non-users. The graph also suggests that some ICT technologies are more important in enhancing labour productivity than other technologies; communication network technologies being particularly important.

Figure 14. **Relative labour productivity of advanced technology users and non-users**
Manufacturing sector in Canada, 1988 versus 1997



1. The graph shows the relative productivity on technology users compared to groups not using any advanced technology.
Note: The following technology groups are distinguished: Group 1 (software); Group 2 (hardware); Group 3 (communications); Group C1 (software and hardware); Group C2 (software and communications); Group C3 (hardware and communications); Group C4 (software, hardware and communications).
Source: Baldwin and Sabourin (2002).

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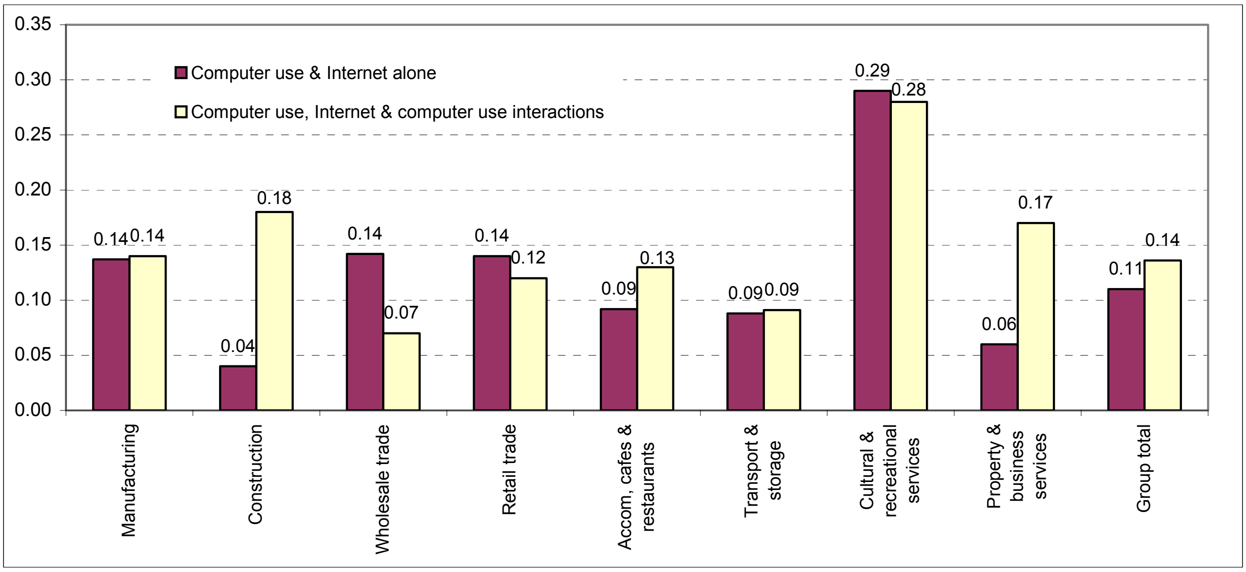
21 . Obviously, the graph does not demonstrate that ICT use caused higher productivity. More sophisticated econometric techniques can distinguish ICT's impact from other firm-level characteristics that may enhance productivity, *e.g.* the size or age of a firm, or a firm's investment in skills.

Figure 15 is based on a study with Australian firm-level data (Gretton *et al.* 2004). Australia is typically considered as an OECD country where ICT already has had considerable impacts. The paper finds through aggregate growth accounting and the aggregation of firm-level results that ICTs and related effects raised Australia's annual MFP growth by around two-tenths of a percentage point. This contribution is significant, although it is a relatively small part of Australia's MFP growth in the 1990s, which amounted to 1.8% a year. The use of computers thus already affected Australian MFP growth in the mid-1990s, *i.e.* before the peak in ICT investment. Moreover, this effect is over and above the substantial contribution of ICT to overall capital deepening, which was estimated at 1% annually over the 1990s. Importantly, the firm-level econometric analysis, which controls for other influences, found positive links between ICT use and productivity growth in all industry sectors that were examined. The analysis also found that the productivity effects of ICT tapered off over time; the ultimate productivity effect from adoption of (a type of) ICT is thus a step up in levels, rather than a permanent increase in the rate of growth.

Figure 15. **Estimated contribution of ICT to multifactor productivity growth in Australia**
1994-95 to 1997-98, in percentage points



Source: Gretton *et al.* (2004).

The results of Figures 14 and 15 are confirmed by many other studies that also point to impacts of ICT on economic performance. For example, Hempell, *et al.* (2004) find that ICT capital deepening raised labour productivity in services firms in both Germany and the Netherlands. Arvanitis (2004) found that labour productivity in Swiss firms is closely correlated with ICT use. A study for Finland, by Maliranta and Rouvinen (2004), also found strong evidence for productivity-enhancing impacts of ICT. It found that after controlling for industry and time effects as well as specific characteristics of the firm and workers using ICT, the additional productivity of ICT-equipped labour ranges from 8% to 18%, which corresponds to a 5 to 6 % elasticity of ICT capital. This effect was much higher in younger firms and in the ICT-producing sector, notably ICT-producing services.

