# THE ECONOMIC IMPACTS OF ICT – WHAT HAVE WE LEARNED THUS FAR?

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**PAPER PREPARED FOR THE 4TH ZEW CONFERENCE ON THE ECONOMICS OF INFORMATION AND COMMUNICATION TECHNOLOGIES, MANNHEIM, JULY 2-3, 2004**

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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? And what are the conditions under which ICT can become a technology that is effective in enhancing growth and productivity? 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 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, 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 can help 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.

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;

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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; 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). Moreover, the European Union lags behind the United States in this sector (O'Mahony and Van Ark, 2003).

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. Moreover, the aggregate 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.[5] Firm-level data can also point to 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.

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).[6] Most OECD countries now collect information at the 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 can also link the performance of individual firms to that of the economy as a whole.

This paper summarises some of the findings on the impacts of ICT, and examines results from aggregate, sectoral and firm-level studies. 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

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).

4 . Gretton, *et al.* (2004) discusses 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 . 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) and OECD (2004).

6 . Progress in this area is partly due 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.

ICT and economic growth (OECD, 2003, 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 paper therefore also discusses some of the key challenges for measurement and analysis. The next section examines some of the evidence on the economic impacts of ICT at the aggregate and industry level. The third section examines the firm-level evidence, while the fourth section discusses the differences between aggregate and firm-level findings. The fifth section concludes.

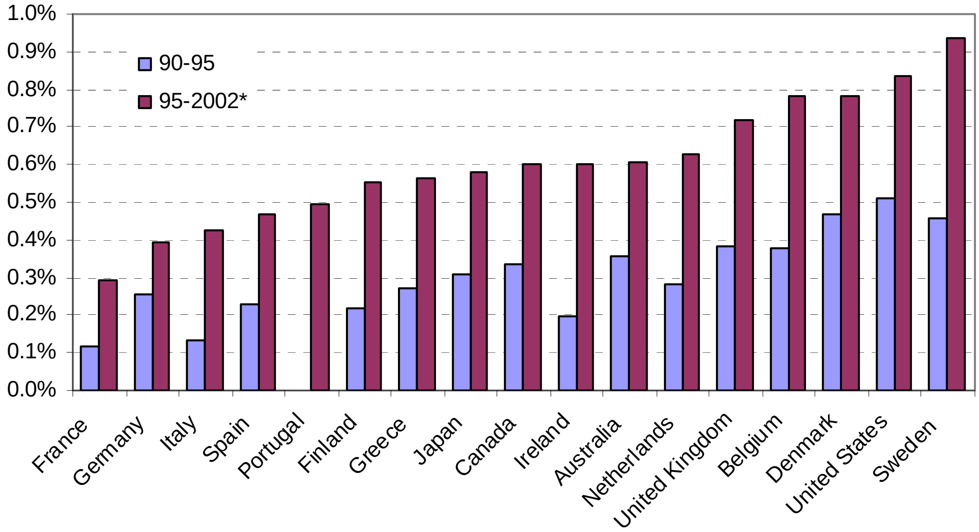
## 2. The impacts of ICT at the aggregate level

### *2.1 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) and Schreyer, *et al.* (2003). All of these studies 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 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 1). Sweden, the United States, Denmark, Belgium and the United Kingdom received the largest boost; Japan a more modest one, and Germany, France and Italy a much smaller one.[7]

Figure 1: **The contribution of investment in ICT capital to GDP growth**

Percentage points contribution to annual average GDP growth, total economy




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

7 . The estimates in Figure 1 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).

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. The method can be applied at both the macro-economic and industry level, providing the appropriate data are available.[8] 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 larger contribution of ICT capital to growth performance. The method used in Figure 1 and in the work by Colecchia and Schreyer (2001) and Van Ark, et al. (2002) adjusts for these differences.

Measuring the impacts of ICT investment is not yet straightforward. This is partly because measures of ICT investment are not available for all OECD countries and when they are, they are not necessarily comparable across countries. Data on software investment are particularly problematic, *e.g.* since countries show a large variety in how much of total software spending is counted as investment. Measuring software has been the subject of an OECD/Eurostat Taskforce that has produced a range of recommendations to improve measurement (see Ahmad, 2003).

A second important issue concerns the adjustment of volume measures of ICT investment for rapid quality change. Hedonic deflators may help to deal with this issue, but these have only been developed in some countries and for some key product categories. To address problems of international comparability, empirical studies often use US hedonic deflators to represent price changes in other countries. This is only a second-best solution as countries should ideally develop deflators that properly account for quality change of ICT products in their own national context. An OECD Handbook on Quality Adjustment of Price Indexes for ICT Products is due for publication in 2004, and may be followed by further steps to implement its findings in national statistical practices. A particular important area is hedonic deflators for software investment; currently, the United States is one of the few OECD countries that use hedonic deflators for pre-packaged software. The range of deflators for software is large, with some countries pointing to large price increases and other to substantial declines over the 1990s (Ahmad, 2003).

There are other measurement problems that affect the analysis of ICT investment. For example, analysis at the industry level is limited by a lack of information on investment and capital stocks by asset. This makes it difficult to apply growth accounting at the industry level.[9] Moreover, the empirical evidence on several key assumptions to construct estimates of capital services is limited. For example, relatively little is known about age-efficiency profiles and retirement patterns of assets.

The other limitation of the work on ICT investment discussed above is that the growth accounting method is based on a number of assumptions. 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

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

9 . Several recent growth accounting studies are available at the industry level, however, e.g. Inklaar, *et al.* (2003).

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.[10]

### *2.2 The role of the ICT-producing sector*

The second impact of ICT derives from the ICT-producing sector. This sector is of particular interest for several countries, as it has been characterised by very high rates of productivity growth, providing a considerable contribution to aggregate performance. The sector has been defined in official statistics (Box 1). Examining the contribution of this sector to aggregate productivity growth is relatively straightforward.

