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MEASURING ICT DIFFUSION IN OECD COUNTRIES

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ABSTRACT. This paper examines the measurement of ICT diffusion, with a particular focus on investment. It explores the problems that exist in producing reliable measures of ICT investment and comparing them across countries. Particular attention is also given to issues associated with the measurement and comparison of ICT prices. The paper also points to work that is currently underway, at the OECD and elsewhere, to further improve the international comparability of measures of ICT investment.

JEL Classification: E22; L16; O47.
Keywords: Investment; ICT; Hedonic Prices; Measurement.

RÉSUMÉ. Cet article analyse comment appréhender la diffusion des technologies de l'information et de la communication (TIC), en étudiant spécialement l'investissement. Il approfondit les difficultés rencontrées pour obtenir des mesures fiables de l'investissement en TIC qui permettent les comparaisons internationales. L'étude accorde aussi une attention toute particulière aux questions soulevées par la mesure et la comparaison des prix des TIC. L'article propose un panorama des travaux actuellement en cours, à l'OCDE et en général, pour améliorer les possibilités de comparaisons internationales dans la mesure de l'investissement en TIC.

Classification *JEL* : E22 ; L16 ; O47.
Mots-clefs : Investissement ; TIC ; prix hédoniques ; mesure.

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Despite the recent economic slowdown, analysts and policy makers continue to be interested in information and communications technology (ICT) and its economic impacts (OECD, 2003a; Van Ark *et al.*, 2002). These impacts are closely linked to the extent to which different ICT technologies have diffused across economies. This is also because ICT is a network technology; the more people and firms that use the network, the more benefits it generates. The diffusion of ICT currently differs considerably between OECD countries. This is partly because some countries have invested more or have started earlier to invest in ICT than other countries. A core indicator of ICT diffusion is therefore the share of ICT in aggregate investment. Investment in ICT establishes the infrastructure for the use of ICT (the ICT networks) and provides productive equipment and software to businesses. The measurement of this indicator and its accuracy in comparing the extent of ICT diffusion across OECD countries, as well as the economic impacts from ICT investment are discussed below.

However, ICT investment is not the only measure of diffusion. There are many other indicators that point to the growing role of ICT, *e.g.* those examining household or business use of ICT. This paper first briefly discusses other available measures of ICT diffusion. Next, it turns to the measurement of ICT investment in current prices and the problems that exist in making such measures comparable across OECD countries. The fourth section discusses the prices that are required to examine trends in ICT investment over time and the specific problems this raises for international comparisons. The final section draws some conclusions and points to work that is currently underway, at the OECD and elsewhere, to further improve the international comparability of measures of ICT investment.

Measuring ICT diffusion

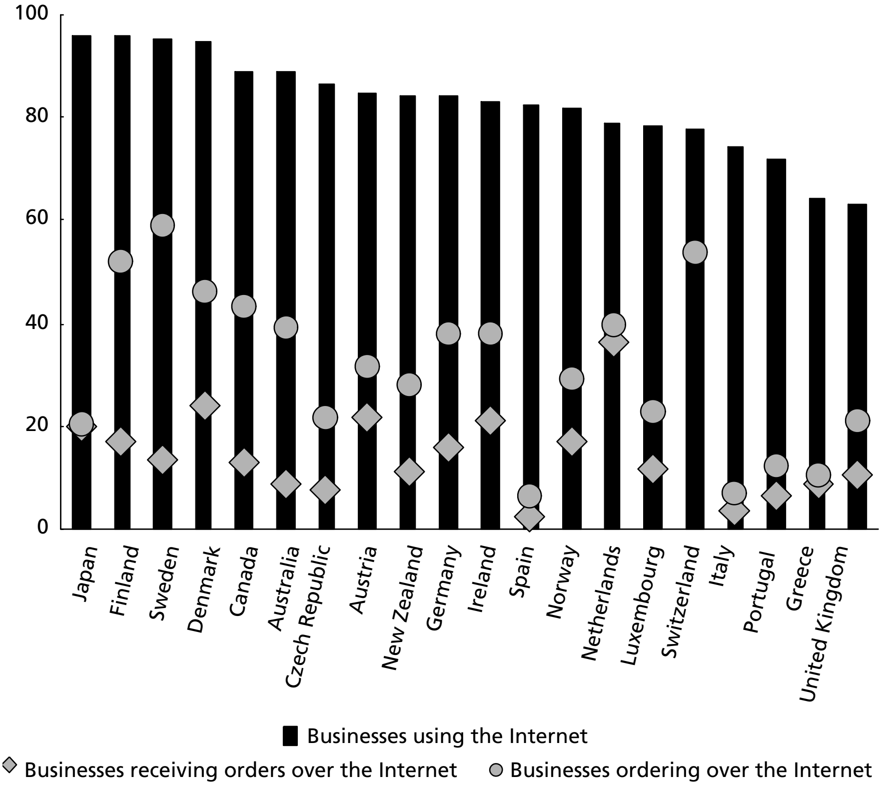
ICT investment is the measure of ICT diffusion that is most closely linked to the economic impacts of the technology. However, it only provides a partial view of the diffusion of ICT. Over the past years, statistical offices in OECD countries have developed a wide range of indicators of ICT diffusion, based on internationally harmonised surveys of households and businesses. For example, FIGURE 1 shows the proportion of businesses that use the Internet for purchases and sales. This shows that a large number of firms use the Internet for sales or purchases in the Nordic countries (Denmark, Finland, Norway and Sweden) as well as in Australia, Canada, Germany, the Netherlands and New Zealand. In contrast, relatively few firms in Greece, Italy, Portugal and Spain use the Internet for sales or purchases, even if many are connected to the Internet.