Baldwin, *et al.* (2004) found strong evidence for Canada that the use of ICTs is associated with superior performance. In particular, greater use of advanced information and communication technologies was associated with higher labour productivity growth during the nineties. In another study for Canada, Baldwin and Sabourin (2002) found that a considerable amount of market share was transferred from declining firms to growing firms over a decade. At the same time, the growers increased their productivity relative to the declining firms. Those technology users that were using communications technologies or that combined technologies from several different technology classes increased their relative productivity the most. In turn, gains in relative productivity were accompanied by gains in market share.

Clayton, *et al.* (2004) examined the economic impacts in the United Kingdom of on specific application of ICT, namely electronic commerce. It found a positive effect on firm productivity associated with use of computer networks for trading. However, there was an important difference between e-buying and e-selling, with e-buying having positive impacts on output growth and e-selling typically having negative impacts. This is likely due to pricing effects, since at least part of the gain from investment in electronic procurement by firms comes from the ability to use the price transparency offered by e-procurement to secure more competitive deals. Part of this comes from efficiency gains, but part is likely to be at the expense of suppliers.

For the United States, Atrostic and Nguyen (2002) were the first in linking computer network use (both EDI and Internet) to productivity. The study found that average labour productivity was higher in plants with networks and that the impact of networks was positive and significant after controlling for several production factors and plant characteristics. Networks were estimated to increase labour productivity by roughly 5%, depending on the model specification. Atrostic, *et al.* (2004) examined the impact of computer networks in three OECD countries, Denmark, Japan and the United States. For Japan, the study found that use of both intra-firm and inter-firm networks was positively correlated with MFP levels at the firm level, thus confirming the findings by Motohashi (2003). Positive and statistically significant coefficients were found for several types of networks, including open networks (the Internet), CAD/CAM technologies and electronic data interchange (EDI).

Impacts in services

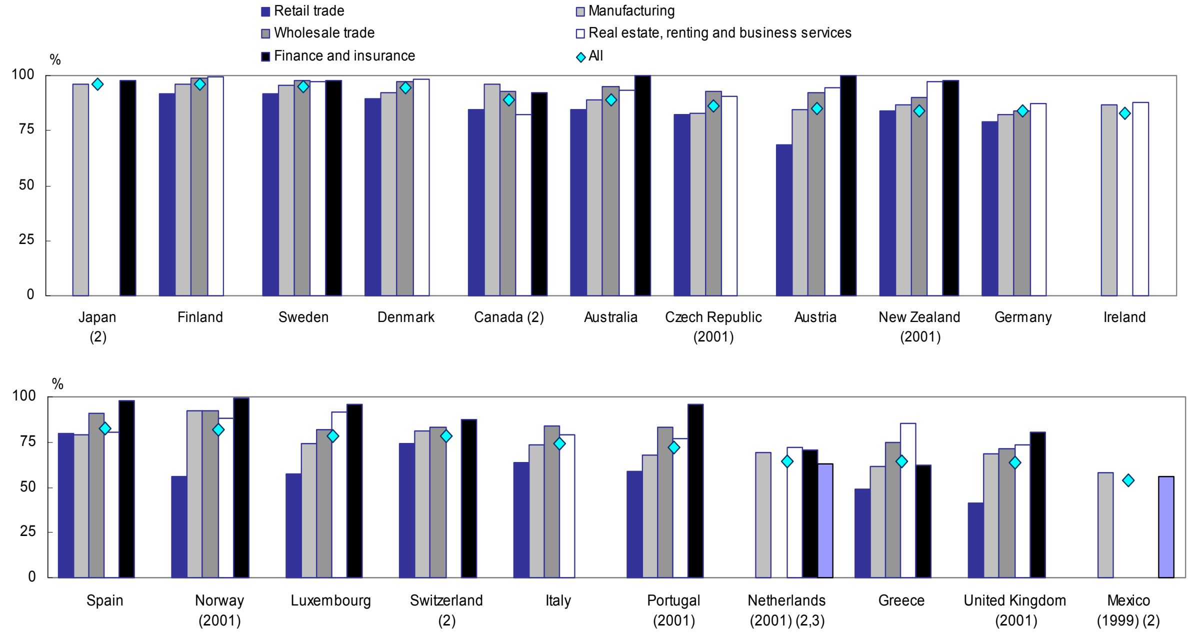
ICT use is more widespread in some parts of the services sector than in manufacturing (OECD, 2003*a*). Moreover, not all sectors use the same technologies. In many countries, financial services are among the most ICT-intensive sectors (Figure 16). Evidence for the United Kingdom suggests that financial intermediation is also the sector most likely to use network technologies (OECD, 2003*a*), and also the sector to use combinations of network technologies. This indicates that this sector is an intensive user of information, and potentially the most likely to benefit from ICT.