Box 1. **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

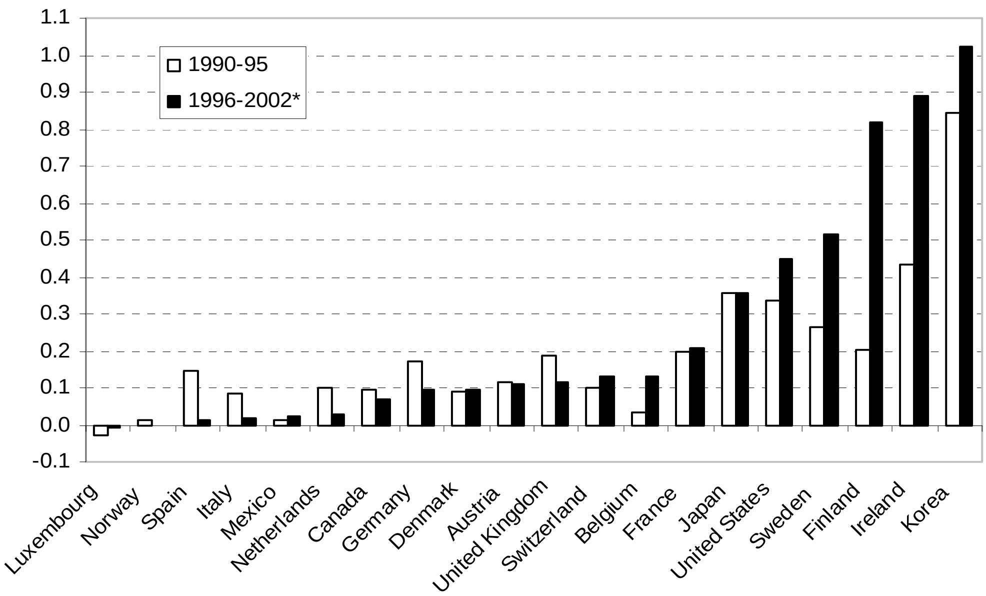
7200 Computer and related activities (hardware consultancy, software consultancy and supply, data processing, database activities, maintenance and repair of office, accounting and computing machinery, other)

*Source:* OECD (2002).

10 . OECD (2003) includes an overview of many growth accounting studies in OECD countries.

Figure 2 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.[11]

Figure 2: **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; 1996-98 for Sweden, 1996-99 for Korea and Spain, 1996-2000 for Ireland, Norway and Switzerland, 1996-2001 for France, Germany, Japan, Mexico, the Netherlands, the United Kingdom and the United States.

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

ICT manufacturing made the largest contributions to aggregate productivity growth in Finland, Ireland, Japan, Korea, Sweden and the United States. In Finland, Ireland and Korea, close to 1 percentage point of aggregate productivity growth in the 1995-2001 period is due to ICT manufacturing.[12] The ICT-producing services sector (telecommunications and computer services) plays a smaller role in aggregate productivity growth, but has also been characterised by rapid

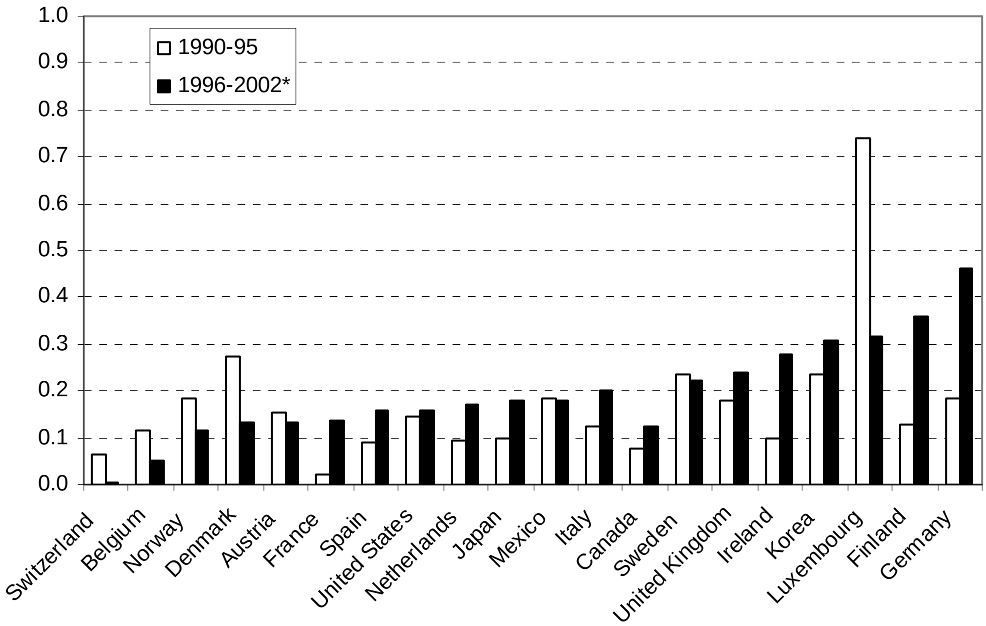
11 . The large product variety also affects productivity comparisons. Some countries, such as the United States, use hedonic price indexes to capture rapid quality changes in the ICT-producing sector. This typically raises productivity growth for these sectors compared to countries that do not use these 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 appropriate for a country producing only computer terminals or peripheral equipment. See Pilat, *et al.* 2002, for details.

12 . Data for 2001 show a sharp slowdown in ICT production in Finland, and consequently a decline in the contribution of this sector to aggregate productivity growth.

progress (OECD, 2003*a*; Figure 3). 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.

Figure 3. **Contribution of ICT-producing services to aggregate labour productivity growth**

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




Note: See Figure 2 for period coverage.