Similar indicators on business use of ICT are available for a wide range of technologies (OECD, 2002). The firm-level data underlying these indicators are increasingly used to examine the economic impacts of ICT use, notably by linking such data to firm-level information that describes the economic performance of firms. Such analysis can help to illustrate, for example, that the use of ICT may help firms in gaining market share and improve efficiency.

They may also point to interactions between ICT use and other factors, such as organisational change, enhancement of skills and innovation. Studies using these data are available for a growing number of OECD countries, since analysis with firm-level data points to interactions that are difficult to explore with more aggregate data.[2]

Figure 1 - Businesses using the Internet for purchases and sales, 2002*

Percentages of businesses with ten or more employees, %



* Or latest available year. The results of the Eurostat survey are based on a selection of industries, which changes slightly across countries. Estimates for Japan, Australia, New Zealand, the Netherlands, Canada, Switzerland and the United Kingdom differ slightly from those in other countries, see source for details.

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

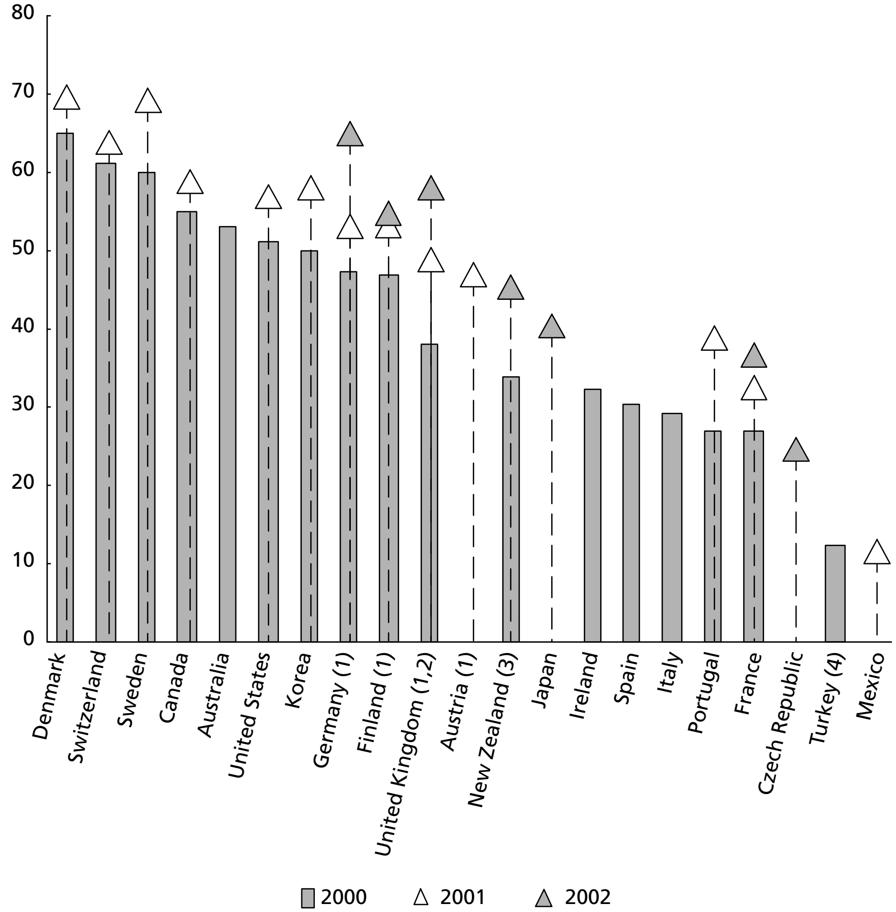
While investment and use of ICT by businesses are important, so is the use by households. Household use of ICT makes a sizeable contribution to total demand for ICT goods and services. However, national accounts information is not always sufficiently detailed to allow for

2. Examples of such firm-level studies include Atrostic and Nguyen (2002), Hempell (2002) and Crepon and Heckel (2000). A compilation of the results from firm-level studies on ICT is available in OECD (2003a).

the identification of both investment in and consumption of ICT goods and services. Household surveys of ICT use provide some interesting information on the uptake of ICT by households, however. For example, FIGURE 2 shows that the uptake of ICT is high in Denmark, Sweden and Switzerland, where approximately two-thirds of households had access to a home computer in 2001. The share in many other OECD countries is less than 50%. Some countries, for which 2002 data are available, such as Germany, have seen a rapid rise in home computers over the past two years.

Figure 2 - Households with access to a home computer, 2000, 2001 and 2002

Percentage of all households, %



1. For 2002, data from the EU Community Survey on household use of ICT relate to the first quarter.
2. March 2001-April 2002 (fiscal year) instead of 2001.
3. July 2000-June 2001.
4. Households in urban areas only.