Studies at the industry level provide only little evidence that ICT use has led to stronger productivity growth in the services sector, the United States and Australia being exceptions (OECD, 2004). Firm-level studies suggest that ICT can enhance the performance of the services sector, however, also in countries for which little evidence is available at the industry level. For Australia and the United States, firm-level studies confirm the evidence at the industry level. For example, Gretton, et al. (2004) found impacts of ICT on MFP growth in several services sectors. For the United States, Doms, Jarmin and Klimek (2002) show that growth in the US retail sector over the 1990s involved the displacement of traditional retailers by sophisticated retailers introducing new technologies and processes.

But impacts are also found in other countries. For Germany, Hempell (2002) showed significant productivity effects of ICT in firms in the German service sector. Moreover, experience gained from past process innovations helped firms to make ICT investments more productive. A comparative study for Germany and the Netherlands (Hempell *et al.* 2004) confirmed the link between ICT and innovation in the German service sector, and also found such a link for the services sector of the Netherlands. Moreover, the study found that ICT capital had a significant impact on productivity in the Netherlands' services sector.

Figure 16. **Internet penetration by activity, 2002**

Percentage of all firms with ten or more employees using the Internet



1. In European countries, only enterprises in the business sector, but excluding NACE activity E (electricity, gas and water supply), NACE activity F (construction) and NACE activity J (financial intermediation), are included. The source for these data is the Eurostat Community Survey on enterprise use of ICT. In Australia, all employing businesses are included, with the exception of businesses in general government, agriculture, forestry and fishing, government administration and defence, education, private households employing staff and religious organisations. Canada includes the industrial sector. Japan excludes agriculture, forestry, fisheries and mining. New Zealand excludes electricity, gas and water supply, and only includes enterprises with NZD 30 000 or more in turnover. Switzerland includes the industry, construction and service sectors.
2. For Canada, 50-299 employees instead of 50-249 and 300 or more instead of 250 or more. For Japan, businesses with 100 or more employees. For the Netherlands, 50-199 employees instead of 50-249. For Switzerland, 5-49 employees instead of 10-49 and 5 or more employees instead of 10 or more. For Mexico, businesses with 21 or more employees, 21-100 employees instead of 10-49, 101-250 instead of 50-249, 151-1000 instead of 250 or more.
3. Internet and other computer-mediated networks.

Source: OECD, ICT database and Eurostat, Community Survey on ICT usage in enterprises 2002, May 2003.

For Finland, Maliranta and Rouvinen (2004) found that the higher productivity induced by ICT seemed to be somewhat greater in services than in manufacturing. Manufacturing firms benefit in particular from ICT-induced efficiency in internal communication, which is typically linked to the use of local area networks (LANs), whereas service firms benefit from efficiency gains in external (Internet) communication. For Switzerland, Arvanitis (2004) found that the use of Internet was less important for firm performance in the manufacturing than in the service sector, presumably because many manufacturing workers do not perform a desk job and are not equipped with a PC and an Internet connection.

4.3. Factors that affect the impact of ICT at the firm level

The evidence summarised above suggests that the use of ICT does have positive impacts on firm performance and productivity, even in countries and industries for which little evidence is available at more aggregate levels of analysis, *e.g.* Germany. However, the evidence also suggests that these impacts occur primarily, or only, when ICT investment is accompanied by other changes and investments. For example, many empirical studies suggest that ICT primarily affects firms where skills have been improved and organisational changes have been introduced. Another important factor is innovation, since users often help make investment in technologies, such as ICT, more valuable through their own experimentation and invention. Without this process of "co-invention", which often has a slower pace than technological invention, the economic impact of ICT may be limited. The firm-level evidence also suggests that the uptake and impact of ICT differs across firms, varying according to size of firm, age of the firm, activity, *etc*. This section looks at some of this evidence and discusses the main complementary factors that are associated with ICT investment.

Skills

A substantial number of longitudinal studies address the interaction between technology and human capital, and their joint impact on productivity performance (Bartelsman and Doms, 2000). Although few longitudinal databases include data on worker skills or occupations, many address human capital through wages, arguing that wages are positively correlated with worker skills. Many of these firm-level studies confirm the complementarity between technology and skills.

Studies for Canada, for example, have found that use of advanced technology is associated with a higher level of skill requirements (Baldwin, *et al.*, 1995). In Canadian plants using advanced technologies, this often led to a higher incidence of training. The study also found that firms adopting advanced technologies increased their expenditure on education and training. Baldwin, *et al.* (2004) found that a management team with a focus on improving the quality of its products by adopting an aggressive human-resource strategy – by continuously improving the skill of its workforce through training and recruitment – was associated with higher productivity growth.