*Source*: Estimates on the basis of the OECD STAN database, February 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 1996-2000 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%.[13]

A number of problems confront the measurement of the economic impacts of the ICT-producing sector. First, the official OECD definition of the ICT sector can not be easily applied in analysis of productivity growth. Analysis of productivity growth requires time series of value added and/or production in constant prices, which implies deflators for the appropriate industries. These are not always available for detailed categories and OECD work has therefore primarily focused on the main categories that can be distinguished in the national accounts by activity, i.e. ISIC 30-33 (Electrical and Optical Equipment), ISIC 64 (Post and Telecommunications) and ISIC 72 (Computer and Related Activities). Second, the available deflators are not always comparable across countries. Several countries currently use hedonic methods to deflate output in the computer industry (*e.g.* Canada, Denmark, France, Sweden and the United States). Adjusting for these methodological differences in computer deflators for the purpose of a cross-country comparison is difficult, however, since there are considerable cross-country differences in industrial specialisation. Only few OECD countries produce computers, where price falls have been very rapid; many only produce peripheral equipment, such as computer terminals. The differences in the composition of output are typically larger than in computer investment, where standardised approaches have been applied (*e.g.* Colecchia and Schreyer, 2001). Third, lack of data on capital stock by industry implies that estimates of multi-factor productivity growth can not always be derived. The problems become more complex when MFP estimates are to be based on capital services, as an asset breakdown by industry is required.

There are also 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 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.

### *2.3 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.

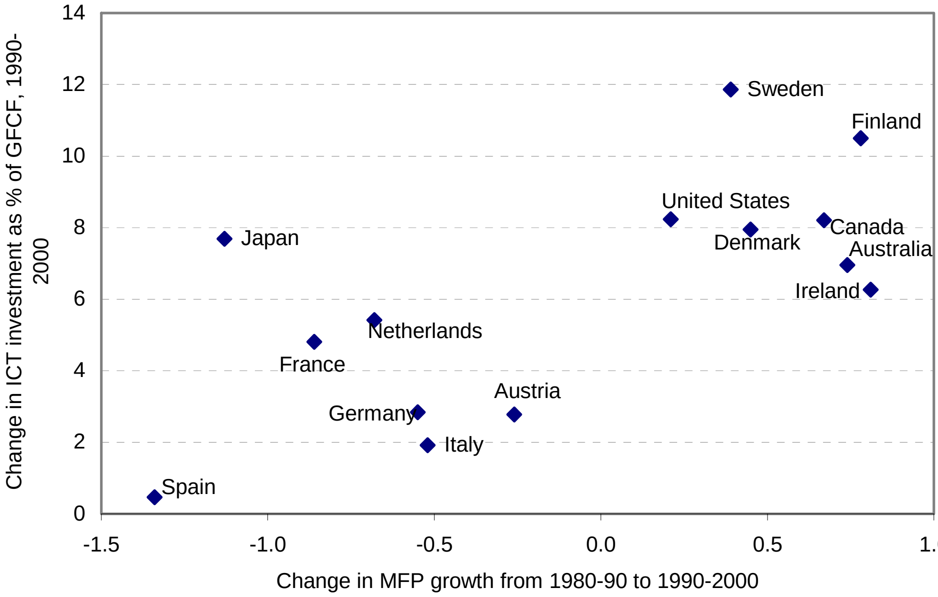
The diffusion of ICT may also have impacts that go beyond individual firms as it may help establish ICT networks, which produce greater benefits (the so-called spill-over effects) the more customers or

13. 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.

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 economic 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 4). 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 for a wide range of OECD countries.

Figure 4. **Pick-up in MFP growth and increase in ICT investment**




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

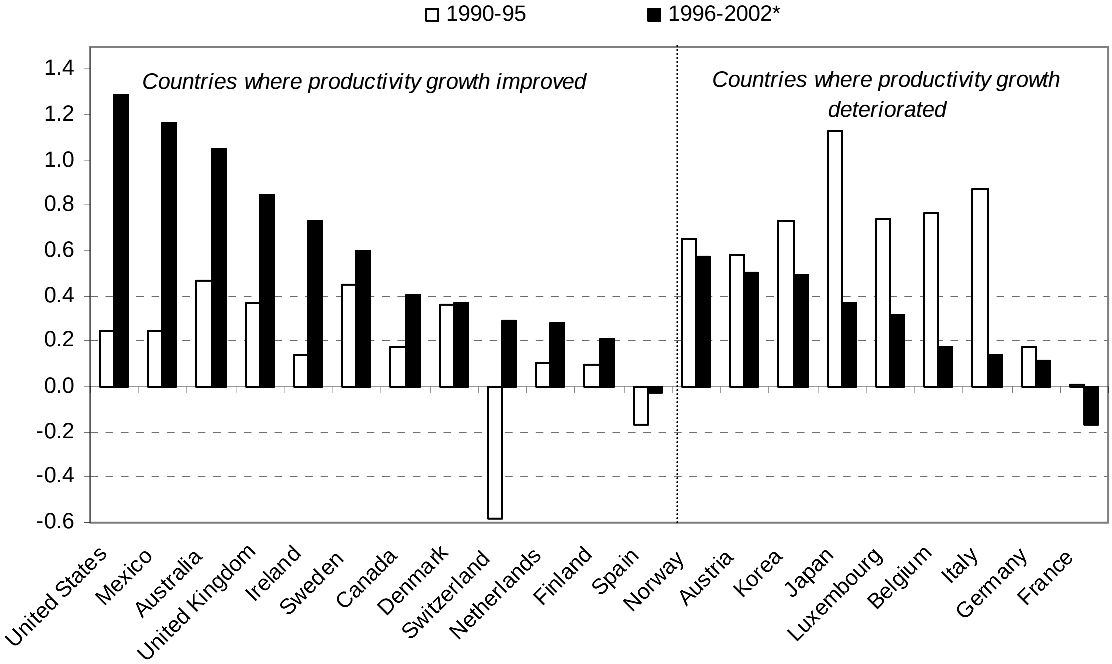
While few studies are available at the aggregate level, a considerably larger number of studies have examined the impacts of ICT use with sectoral data. Several of these studies have distinguished an ICT-using sector, composed of industries that are intensive users of ICT (McGuckin and Stiroh, 2001; 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.[14] Services sectors such as finance and business services are

14. 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. This makes it difficult to delineate the main ICT-using sectors. Moreover, the lack

typically the most intensive users of ICT. Figure 5 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.