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

There are many other indicators that point to the role of ICT in different OECD economies, most of which are available in separate studies (*e.g.* OECD, 2002a*;* OECD, 2003b). In practice, the different indicators are closely correlated and tend to point to the same countries as having the highest rate of diffusion of ICT. These typically are the United States, Canada, New-Zealand, Australia, the Nordic countries and the Netherlands. From this perspective, it is likely that the largest economic impacts of ICT should also be found in these countries. The measures of ICT investment that are discussed below provide further insights in the role of ICT in OECD economies.

Measuring ICT investment

Investment is usually estimated by statistical offices using business surveys specifically designed to capture investment. These surveys usually allow total investment to be disaggregated into a number of well established and well defined asset groups: plant & machinery, dwellings, vehicles and intangibles. This is not the case for investment in ICT however, since no internationally agreed definitions currently exist. A first step towards comparable data would involve a definition of ICT products based on an international product classification list. A proposal for manufactured goods has been developed by the OECD Working Party on Indicators for the Information Society (WPIIS). This definition is close to being approved but, in its absence, comparisons of ICT investment will inevitably involve some degree of incomparability. Nevertheless, there is a broad understanding in the statistical community about the definition of ICT products, based largely on the criteria set out to define the ICT producing sector (Box). As considerable effort has gone into producing this definition, the size of definitional differences in ICT investment should, in principle, be limited.

Investment in ICT

Comparability issues

Because ICT investment is only a subset of ICT products (since it reflects only expenditure on ICT products that satisfy the rules on investment of the basic system of national accounts or SNA); it should, in theory, be relatively easy to achieve international comparability. For example, expenditure on rental of office machinery (7123, ISIC Rev3) will normally not be recorded as investment. In practice, ICT investment is typically divided into three components: IT equipment, communications equipment and software. These components represent the subset of ICT products that can usually be capitalised. Nevertheless, even when presented at this relatively aggregated level comparability problems remain.

One of the main problems reflects the delineation between the groups and also between other asset types. For example, the total value of software sold as a bundle with hardware may be recorded as either software or IT investment; depending on the value of each component. Moreover, the definition of ICT investment only covers assets that are themselves clearly distinguishable as ICT goods even though the diffusion of ICT goes beyond this. ICT

BOX 1 - OECD DEFINITION OF THE ICT SECTOR

In 1998, the WPIIS adopted a definition of the ICT producing sector based on the class level of ISIC rev 3[3] and the following criteria, for manufacturing and service industries.

For *manufacturing* industries, the products of a candidate industry:
– Must be intended to fulfil the function of information processing and communication including transmission and display.
– Must use electronic processing to detect, measure and/or record physical phenomena or control a physical process.

For *service* industries, the products of a candidate industry:
– Must be intended to enable the function of information processing and communication by electronic means.

Using these criteria the ICT sector has been defined as the following group of ISIC Rev 3 industries:
Manufacturing: 3000 – Office, accounting and computing machinery; 3130 – Insulated wire and cable; 3210 – Electronic valves and tubes and other electronic components; 3220 – Television and radio transmitters and apparatus for line telephony and line telegraphy; 3230 – Television and radio receivers, sound or video recording or reproducing apparatus and associated goods; 3312 – Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process equipment; 3313 – Industrial process equipment.
Services: 5150 – Wholesaling of machinery, equipment and supplies (if possible only the wholesaling of ICT goods should be included); 7123 – Renting of office machinery and equipment (including computers); 6420 – Telecommunications; 72 – Computer and related activities.

products are embodied in many other capital products. Robotic machinery in a production plant, for example, usually embodies significant ICT components such as software, semiconductors *etc.* The value of these components will not be directly recorded as ICT investment, although indirectly they will be; as their value will be embodied in the value of the robot. Focusing exclusively on ICT investment products therefore does not fully reflect the benefits of ICT diffusion within investment products or in the economy at large (see Papaconstantinou, Sakurai, and Wyckoff, 1996; OECD, 2003*a*). Comparisons of ICT investment in the manufacturing and service sectors may also be misleading in this context, since most expenditure on ICT products will be capitalised by the service sector, whereas significant expenditures by the manufacturing sector will be recorded as intermediate consumption.

3. ISIC denotes the International Standard Industrial Classification system. It is a standard classification of economic activities, managed by the United Nations Statistics Division.

TABLE 1 illustrates, at a broad level, the composition of the three ICT components readily available for some countries. The table is not necessarily comprehensive. For example estimates of investment in IT and/or communications equipment in Finland can be ascertained from their supply-use table.

The development of a product classification definition for ICT products is unlikely to prove a complete panacea for the problems noted above. International product classification lists are relatively static, changing usually every decade, but products change much more quickly, particularly ICT products or products that embody significant ICT components. An additional problem arises from business accounting which, in many cases, allows some expenditure to be treated as intermediate costs although it would be recorded as investment under SNA93. This is particularly true for software produced on own-account (or in-house), which, for the first time, was recognised as investment in the 1993 revision of the SNA. Moreover, for software in particular, achieving a common understanding of investment across national statistical offices has proven to be difficult. This partly reflects differences in estimating own-account software but it also reflects differences in interpreting SNA93 rules for pre-packaged software; since pre-packaged software can be bought in a multitude of ways; e.g. via rental, licenses, bundles, embedded in hardware etc. These problems are partly conceptual and partly practical.