For Australia, Gretton *et al.* (2004) found that the positive benefits of ICT use on MFP growth were typically linked to the level of human capital and the skill base within firms, as well as firms' experience in innovation, their application of advanced business practices and the intensity of organisational change within firms. The data for Australia also showed that the earliest and most intensive users of ICTs and the Internet tended to be large firms with skilled managers and workers.

For France, the data include details about worker characteristics, which allow more detailed analysis. Entorf and Kramarz (1998) found that computer-based technologies are often used by workers with higher skills. These workers became more productive when they got more experience in using these technologies. The introduction of new technologies also contributed to a small increase in wage differentials within firms. Greenan *et al.* (2001) examined the late 1980s and early 1990s and found strong positive correlations between indicators of computerisation and research on the one hand, and productivity, average wages and the share of administrative managers on the other hand. They also found negative correlations between these indicators and the share of blue-collar workers.

For the United Kingdom, Haskel and Heden (1999) used the UK's Annual Respondents Database (ARD) together with a set of data on computerisation. They found that computerisation reduces the demand for manual workers, even when controlling for endogeneity, human capital upgrading and technological opportunities. Caroli and Van Reenen (1999) found evidence for the United Kingdom that human capital, technology and organisational change are complementary, and that organisational change reduced the demand for unskilled workers.

A few studies have also looked at other worker-related impacts. For example, Luque and Miranda (2000) found that the skill-biased technological change associated with the uptake of advanced technologies also affects worker mobility. The larger the number of advanced technologies adopted by a plant, the higher is the probability that a worker will leave. Their interpretation is that workers at technologically advanced plants have greater (often unobserved) abilities, and therefore can claim a higher wage when they leave. The other mechanism at work is that less skilled workers tend to be pushed to plants that are less technologically advanced.

Organisational factors

Closely linked to human capital is the role of organisational change. Studies typically find that the greatest benefits from ICT are realised when ICT investment is combined with other organisational changes, such as new strategies, new business processes and practices, and new organisational structures. The common element among these practices is that they entail a greater degree of responsibility of individual workers regarding the content of their work and, to some extent, a greater proximity between management and labour. Because such organisational change tends to be firm-specific, empirical studies show on average a positive return to ICT investment, but with a large variation across organisations.

Several studies have addressed ICT's link to human capital, organisational change and productivity growth. Black and Lynch (2001), for example, found that the implementation of human resource practices is important for productivity, *e.g.* giving employees greater voice in decision-making, profit-sharing mechanisms and new industrial relations practices. They also found that productivity was higher in firms with a large proportion of non-managerial employees that use computers, suggesting that computer use and the implementation of human resource practices go hand-in-hand.

Several studies on organisational change are also available for European countries. For Germany, Falk (2001) found that the introduction of ICT and the share of training expenditures were important drivers of organisational changes, such as the introduction of total quality management, lean administration, flatter hierarchies and delegation of authority. For France, Greenan and Guellec (1998) found that the use of advanced technologies and the skills of the workforce were both positively linked to organisational variables. Organisations that enabled communication within the firm and that innovated at the organisational level seemed more successful in the uptake of advanced technologies. Moreover, such organisational changes also increased the ability of firms to adjust to changing market conditions, *e.g.* through technological innovation and the reduction of inventories.

Gretton, *et al.* (2004) on Australia also found significant interactions between ICT use and complementary organisational variables in nearly all sectors. The complementary factors for which data were available and which were found to have significant influence were: human capital, a firm's experience in innovation, its use of advanced business practices and the intensity of organisational restructuring. Computer use was also commonly associated with use of advanced business practices, the incorporation of companies and firm reorganisation.

Arvanitis (2004) found important complementarities for Switzerland. He found that labour productivity is positively correlated with human capital intensity and also with organisational factors such as team-work, job rotation and decentralisation of decision making. His study also found some evidence for complementarities between human capital and ICT capital with respect to productivity. However, he did not find evidence of complementarities between organisational capital, human capital and ICT capital, a combination that is found in some other studies.

Maliranta and Rouvinen (2004) find some evidence of complementarities for Finland, notably for human capital and organisational factors. Organisational factors appear important in Finland since the productivity effects of ICT in the manufacturing sector seem to be much larger in younger than in older firms. Some other studies have shown that the productivity of capital (primarily non-ICT) tends to be higher in *older* plants, which is possibly due to learning effects. While learning effects undoubtedly also exist with ICT, the finding for Finland is consistent with a view that it may be even more important to be able to make complementary organisational adjustments. Such changes are arguably more easily implemented in younger firms and even more so in new firms.