Figure 5. **Contribution of ICT-using services to aggregate labour productivity growth, 1990-95 and 1996-2002**

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




*Note:* See Figure 2 for period coverage. Data for Australia are for 1996-2001.
*Source*: Estimates on the basis of the OECD STAN database, February 2004. See Pilat and Wölfl (2004) for detail.

The graph suggests small improvements in the contribution of ICT-using services in Finland, the Netherlands, Norway and Sweden, and substantial increases in Australia, Canada, Ireland, Mexico, 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.[15]

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

of capital stock at the activity level also implies that it is often not possible to examine MFP growth, as opposed to labour productivity growth.

15 . 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.

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. First, 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, it is difficult to separate service output from the consumer’s role in eliciting the output. For example, output of the education sector is partly due to the efforts made by students themselves. Such difficulties indicate that the volume and price of services – and changes in their quality – are harder to measure than those of goods. 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 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 to improve measurement. Work is currently underway at OECD in some areas, e.g. finance and insurance.

Further analytical work with industry-level data would also 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.

## 3. The impacts of ICT at the firm level

### *3.1 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. The first studies in this area were typically based on ICT data derived from technology use surveys, such as the Survey of Manufacturing Technology in the Netherlands or the United States, and the Survey of Advanced Technology in Canada[16]. Other studies used data on IT investment derived from production or investment surveys. In recent years, more data on ICT have become available, *e.g.* from surveys of ICT use and e-commerce undertaken in many OECD countries. Moreover, innovation surveys, such as the European Union's Community Innovation Survey, often include some questions on computer use that can, in principle, be used for empirical analysis. In addition, several countries have other statistical surveys that provide data on ICT use by firms. In principle, such data can all be used for firm-level analysis.

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

16 . Vickery and Northcott (1995) provide an overview of these technology use surveys.

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). Examining the impacts of ICT in isolation may thus be of limited use.

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 1). 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 1: **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; 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).

### *3.2. 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 2).

Box 2: **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.

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 some OECD countries, but this remains an important problem in examining the impact of ICT on performance.

A second reason for the delay 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.

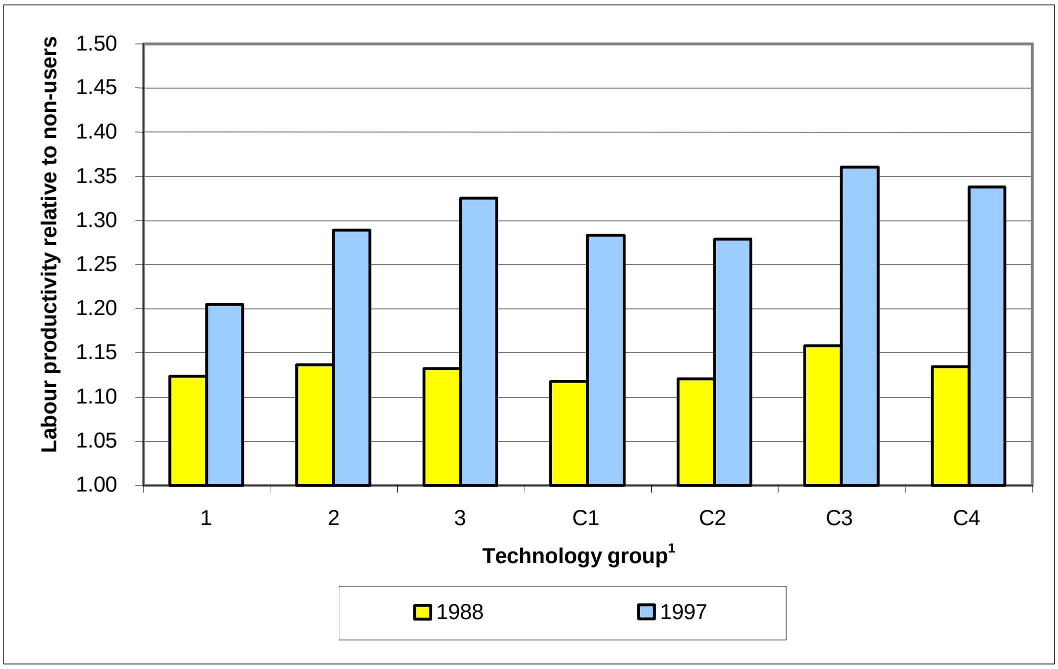
A third reason is that many early studies that attempted to capture the impact of ICT at the firm level were based on relatively small samples of firms, drawn from private sources. If the initial impact of ICT on performance was small, such studies might find little evidence, as it would easily get lost 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 statistically sounder 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 an expert group, composed of researchers and statisticians from 13 OECD countries to generate further evidence on the link between ICT and business performance (OECD, 2003, 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 6 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.[17] 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 productivity than other technologies; communication network technologies being particularly important.