For other ICT products, such as hardware and communications equipment, conceptual differences in assigning expenditure to investment or intermediate consumption are likely to be negligible, or non-existent, though practical measurement differences may exist. To what extent this is the case remains to be seen, since no comprehensive analysis of cross-country differences has been undertaken. Simple cross-country comparisons of intermediate consumption and investment in some ICT products, for example communications equipment, indicate that measurement differences may indeed explain some of the recorded differences in ICT investment rates across countries. Further work will be needed to fully establish this.

Investment in software

For software, considerable progress has been made in resolving the issues that affect international comparability. In November 2001, an OECD-Eurostat Task Force was set up to investigate this lack of comparability and to provide recommendations that could improve matters. For example, the Task Force found that methods used to estimate own-account software differed significantly. All countries surveyed estimated own-account software using an input method (taking the sum of all or some input components: intermediate consumption, wages *etc*) rather than using information from business surveys. This is because these were considered to provide unrealistically low estimates, owing to the fact that companies rarely capitalised own-account software. However, even though all countries used the same (input) method, significant differences remained. For example, not all countries included estimates of operating surplus in the value of own-account software. Others included only labour costs. Indeed even where the methods appeared to be the same this was often only superfi-

Table 1 - Current price ICT investment series available in official statistics by 2001

	Available aggregates	Software	IT equipment	Communications equipment
Australia	Private, public enterprise and general government	Purchased and own-account software	Computer equipment and peripherals	*n/a*
Canada	Total economy, business sector and government	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment
Finland	Total economy, business sector and government	Purchased and own-account software	*n/a*	*n/a*
France	Total economy and major institutional sectors	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment
Germany	Total economy	Purchased and own-account software	Computers, office and accounting equipmen0t	Communications eqpt (inc radio & television sets)
Italy	Total economy	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment
Japan	Total economy	Purchased software	Electric computing equipment and accessory devices	Wired and radio communications equipment
United Kingdom	Total economy	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment
United States	Private sector	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment

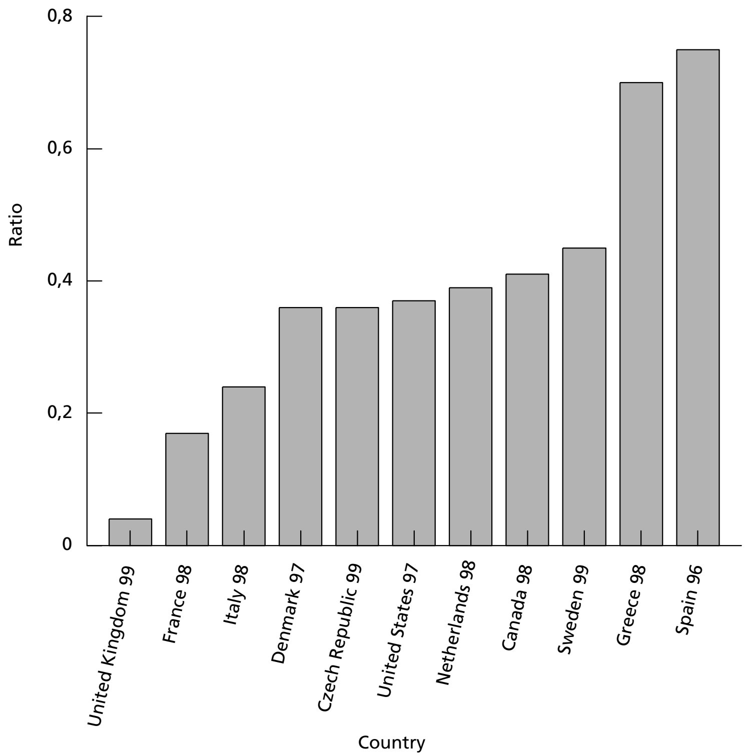
Source: Colecchia and Schreyer (2001).

cial, as the definitions of labour costs often differed, as did the definitions of employees working on own-account production and the proportion of time spent by these individuals on own-account activities. For example in Australia, Denmark, Finland, the Netherlands and Sweden it was assumed that employees engaged in own-account production spent all of their time on this activity, whereas in Canada, France and the United States, it was assumed that only 50% of their time was spent on this activity (Ahmad, 2003).

The Task Force also found that estimates of investment in *purchased* software were largely incomparable. FIGURE 3 compares the ratio of purchased software capitalised by businesses and government as a percentage of total expenditure (intermediate and investment) on computer services (software). If one reasonably interprets the ratio as being a broad measure of the propensity of a statistical office to capitalise software, the obvious conclusion is that countries are not adopting the same rules for capitalising purchased software. Spain, for example, capitalises over 70% of all expenditure whereas the United Kingdom capitalises only about 5%.