Innovation

Several studies point to an important link between the use of ICT and the ability of a company to innovate. The role of innovation was raised by Bresnahan and Greenstein (1996), who argued that users help make investment in technologies, such as ICT, more valuable through their own experimentation and invention. Without this process of "co-invention", which often has a slower pace than technological invention, the economic impact of ICT may be limited. For example, work for Germany, based on innovation surveys found that firms that had introduced process innovations in the past were particularly successful in using ICT (Hempell, 2002); the output elasticity of ICT capital for these firms was estimated to be about 12%, about four times that of other firms. This suggests that the productive use of ICT is closely linked to innovation in general, and notably to process innovation. Studies in other countries also confirm this link. For example, Greenan and Guellec (1998) found that organisational change and the uptake of advanced technologies increased the ability of firms to adjust to changing market conditions through technological innovation.

Hempell, *et al.* (2004) points to the complementarity of innovation and ICT for both Germany and the Netherlands. They test the hypothesis that firms that introduce new products, new processes or adjust their organisational structure can reap higher benefits from ICT investment than firms that refrain from such complementary efforts. For both countries, the results indicate that ICT is used more productively if it is complemented by a firm's own efforts to innovate. These spill-over effects are a particular feature of ICT capital, since no complementarities between non-ICT capital and innovation could be found in the study. The results also show that innovating on a more continuous basis seems to pay off more in terms of ICT productivity than innovating occasionally. This effect is found for product innovations (Germany) and non-technical innovations (Netherlands) and, to a much smaller extent, for process innovations. For Germany, they also find evidence for direct benefits from product and process innovation in services on multi-factor productivity (MFP). Service firms that innovate permanently show higher MFP levels. This positive direct effect of innovation on productivity, however, cannot be found for the Netherlands.

Baldwin, *et al.* (2004) finds that such characteristics are also important in Canada. The innovation strategy of a firm, its business practices, and its human-resource strategies all influence the extent to which a firm adopts new advanced technologies. A central theme emerging from the Canadian evidence is that a strategic orientation on high-technology is often the core of a successful firm strategy. The study also finds that firms that combined ICT with other advanced technologies do better than firms that only use one technology. Furthermore, the results emphasise that combinations of technologies that involve more than just ICT are important. For example, adoption of advanced process control technology, by itself, has little effect on the productivity growth of a firm, but when combined with ICT and advanced packaging technologies, the effect is significant. Similar effects are evident when firm performance is measured by market-share growth instead of productivity growth.

Competitive effects and the role of experimentation

In a competitive economy, the effective use of ICT may help efficient firms gain market share at the cost of less productive firms, raising overall productivity. For example, Maliranta and Rouvinen (2004) point to the role of firm selection in Finland. While most of the increase in ICT use in Finland is driven by growth within firms, restructuring (the growth of some firms and decline of others) also plays an important role. This is notably the case among young firms, where some succeed and grow, and many others fail.

Several other studies also point to the role of competition. A study by Baldwin and Diverty (1995) found that foreign-owned plants were more likely to adopt advanced technologies than domestic plants. For Germany, Bertschek and Fryges (2002) found that international competition was an important factor driving a firm's decision to implement B2B electronic commerce. These findings should be linked to the results of several firm-level studies that show that the implementation of advanced technologies can help firms to gain market share and may reduce the likelihood of plant exit (*e.g.* Doms *et al.* 1995; Doms, Jarmin and Klimek, 2002; Baldwin *et al.* 1995*a*; Baldwin and Sabourin, 2002).

A closely related issue is that of experimentation. This was raised in a recent comparison between the United States and Germany (Haltiwanger *et al.* 2003), that examined the relationship between labour productivity and measures of the choice of technology. The study distinguished between different categories of firms according to their total level of investment and their level of investment in ICT. It found that firms in all categories of investment had much stronger productivity growth in the United States than in Germany. Moreover, firms with high ICT investment had stronger productivity growth than firms with low or zero ICT investment. The study also found that firms in the United States had much greater variation in their productivity performance than firms in Germany.

These differences may occur because US firms engage in much more experimentation than their German counterparts; they take greater risks and opt for potentially higher outcomes (see Bartelsman, *et al.*, 2003). This may be related to differences in the business environment between the two regions; the US business environment permits greater experimentation as barriers to entry and exit are relatively low, in contrast to many European countries. Having scope for experimentation may be an advantage in times of great technological uncertainty, when firms need to learn in the market place about what works and what does not. The current period of ICT-driven growth might be such a period.

Firm size and age

A substantial number of studies have looked at the relationship between ICT and firm size, notably as regards differences in the uptake of ICT by size of firm.[22] This question has been addressed in a large number of studies, most of which find that the adoption of advanced technologies, such as ICT, increases with the size of firms and plants.