Figure 6. **Relative productivity of advanced technology users and non-users**
Manufacturing sector in Canada, 1988 versus 1997

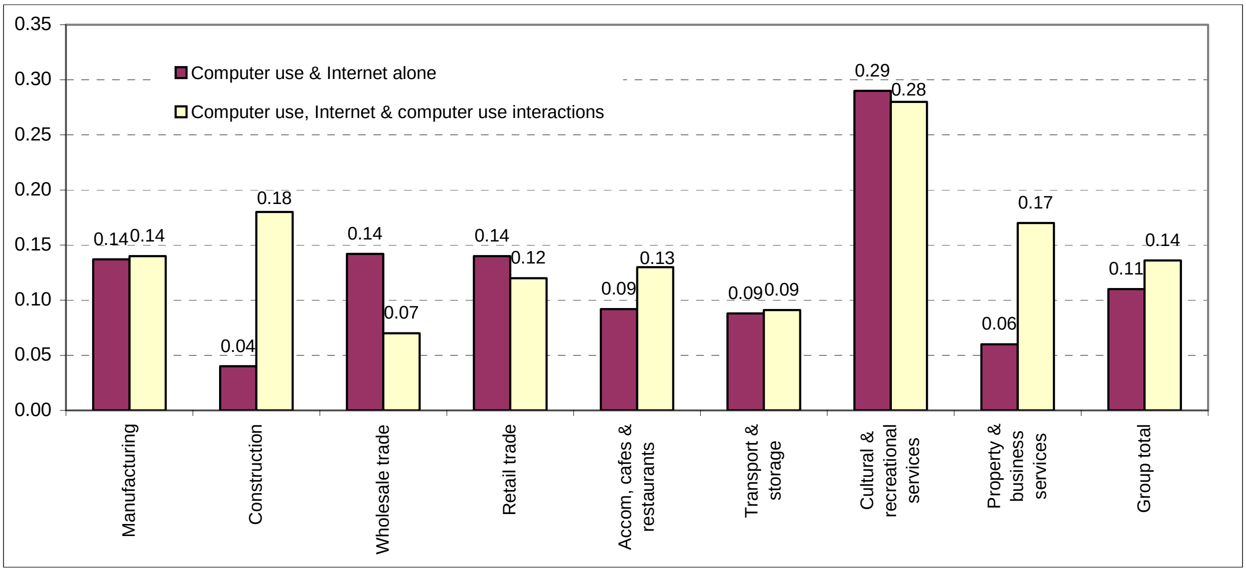



1. The graph shows the relative productivity on technology users compared to groups not using any advanced technology.
Note: The following technology groups are distinguished: Group 1 (software); Group 2 (hardware); Group 3 (communications); Group C1 (software and hardware); Group C2 (software and communications);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

17 . 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 7 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 7. **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 6 and 7 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).

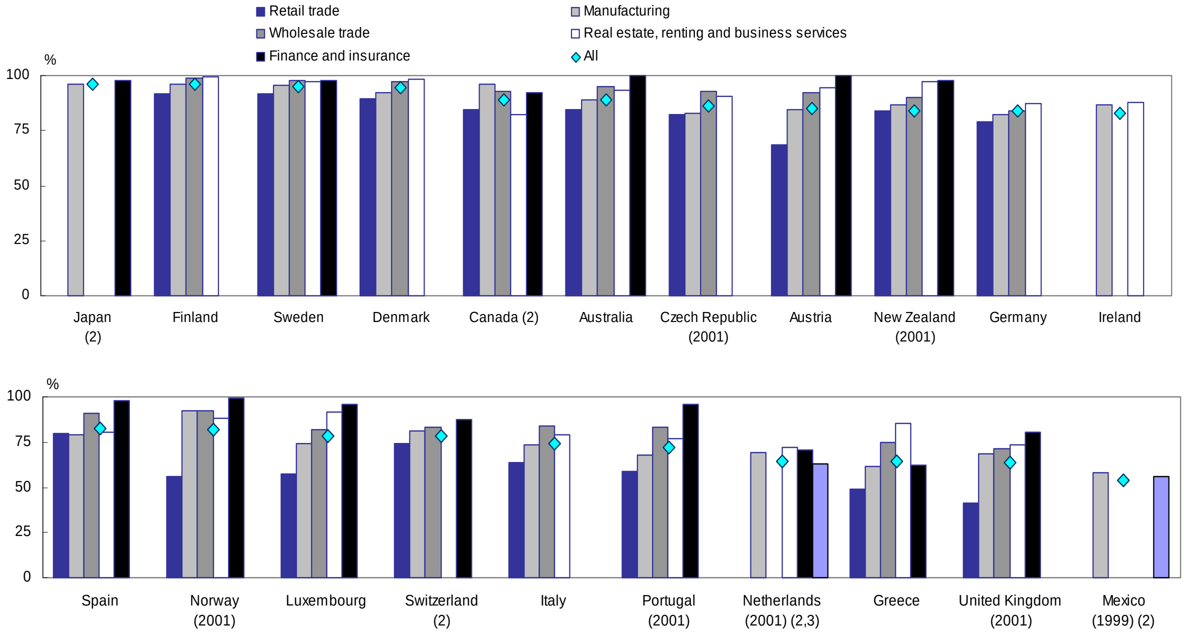
*Impacts in services*

ICT use is more widespread in some parts of the services sector than in manufacturing (OECD, 2003). Moreover, not all sectors use the same technologies. In many countries, financial services are among the most ICT-intensive sectors (Figure 8). Evidence for the United Kingdom suggests that financial intermediation is also the sector most likely to use network technologies (OECD, 2003), 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 8. **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.

### *3.3. 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. However, these impacts occur primarily, or only, when 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 experimentation and 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 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.[18] 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.

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

18. 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) for some discussion of this issue.

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. 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.

## 4. Aggregate versus firm-level evidence

Examining the role of ICT at the aggregate, sectoral and firm level raises some difficult questions (see Gretton *et al.* 2004; OECD, 2004). The firm-level evidence suggests that ICT use is beneficial – though under certain conditions – to firm performance in all countries for which micro-level studies have been conducted. However, the aggregate and sectoral evidence is less conclusive about the benefits of ICT use. It shows that investment in ICT capital has contributed to growth in most OECD countries, and that the ICT-producing sector has contributed to productivity growth in some OECD countries. There is, however, little evidence that ICT-using industries have experienced more rapid productivity growth, the United States and Australia being the major exceptions. There are several reasons why this may be the case and why aggregate evidence may differ from firm-specific evidence.