Figure 3 - Investment ratios for purchased software

Share of total expenditure on computer services that is capitalised, %

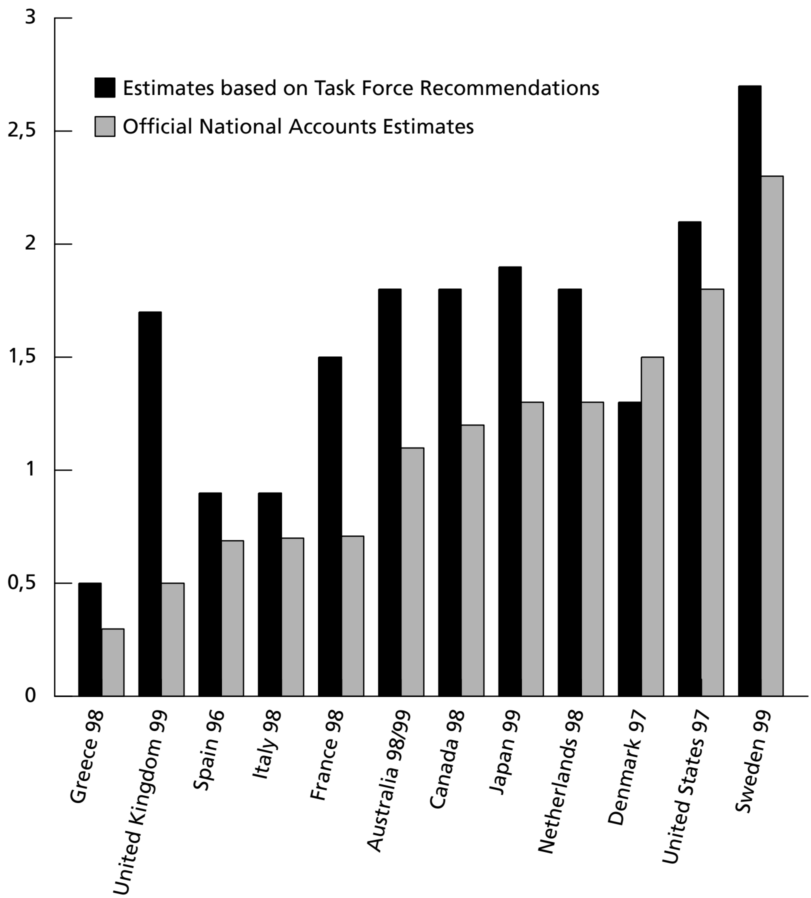


Source: Ahmad, 2003.

Many national statistical offices have already begun to revise their estimates of software investment in line with the recommendations and methods advocated by the Task Force; although some of the recommendations remain the subject of debate (Ahmad, 2003). Adopting the recommendations in their entirety will have a considerable impact on the recorded levels of software investment in some countries. FIGURE 4 below compares estimates of software investment, as a percentage of GDP based on these recommendations, against currently published estimates. It implies considerable differences for the United Kingdom and, to a lesser extent, France. The higher estimate for Japan reflects the fact that currently published estimates of software investment in Japan do not include own-account software.

Figure 4 - Comparison of estimates of investment in software

As a percentage of GDP



Source: Ahmad, 2003.

Estimates of ICT Investment

As described above, international comparisons of ICT estimates are hampered by the lack of comparability, or indeed availability, of estimates by statistical offices. To improve comparability, adjustments to national data sources, or estimates where no data exists, are often needed. The OECD's capital services database is a step in this direction. It uses national data sources, where available, and where they are broadly consistent with the generally understood definition of ICT investment, supplementing this data from additional sources or estimates where this is not the case (see, Schreyer, Bignon, and Dupont, 2003). For example, estimates of investment in software in the United Kingdom are consistent with the estimates obtained by applying the OECD Task Force recommendations, as shown in FIGURE 4 above, and not with the estimates produced by the UK Office for National Statistics.

The database shows that ICT investment accounts for a large part of total investment in OECD countries. In the Netherlands, Canada, the United Kingdom and Sweden, such investment exceeded 20% of all non-residential investment in 2000, while the share of such investment in the United States was approximately 30% in 2000 (FIGURE 5). In addition, this share has been growing considerably over the past decade, providing evidence that the importance of ICT investment has been increasing.[4] For example, in Finland and Sweden, the share of ICT investment in total investment more than doubled between 1990 and 2000. In Australia, France, Canada, the United Kingdom, Greece, Denmark, Ireland and Japan, the corresponding growth rate over this period was also over 50%. The contribution of ICT investment to GDP is also significant and growing. By 2000, ICT investment accounted for between 2% and 4% of GDP (FIGURE 6), a share that has almost doubled since 1980 in almost all OECD countries (OECD, 2003a).