Evidence for the United Kingdom, with 2000 data for a variety of network technologies used in different combinations, shows that large firms of over 250 employees are more likely to use network technologies such as Intranet, Internet or EDI than small firms; they are also more likely to have their own Web site. However, small firms of between 10 and 49 employees are more likely to use Internet as their only ICT network technology. Large firms are also more likely to use a combination of network technologies. For example, over 38% of all large UK firms use Intranet, EDI and Internet, and also have their own Web site, as opposed to less than 5% of small firms. Moreover, almost 45% of all large firms already used broadband technologies in 2000, as opposed to less than 7% of small firms.

22. There is also a question whether ICT has an effect on the size of firms or changes the boundaries of firms over time. See OECD (2003*a*) for some discussion of this issue.

These differences are partly due to the different uses of the network technologies by large and small firms. Large firms may use the technologies to redesign information and communication flows within the firm, and to integrate these flows throughout the production process. Some small firms only use the Internet for marketing purposes. Moreover, skilled managers and employees often help in making the technology work in large firms (Gretton *et al.* 2004).

There is also a question whether ICT has an effect on the size of firms or changes the boundaries of firms over time. This question is linked to the expectation that ICT might help lower transaction costs and thus changes the functions and tasks that should be carried out within firms and those that could be carried out outside the firm boundaries. This issue has been researched by only few firm-level studies, most of which use private data. For example, Hitt (1998) found that increased use of ICT was associated with decreases in vertical integration and increased diversification. Moreover, firms that were less vertically integrated and more diversified had a higher demand for ICT capital. Motohashi (2001) found that firms with computer networks outsourced more activities.

The link between size and age is also important, as it provides a link to firm creation. Dunne (1994) found that the impact of age on the likelihood of adopting advanced technologies was quite small. Luque (2000) confirmed this result, but found that age may have a role depending on plant size. Small new plants were more likely to adopt advanced technologies than small old plants. Maliranta and Rouvinen (2004) did find some impacts of firm creation for Finland, however, as part of the increase in ICT uptake was driven by the emergence of new firms and the demise of others.

Lags

Given the time it takes to adapt to ICT, it should not be surprising that the benefits of ICT may only emerge over time.[23] This can be seen, for example, in the relationship between the use of ICT and the year in which firms first adopted ICT. Evidence for the United Kingdom shows that among the firms that had already adopted ICT in or before 1995, close to 50% bought using electronic commerce in 2000 (Clayton and Waldron, 2003). For firms that only adopted ICT in 2000, less than 20% bought using e-commerce. The evidence presented by Clayton and Waldron suggests that firms move towards more complex forms of electronic activity over time; out of all firms starting to use ICT prior to 1995, only 3% had not yet moved beyond the straightforward use of ICT in 2000. Most had established an Internet site, or bought or sold through e-commerce. Out of the firms adopting ICT in 2000, over 20% had not yet gone beyond the simple use of ICT.

The role of lags also emerges from analysis for Australia. Gretton *et al.* (2004) used firm level information on productivity growth and the duration of computer use to examine the dynamics of the impact of the introduction of computers. They found that computers had a positive effect on MFP growth that varied between industries and that the positive effect was largest in the earlier years of uptake but appeared to taper off as firms returned to 'normal' growth after the productivity boost of the new technology. This indicates that the ultimate productivity effect from adoption of ICT is a step up in levels, rather than a permanent increase in the rate of growth. However, further technical developments can set further productivity-enhancing processes in motion.

23 . The existence of lags linked to the impacts of ICT is consistent with a view that ICT is a general purpose technology (GPT), a technology that requires a major redesign of existing ways of work (Lipsey, 2002).

5. Europe versus the United States

The evidence presented above points to a number of important differences between the impacts of ICT in the United States and those in the European Union – although the experience of different EU countries various considerably. The following differences can be noted:

- The aggregate evidence demonstrates that all OECD countries have experienced a substantial increase in the contribution of ICT investment to GDP growth over the 1990s. At the same time, there are considerable differences across countries with the United States, Japan, Canada, Australia and several small European countries deriving considerably larger benefits from ICT investment than several large EU countries such as France, Germany, Italy and Spain. The paper noted a few reasons for the more limited increase in ICT investment in Europe, including more stringent product and labour market regulations, that have limited competitive pressures and made it more difficult for European firms to engage in certain complementary investments, e.g. in organisational change.

- European countries typically have benefited less from ICT manufacturing production than the United States or Japan, with the exception of certain small EU countries such as Finland, Hungary, Ireland and Sweden.

- The production of ICT services, notably telecommunications, has made a sizable contribution to productivity growth in certain EU countries, notably in Germany. Overall, this sector has made a more important contribution to aggregate productivity growth in Europe than in the United States (O'Mahony and Van Ark, 2003).

- Most EU countries, notably large countries such as France, Germany and Italy, have not yet experienced an improvement in labour (or multi-factor) productivity growth in ICT-using services industries, such as wholesale and retail trade, finance, insurance and business services. This contrasts with the experience of countries such as the United States, Australia, Canada, Ireland and the United Kingdom, where productivity growth in this sector has increased from 1995 onwards.