First, 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.

Second, the firm-level benefits of ICT 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, might be more firmly established in the United States than in many other OECD countries.

Third, 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.

Fourth, measurement may 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. Since services sectors are the main users of ICT, inadequate measurement of service output might be a considerable problem.

Fifth, countries outside the United States may not yet have benefited from spill-over effects that could create a wedge between the impacts observed for individual firms and those at the macroeconomic level. The discussion above has already suggested that the impacts of ICT may be larger than the direct returns flowing to firms using ICT. For example, ICT may lower transaction costs, that can improve the functioning of markets (by improving the matching process), and make new markets possible. Another effect that can create a gap between firm-level returns and aggregate returns is ICT's impact on knowledge creation and innovation. ICT enables more data and information to be processed at a higher speed and can thus increase the productivity of the process of knowledge creation. A greater use of ICT may thus gradually improve the functioning of the economy. Such spill-over effects may already have shown up in the aggregate statistics in the United States, but not yet in other countries.

Finally, the state of competition may also play a role in the size of spill-over effects. In a large and highly competitive market, such as the United States, firms using ICT may not be the largest beneficiaries of investment in ICT. Consumers may extract a large part of the benefits, in the form of lower prices, better quality, improved convenience, and so on. In other cases, firms that are upstream or downstream in the value chain from the firms using ICT might benefit from greater efficiency in other parts of the value chain. In countries with a low level of competition, firms might be able to extract a greater part of the returns, and spill-over effects might thus be more limited. Further cross-country research may help to address these questions, and provide new insights in the extent of any ICT-related spill-overs.

## 5. Concluding remarks

The studies discussed above demonstrate that the empirical evidence of the economic impacts of ICT is significantly improved from what it was only a few years ago. Many OECD countries now provide estimates of ICT investment that enable calculations of capital services and of the contribution of ICT investment to overall growth (Schreyer, *et al.*, 2003). Data on the ICT industry and on those parts of the services sector that are intensive users of ICT are also available for many countries, permitting a breakdown of productivity growth by industry. Moreover, many countries now have regular business surveys of ICT use that provide an overview of diffusion patterns. These surveys provide a wealth of information for empirical research.

The evidence also suggests that turning investment in ICT into higher productivity is not straightforward. It typically requires complementary investments and changes, *e.g.* in human capital, organisational change and innovation. Moreover, ICT-related changes are part of a process of search and experimentation, where some firms succeed and grow and others fail and disappear. Countries with a business environment that enables this process of creative destruction may be better able to seize benefits from ICT than countries where such changes are more difficult and slow to occur.

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. However, 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 or software investment, and improved output measures for services. Much more analytical work can also be done, e.g. in linking ICT investment more systematically to economic impacts, e.g. through regression analysis at the aggregate or industry level. The role of the ICT producing sector in seizing the benefits of ICT also remains controversial and would benefit from further econometric work.

However, the largest potential for further work probably lies 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 al.*, 2004; Haltiwanger *et al.*, 2003). Understanding the reasons for the cross-country differences in the impacts of ICT 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 more broadly 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 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 for several OECD countries.

**References**


Ahmad, N. (2003), "Measuring Investment in Software", *STI Working Paper 2003/6*, OECD, Paris.

Ahmad, N., P. Schreyer and A. Wölfl (2004), "ICT Investment in OECD Countries and its Economic Impacts", in OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris, pp. 61-83.

Arvanitis, S. (2004), "Information Technology, Workplace Organisation, Human Capital and Firm Productivity: Evidence for the Swiss Economy", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris.

Atrostic, B.K., P. Boegh-Nielsen, K. Motohashi and S. Nguyen (2004), "IT, Productivity and Growth in Enterprises: Evidence from New International Micro Data", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris.

Atrostic, B.K. and S. Nguyen (2002), "Computer Networks and US Manufacturing Plant Productivity: New Evidence from the CNUS Data", *CES Working Paper 02-01*, Center for Economic Studies, Washington DC.

Baily, M.N. (2002), "The New Economy: Post Mortem or Second Wind", *Journal of Economic Perspectives*, Vol. 16, No. 2, Spring 2002, pp. 3-22.

Baldwin, J.R. and B. Diverty (1995), "Advanced Technology Use in Canadian Manufacturing Establishments", Working Paper No. 85, Microeconomics Analysis Division, Statistics Canada, Ottawa.

Baldwin, J.R., B. Diverty, and D. Sabourin (1995*a*), "Technology Use and Industrial Transformation: Empirical Perspective", Working Paper No. 75, Microeconomics Analysis Division, Statistics Canada, Ottawa.

Baldwin, J.R., T. Gray, and J. Johnson (1995*b*), "Technology Use, Training and Plant-Specific Knowledge in Manufacturing Establishments", *Working Paper No. 86*, Microeconomics Analysis Division, Statistics Canada, Ottawa.

Baldwin, J.R. and D. Sabourin (2002), "Impact of the Adoption of Advanced Information and Communication Technologies on Firm Performance in the Canadian Manufacturing Sector", *STI Working Paper 2002/1*, OECD, Paris.

Baldwin, J.R., D. Sabourin and D. Smith (2004), "Firm Performance in the Canadian Food Processing Sector: the Interaction between ICT Advanced Technology Use and Human Resource Competencies", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris, pp. 153-181.

Bartelsman, E.J. and M. Doms (2000), "Understanding Productivity: Lessons from Longitudinal Micro Datasets", *Journal of Economic Literature*, Vol. 38, September.

Bartelsman, E. and J. Hinloopen (2002), "Unleashing Animal Spirits: Investment in ICT and Economic Growth", *mimeo*.