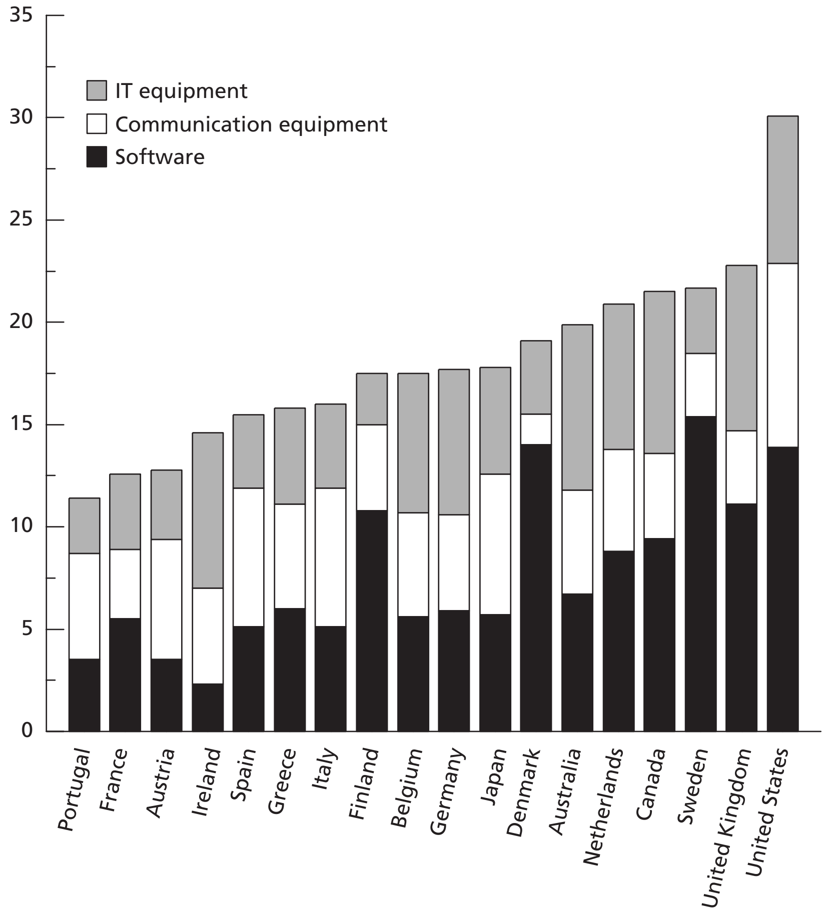
The OECD database on capital services is still relatively new but over time, the comparability of estimates can be expected to improve. This and the preceding discussion on measurement problems highlight the need for caution in interpreting statistics on ICT investment. For example, FIGURE 5 suggests that most ICT investment in Denmark is software, while the corresponding share in Belgium, Italy, Portugal and Spain is only around 30%.

It is difficult to explain these differences and they might simply point to the difficulties in measuring and compiling data on ICT investment in these countries. Ahmad (2003) looks specifically at the category of ICT investment that is most complicated in terms of measurement, *i.e.* software, and calculates alternative estimates of software investment based on harmonised estimation methods. These alternative estimates are able to shed some light on the cross-country differences of ICT estimates used in the capital services database. For example, these estimates propose a lower measure of own-account software for Denmark. Using these estimates reduces Denmark's very high share of software investment to a percentage more comparable with those recorded for other countries.

4. However, in 2001, the share of ICT investment declined in many OECD countries (see OECD, 2003a; OECD, 2003b).

Figure 5 - ICT investment by assets in OECD countries, 2000

Percentage of non-residential gross fixed capital formation, total economy, %

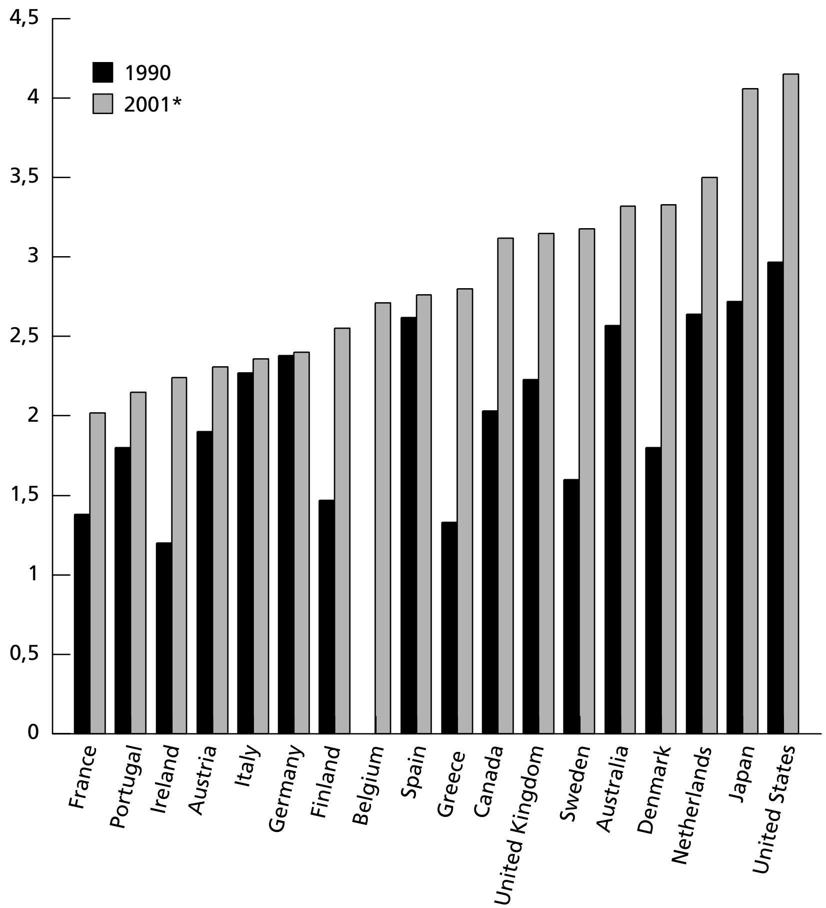


Source: OECD, Database on capital services.