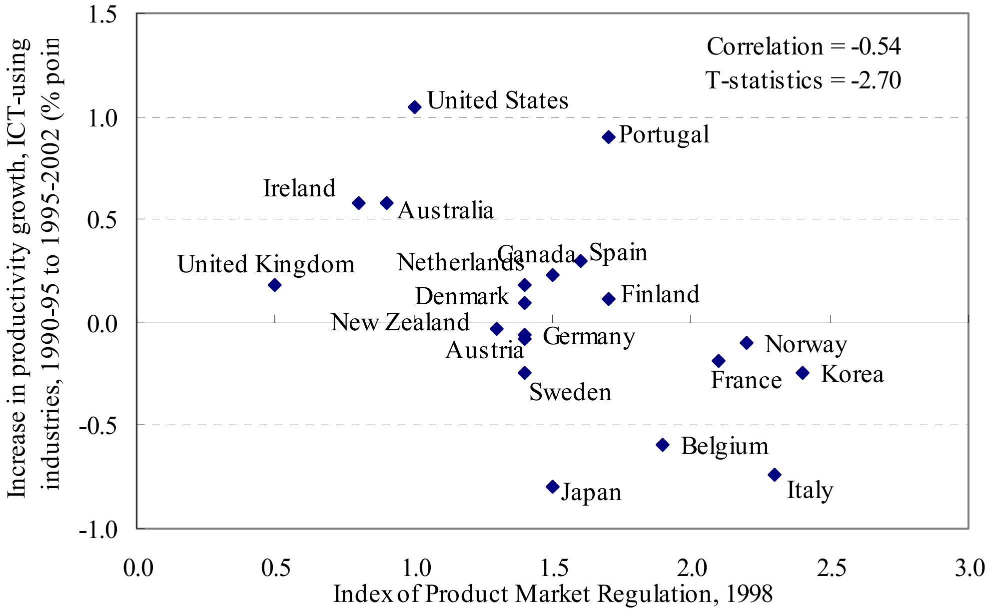
- In contrast to this aggregate and industry-level evidence, the firm-level evidence suggests that ICT use is beneficial – though under certain conditions – to firm performance and productivity in all countries for which micro-level studies have been conducted. The discussion below will briefly return to this apparent inconsistency between aggregate and firm-level evidence.

Overall, the evidence discussed above demonstrates that turning investment in ICT into higher productivity is not straightforward, and that many EU countries still have not experienced an uptake in productivity growth. This may be because turning ICT investment into productivity growth typically requires complementary investments and changes, *e.g.* in human capital, organisational change and innovation. Some of these changes may not yet have occurred to a sufficient degree in Europe. Since many studies point to a lag before the returns from investment in ICT become evident (OECD, 2004), this explanation would imply that the returns of ICT investment on productivity could still emerge in the near future.

However, this is not the only possible explanation for the lack of aggregate productivity impacts of ICT in many European countries. There is some evidence that the firm-level benefits may be larger in the United States (and possible also in Australia) than in other OECD countries, and thus show up more clearly in aggregate and sectoral evidence. For example, Haltiwanger *et al.* (2003) suggest that the impacts of ICT are smaller in Germany than in the United States. Given the more extensive diffusion of ICT in the United States, and its early start, this interpretation should not be surprising. This is particularly the case if it takes time before the benefits from ICT become apparent, *e.g.* because of high costs of adjustment to the new technology. Moreover, the conditions under which ICT is beneficial to firm performance, such as having sufficient scope for organisational change or process innovation, might be more firmly established in the United States than in many other OECD countries. Small firm-level benefits in European countries might thus lead to relatively small productivity benefits at the aggregate level.

Product market regulations may also play a role as they can limit firms in the ways that they can extract benefits from their use of ICT. For example, product market regulations may limit firms' ability to extend beyond traditional industry boundaries. Since ICT offers firms new capabilities, e.g. in selling or purchasing on-line, firms may be able to enter markets and introduce products and services that were not feasible before. For example, selling books on-line enables companies to sell in markets that they could not easily enter before. This may be in conflict with the regulations that are in place in such markets, simply because such electronic selling was not possible before. The impact of product market regulations on ICT investment is confirmed by several studies. For example, OECD countries that had a high level of product market regulation in 1998 have had lower shares of investment in ICT than countries with low degrees of product market regulation (Gust and Marquez, 2002; OECD, 2003*a*). Moreover, countries with a high degree or product market regulation have not seen the same pick-up in productivity growth in ICT-using services than countries with low levels of regulation (Figure 17).

Figure 17. **Relationship between growth in the contribution of ICT-using services to aggregate productivity growth and the state of product market regulation**



Source: Figure 13 and Nicoletti, *et al.*, 1999.