Bartelsman, E.J., S. Scarpetta and F. Schivardi (2003), "Comparative Analysis of Firm Demographics and Survival: Micro-Level Evidence for the OECD Countries", *OECD Economics Department Working Paper No. 348*, OECD, Paris.

Bertschek, I. and H. Fryges (2002), "The Adoption of Business-to-Business E-Commerce: Empirical Evidence for German Companies", ZEW Discussion Paper No. 02-05, ZEW, Mannheim.

Black, S.E. and L.M. Lynch (2001), "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity", *The Review of Economics and Statistics*, August, Vol. 83, No. 3, pp. 434-445.

Bosworth, B.P and J.E. Triplett (2003), "Services Productivity in the United States: Griliches' Services Volume Revisited", paper prepared for CRIW Conference in Memory of Zvi Griliches, Brookings Institution, Washington, DC, September.

Bresnahan, T.F., E. Brynjolfsson, and L.M. Hitt (2002), "Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-Level Evidence", *Quarterly Journal of Economics*, Vol. 117, February, pp. 339-376.

Bresnahan, T.F. and S. Greenstein (1996), "Technical Progress and Co-Invention in Computing and the Use of Computers", *Brookings Papers on Economic Activity: Microeconomics*, pp. 1-77.

Brynjolfsson, E. and L. Hitt (1997), "Computing Productivity: Are Computers Pulling Their Weight?", mimeo MIT and Wharton, http://ccs.mit.edu/erik/cpg/.

Brynjolfsson, E. and S. Yang (1996), "Information Technology and Productivity: A Review of the Literature", *mimeo*, http://ecommerce.mit.edu/erik/.

Caroli, E. and J. Van Reenen (1999), "Organization, Skills and Technology: Evidence from a Panel of British and French Establishments", IFS Working Paper Series W99/23, Institute of Fiscal Studies, August.

Chakraborty, A. and M. Kazarosian (1999), "Product Differentiation and the Use of Information Technology: New Evidence from the Trucking Industry", *NBER Working Paper*, No. 7222, NBER, July.

Clayton, T., C. Criscuolo, P. Goodridge and K. Waldron (2004), “Enterprise E-commerce: Measurement and Impact”, in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris, pp. 241-260.

Clayton, T. and K. Waldron (2003), “E-Commerce Adoption and Business Impact, A Progress Report”, *Economic Trends*, forthcoming.

Colecchia, A. and P. Schreyer (2001), “The Impact of Information Communications Technology on Output Growth”, *STI Working Paper 2001/7*, OECD, Paris.

Council of Economic Advisors (2001), *Economic Report of the President, 2001*, United States Government Printing Office, Washington, DC, February.

Crepon, B. and T. Heckel (2000), « Informatisation en France: une évaluation à partir de données individuelles », G2000/13, Document de travail (Working paper, in French), INSEE.

Criscuolo, C. and K. Waldron (2003), “Computer Network Use and Productivity in the United Kingdom”, Centre for Research into Business Activity and Office of National Statistics, *mimeo*.

De Gregorio, C. (2002), “Micro Enterprises in Italy: Are ICTs and Opportunity for Growth and Competitiveness?”, paper presented at OECD workshop on ICT and Business Performance, ISTAT, Rome, December.

De Panniza, A., L. Nascia, A. Nurra, F. Oropallo and F. Riccardini (2002), “ICT and Business Performance in Italy”, paper presented at OECD workshop on ICT and Business Performance, ISTAT, Rome, December.

Doms, M., T. Dunne, and M.J. Roberts (1995), “The Role of Technology Use in the Survival and Growth of Manufacturing Plants”, *International Journal of Industrial Organization* 13, No. 4, December, pp. 523-542.

Doms, M., R. Jarmin and S. Klimek (2002), “IT Investment and Firm Performance in US Retail Trade”, *CES Working Paper 02-14*, Center for Economic Studies, Washington DC.

Dunne, T. (1994), “Plant Age and Technology Use in US Manufacturing Industries”, *Rand Journal of Economics*, Vol. 25, No. 3, pp. 488-499.

Entorf, H. and F. Kramarz (1998), “The Impact of New Technologies on Wages: Lessons from Matching Panels on Employees and on their Firms”, *Economic Innovation and New Technology*, Vol. 5, pp. 165-197.

Falk, M. (2001), “Organizational Change, New Information and Communication Technologies and the Demand for Labor in Services”, *ZEW Discussion Paper No. 01-25*, ZEW, Mannheim.

Fixler, D. and K. Zieschang (1999), “The Productivity of the Banking Sector: Integrating Approaches to Measuring Financial Service Output”, *Canadian Journal of Economics*, Vol. 32, No. 2, pp. 547-569.

Gordon, R.J. (2002), “Technology and Economic Performance in the American Economy”, *NBER Working Papers*, No. 8771, National Bureau of Economic Research, February.

Greenan, N. and D. Guellec (1998), "Firm Organization, Technology and Performance: An Empirical Study", *Economics of Innovation and New Technology*, Vol. 6, No. 4, pp. 313-347.

Greenan, N., J. Mairesse and A. Topiol-Bensaid (2001), "Information Technology and Research and Development Impacts on Productivity and Skills: Looking for Correlations on French Firm Level Data", NBER Working Paper 8075, Cambridge, MA.

Gretton, Paul, Jyothi Gali and Dean Parham (2004), "The Effects of ICTs and Complementary Innovations on Australian Productivity Growth", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris.

Haltiwanger, J., R. Jarmin and T. Schank (2003), "Productivity, Investment in ICT and Market Experimentation: Micro Evidence from Germany and the United States", *Center for Economic Studies Working Paper CES-03-06*, US Bureau of the Census, Washington, D.C.

Haskel, J. and Y. Heden (1999), "Computers and the Demand for Skilled Labour: Industry- and Establishment-Level Panel Evidence for the UK", *The Economic Journal*, 109, C68-C79, March.