Measuring ICT prices

Measures of ICT expenditure at current prices are valuable for a number of indicators, such as the share of ICT in total investment or in GDP. For many other indicators, however, a volume measure is needed that controls for changes in the price level of ICT products. Price indices are therefore needed to deflate current-price expenditure data and to obtain "constant price" measures. Constructing price indices for ICT products is a challenging task for statisticians. Due to rapid technological progress in the production of key ICT technologies,

Figure 6 - The share of investment in ICT in total GDP (%)



* Or latest available year.

Source: OECD, Database on capital services.

such as semi-conductors, and strong competitive pressure in their production,[5] the prices of key technologies have fallen by between 15 and 30% annually over the second half of the 1990s. The rate of price decline was even more rapid from 1995 to 1999 as technological progress was more rapid during this period and new micro-processors were introduced at a more rapid pace than prior to 1995 or after 1999.[6]

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5. Aizcorbe (2002) shows that part of the decline in the prices of Intel chips can be attributed to a decline in Intel's mark-ups over the 1990s, which points to stronger competition.

6. An international roadmap for the production of semiconductors is published by the International Technology Roadmap for Semi-conductors (ITRS). See http://public.itrs.net/

Hardware and communications equipment

Generally, price indices are constructed by comparing prices of sampled products between two periods in time. Two conditions have to be fulfilled for this to yield reliable estimates: the products in the sample have to be representative of a whole product group and they should be comparable between the two periods. Rapid technical change implies that neither condition is easily satisfied in the case of ICT goods such as computers: models change very rapidly and there is a risk of comparing two non-identical products. And if only prices of those models that are available in both periods are compared, there is a risk of using a non-representative sample if the price movements of these goods do not reflect the broader market conditions. In a situation where the price statistician has to compare two different models, the fundamental question is: how much of the observed price change is due to quality change and how much to a true change in prices?

Consider the following example: in year 1, an old model costs 100; in year 2, a new model costs 90. How does one split the observed price change of 10 into a price and a quality component? What is missing here is the price that the old model would have collected in year 2, had it still been on the market[7]. Suppose we know that price, and suppose it is 80. Then it would be easy to state that the price change between the two periods is 80 – 100 = – 20 and that the quality change equals + 10.

But the price of the old model in year 2 is not known, and the price statistician, implicitly or explicitly, has to make some estimate. Simply ignoring the model change and calling – 10 the true price decline is tantamount to saying that there has been no improvement in quality, or that the price of the old model in year 2 would have been 90 as well. As a consequence, the fall in prices would have been understated by half. Thus, to get price changes right, a more informed estimate of the year 2 price of the old model is required. Such an estimate may come from expert advice, from "option pricing", or from some observation of the price at which the old model is traded by in second-hand markets.

The hedonic method[8] is a systematic way to obtain an informed estimate for the price of the old model in year 2. Under this method, a hedonic function is estimated, that links the price of computer models to their characteristics such as speed, memory, equipment etc. Suppose, for ease of exposition that there is only one such characteristic. By observing a sufficiently large number of computer models in year 2, it is possible to establish a systematic relationship between price and this characteristic. One can then infer a hypothetical price for the old computer model in year 2 by using the information about its technical characteristics (which are known from period 1) and so obtain an approximation to the true price change.

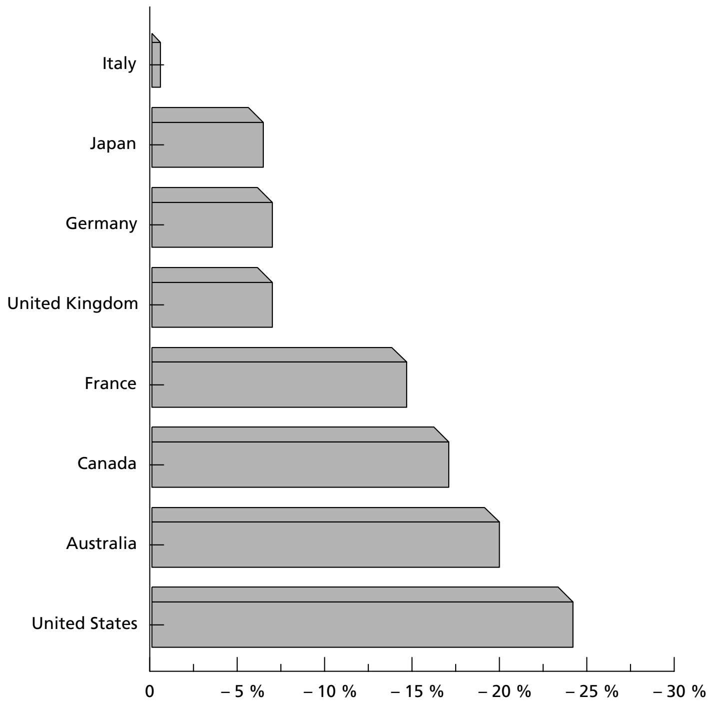
7. This is a simplified example. Strictly speaking, looking for a price of the old model in year 2 is correct only if the price index uses expenditure weights of period 1, *i.e.* if it is formulated as a Laspeyres-type index. Under a Paasche price index, weights of period 2 are relevant, and one would seek a proxy for the price of the new model in year 1.
8. For a much more complete description and discussion see OECD (forthcoming).

A number of countries use such hedonic methods, among them the United States where hedonic functions are constructed for different types of computers and peripheral equipment, semiconductors and software. Australia, Canada, Japan, France, Germany and some other countries have also developed hedonic functions or adopted those of the United States. For ICT products, the hedonic method tends to yield price changes that drop more rapidly than price indices based on other estimates.