Moreover, firms that are successful in implementing ICT may be better able to gain market share and grow in a competitive market such as the United States than in less competitive markets. This would contribute to greater overall impacts of ICT in the United States. For example, some of pick-up in US productivity growth over the second half of the 1990s can be attributed to the growth in market share of Wal-Mart, a company that replaced many less efficient retailers, partly owing to its effective use of ICT throughout the value chain. If the most efficient firms in Europe find it difficult to expand and gain market share, even if they do benefit from ICT, the overall impacts on productivity might be more limited than in the United States.

Lack of complementary process innovation in the service sector may also limit the gains from ICT in European countries (OECD, 2003*a*). Innovation is important since firms often make their investments in ICT more valuable through their own experimentation and innovation, *e.g.* the introduction of new processes, products and applications. In the absence of this process of "co-invention", which often has a slower pace than technological innovation, the economic impact of ICT could be more limited in European countries than in the United States.

Examining the role of ICT also raises some difficult questions about the consistency of measures and empirical analysis at the aggregate, sectoral and firm level (see Gretton *et al.* 2004; OECD, 2004). There are several reasons why aggregate evidence on ICT may differ from firm-specific evidence. For example, aggregation across firms and industries, as well as the effects of other economic changes, may disguise the impacts of ICT in sectoral and aggregate analysis. This is also because the impacts of ICT depend on other factors and policy changes, which may differ across industries. The size of the aggregate effects over time depends on the rate of development of ICT, their diffusion, lags, complementary changes, adjustment costs and the productivity-enhancing potential of ICT in different industries (Gretton *et al.,* 2004). Disentangling such factors at the aggregate level is not straightforward.

Measurement may also play a role. The impacts of ICT may be insufficiently picked up in macroeconomic and sectoral data outside the United States, due to differences in the measurement of output. For example, the United States is one of the few countries that have changed the measurement of banking output to reflect the convenience of automated teller machines.[24] Since services sectors are the main users of ICT, inadequate measurement of service output might be a considerable problem.

6. Concluding remarks

This paper has shown that the evidence on the economic impacts of ICT is currently much better than it was 5 years ago. The more solid evidence on the economic impacts of ICT and the conditions under which these impacts occur are important for policy, as it helps underpin evidence-based policies (OECD, 2003*e*). For example, empirical analysis has demonstrated to policy makers that ICT does indeed matter for growth. Moreover, it has shown that ICT is no panacea and that there are large cross-country differences in the extent to which countries have thus far benefited from ICT.

Despite these achievements, further progress in both measurement and economic analysis is feasible and desirable. One important area concerns the measures of economic impacts that are available at the aggregate or industry level (see Ahmad, *et al.*, 2004; Pilat and Wölfl, 2004). This will require more comparable investment data, a greater use of quality-adjusted deflators, including for software investment, and improved output measures for services. More analytical work would also be helpful, *e.g.* in linking ICT investment more systematically to economic impacts, for example through econometric analysis at the aggregate or industry level.

However, a large potential for further work also lies in further work with firm-level data. There are at least two aspects to this. First, cross-country studies on the impact of ICT at the firm level are still relatively scarce, primarily since comparable data sources are still relatively new. Some studies discussed above have already engaged in international comparisons (Atrostic, *et al.*, 2004; Hempell, *et*

24. Although better measurement does not necessarily lead to higher output or productivity growth.

al., 2004; Haltiwanger *et al.,* 2003). Understanding the reasons for the cross-country differences reported in such studies would benefit from further work, and could lead to helpful insights for policy.

Second, there are several key issues that remain poorly analysed and that offer scope for progress. For example, further work with firm-level data could provide greater insights into the contribution of firm dynamics to productivity gains, *e.g.* the role of new firms, the conditions that lead to successful survival and the factors determining firm exit. Moreover, the link between innovation and ICT has only been examined for some OECD countries. Understanding this link is of great importance as long-term growth largely depends on the future pace of innovation. Moreover, quantitative analysis of the price and productivity impacts of electronic commerce and e-business processes is still in its early stages, but is a promising area of further work, as suggested in a recent study for the United Kingdom (Clayton, et al., 2004). Finally, while there is good evidence for some OECD countries that ICT can help transform the service sector and make it more innovative and productive, a good understanding of ICT's impact on the service sector is still lacking, partly because of some thorny measurement problems but also due to lack of cross-country empirical analysis.

Finally, the work discussed above also serves to highlight the importance of close interaction between statistical development and policy analysis. Many of the data used in the studies discussed above were not yet available 5 or 6 years ago; the bulk were developed in response to demands by policy makers for new and better data on ICT diffusion. The response of statistical offices to this demand has been quick and comprehensive. But this interaction also works the other way; effective use of the large amounts of data held by statistical offices can provide a wealth of policy-relevant information if the data is made accessible for research by academics and other analysts. This remains a challenge in several OECD countries.

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