Hempell, T. (2002), "Does Experience Matter? Productivity Effects of ICT in the German Service Sector", *Discussion Paper No. 02-43*, Centre for European Economic Research, Mannheim.

Hempell, T., G. Van Leeuwen and H. Van Der Wiel (2004), "ICT, Innovation and Business Performance in Services: Evidence for Germany and the Netherlands", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris.

Hitt, L.M. (1998), "Information Technology and Firm Boundaries: Evidence from Panel Data", University of Pennsylvania, *mimeo.*

Hollenstein, H. (2004), "The Decision to Adopt Information and Communication Technologies (ICT): Firm-Level Evidence for Switzerland", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris, pp. 37-60.

Inklaar, R., M. O'Mahony and M. Timmer (2003), "ICT and Europe's Productivity Performance

Jorgenson, D.W. (2001), "Information Technology and the US Economy", *American Economic Review*, Vol. 91, No. 1, pp. 1-32.

Jorgenson, D.W. (2003), "Information Technology and the G7 Economies", Harvard University, December, *mimeo*, http://post.economics.harvard.edu/faculty/jorgenson/

Jorgenson, D.W., M.S. Ho and K.J. Stiroh (2002), "Projecting Productivity Growth: Lessons from the US Growth Resurgence", *Federal Reserve Bank of Atlanta Economic Review*, third quarter, pp. 1-13.

Luque, A. (2000), "An Option-Value Approach to Technology Adoption in US Manufacturing: Evidence from Plant-Level Data", *CES WP-00-12*, Center for Economic Studies, Washington, DC.

Luque, A. and J. Miranda (2000), "Technology Use and Worker Outcomes: Direct Evidence from Linked Employee-Employer Data", *CES WP-00-13*, Center for Economic Studies, Washington, DC.

Maliranta, M. and P. Rouvinen (2004), "ICT and Business Productivity: Finnish Micro-level Evidence", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris, pp. 213-239.

McGuckin, R.H. and G.A. Pascoe (1988), "The Longitudinal Research Database: Status and Research Possibilities", *Survey of Current Business*, 68, November, pp. 30-37.

McGuckin, R.H. and K.J. Stiroh (2001), "Do Computers Make Output Harder to Measure?", *Journal of Technology Transfer*, Vol. 26, pp. 295-321.

McKinsey (2001), *US Productivity Growth 1995-2000: Understanding the Contribution of Information Technology Relative to Other Factors*, McKinsey Global Institute, Washington, D.C. October.

Milana, C. and A. Zeli (2004), "Productivity Slowdown and the Role of ICT in Italy: A Firm-Level Analysis", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris, pp. 261-277.

Motohashi, K. (2001), "Economic Analysis of Information Network Use: Organisational and Productivity Impacts on Japanese Firms", Research and Statistics Department, METI, *mimeo*.

Motohashi, K. (2003), "Firm level analysis of information network use and productivity in Japan", *RIETI Discussion Paper Series 03-E-021*, RIETI, Tokyo.

OECD (2002), *Measuring the Information Economy*, OECD, Paris.

OECD (2003), *ICT and Economic Growth – Evidence from OECD Countries, Industries and Firms*, OECD, Paris.

OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris.

Oliner, S.D. and D.E. Sichel (2002), "Information Technology and Productivity: Where Are We Now and Where Are We Going?", *Federal Reserve Bank of Atlanta Economic* Review, third quarter, pp. 15-44.

O'Mahony, M. and B. van Ark (2003) (eds.), *EU Productivity and Competitiveness: An Industry Perspective – Can Europe Resume the Catching Up Process?*, European Community, Luxembourg.

Pilat, D., F. Lee and B. Van Ark (2002), "Production and use of ICT: A sectoral perspective on productivity growth in the OECD area", *OECD Economic Studies*, No. 35, Paris, pp. 47-78.

Pilat, Dirk and Anita Wölfl (2004), "ICT production and ICT use – what role in aggregate productivity growth?", in: OECD (2004), *The Economic Impact of ICT – Measurement, Evidence and Implications*, OECD, Paris.

Schreyer, Paul, Pierre-Emmanuel Bignon and Julien Dupont (2003), “OECD Capital Services Estimates: Methodology and A First Set of Results”, *OECD Statistics Working Papers 2003/6*, OECD, Paris.

Solow, R.M. (1987), “We’d Better Watch Out”, *New York Times*, July 12, Book Review, No. 36.

Stolarick, K.M. (1999), “Are Some Firms Better at IT? Differing Relationships between Productivity and IT Spending”, *CES WP-99-13*, Center for Economic Studies, Washington, DC.

Triplett, J.E. (1999), “The Solow Productivity Paradox: What Do Computers Do to Productivity”, *Canadian Journal of Economics*, Vol. 32, No. 2, pp. 309-334.

Triplett, J. and B. Bosworth (2004), *Services Productivity in the United States – New Sources of Economic Growth*, Brookings Institution, Washington, D.C.

Van Ark, B., R. Inklaar and R.H. McGuckin (2002), “Changing Gear – Productivity, ICT and Service Industries: Europe and the United States”, *Research Memorandum GD-60*, University of Groningen, December.

Van Ark, B., J. Melka, N. Mulder, M. Timmer and G. Ypma (2003), “ICT Investments and Growth Accounts for the European Union, 1980-2000”, *Research Memorandum GD*-56, Groningen Growth and Development Centre, Groningen, http://www.eco.rug.nl/ggdc/homeggdc.html

Vickery, G. and J. Northcott (1995), “Diffusion of Microelectronics and Advanced Manufacturing Technology: A Review of National Surveys”, *Economics of Innovation and New Technology*, Vol. 3, No 3-4, pp. 253-275.

Wölfl, A. (2003), “Productivity Growth in Service Industries: An Assessment of Recent Patterns and the Role of Measurement”, *STI Working Papers* 2003-6, *OECD*, Paris.