FIGURE 7 shows price indices for ICT hardware investment for selected countries. The United States, Canada, France and Australia employ hedonic methods, and show the fastest rates of price decline. Although a hedonic price index has recently been developed in Germany, and introduced into the consumer price index, the investment deflator shown here is still based on the previous methodology. This explains its slower rate of change. No hedonic adjustment is carried out in Italy and in the United Kingdom. Japan constructs a hedonic producer price index for ICT hardware but it is not clear whether this deflator is also used in the national accounts. TABLE 2 summarises the use of hedonic methods for ICT hardware components and communications equipment.

Figure 7 - Price indices for computers and office equipment

Average annual rates of change, 1995-2001*



* United Kingdom: 1995-2000.

Source: National sources.

Table 2 - Use of hedonic deflators

IT Equipment Communications equipment		
Australia	Hedonic price index linked to US-BEA computer price index, exchange rate-adjusted New deflator for Australia under development	No
Canada	Hedonic price index for PCs, portable computers and peripheral equipment	No
France	Hedonic price index for computers: combined measure of hedonic price index for France and the US-BEA computer price index, exchange rate-adjusted	No
Germany	Hedonic price index for personal computers in CPI since June 2002 No Japan Hedonic price index for computers	No
United States	Hedonic deflators for computers and peripheral equipment	Hedonic deflators for telephone switching equipment

The cross-country variation in price declines has either been taken as a sign that conventional estimates understate true price changes, or as an argument to dismiss hedonic methods as producing unrealistically rapid price declines for some goods and thus overstate true price changes[9]. One strand of discussion[10] about hedonic methods concerned the question of whether they reflected user values or production costs. For example, when computers are used for investment, one wants the valuation of computers to depend on computers' contributions to production. This is known in the literature as a "user value" measure of quality change. But if hedonic indexes reflect user value, the implication is that they are not the appropriate measure for output and producer price indexes where resource cost, not user value, is the theoretically appropriate way to value quality change (Fisher and Shell, 1971; Triplett, 1983). The issue of user value and resource cost was played out in a major debate on productivity measurement between Jorgenson and Griliches (1972) and Denison (1972). However, Rosen (1974) showed that hedonic functions were not uniquely identified with the demand side of the market, so that hedonic indexes were not uniquely described as measures of user value. That means that they do not trace demand functions for characteristics (utility functions for computer buyers), nor do they map supply functions for characteristics

9. For a discussion of hedonic methods, see Triplett (1990).
10. This draws on OECD (forthcoming).

(production functions for computer suppliers). In other words, the user value-resource cost argument is inadequate to dismiss hedonic methods for output price indices.

Other arguments in the debate about hedonic price indices concern practical problems of choosing the right characteristics and selecting the correct function form of hedonic equations. Overall, however, few convincing arguments have been brought forward why hedonic methods should overstate price changes. If one accepts that the computer industry produces computing power, rather than computer "boxes", the hedonic approach would seem to be much closer to the true price developments than some of its alternatives. A rising number of statistical offices recognise the usefulness of the hedonic approach, and Eurostat (2001) qualifies the hedonic method as the preferred one in the field of computer and software price indices. Moreover, whether one believes that hedonic deflators produce a good approximation of the true picture of price changes or not[11], the issue of international comparability of growth and productivity between countries that use and those that do not this method remains important.

Software

Although most of the above discussion about estimating prices of hardware and communications equipment applies to software as well, there are a number of additional issues specific to software prices. For practical and conceptual reasons, the price indices of the three types of software – own account, customised and pre-packaged – tend to be very distinct.

Own-account software investment at current prices is typically estimated by its input costs (see above) and accordingly, input-based indicators serve as deflators. This raises two issues: (i) it is well known that input-based cost measures are poor proxies for output prices. Changes in productivity that may enable lower output prices at constant cost are ignored and consequently, the deflated software series may be downward or upwards biased, depending on whether productivity growth has been positive or negative[12]; (ii) even though nearly all countries employ cost measures as deflators, the precise choice of these measures varies considerably across countries, thus reducing comparability of the resulting volume measures.

Customised and pre-packaged software – when separately identified from own-account software – feature an even more diverse treatment across countries (see TABLE 3). Only two of the surveyed countries have explicit price indices for pre-packed software. In several cases, the price index for customised software is a weighted average of that for pre-packaged and own account software. In many other instances, the price indices for customised and pre-

11. Aizcorbe *et al.* (2000) challenge the widely held view that only hedonic functions generate steep price declines in high-technology goods. The authors use a very detailed and high-frequency (quarterly) data set for computers and semiconductors and compute price indices and apply a traditional matched-model technique to establish a price index. They compare their findings with a hedonic-based price index and find very similar price developments in the 1990s, in particular an acceleration in the rate of decline in computer prices in the late 1990s.
12. Some researchers (Jorgenson, 2001) have therefore replaced the official, cost-based, deflators by the output price deflator of pre-packaged software.

packaged software are based on input costs or on output prices of related products such as hardware. Applying the hardware-related deflator could mean introducing a downward bias to software prices, however; where price indices for hardware and software have been established separately, software price indices fell less rapidly than price indices for hardware.

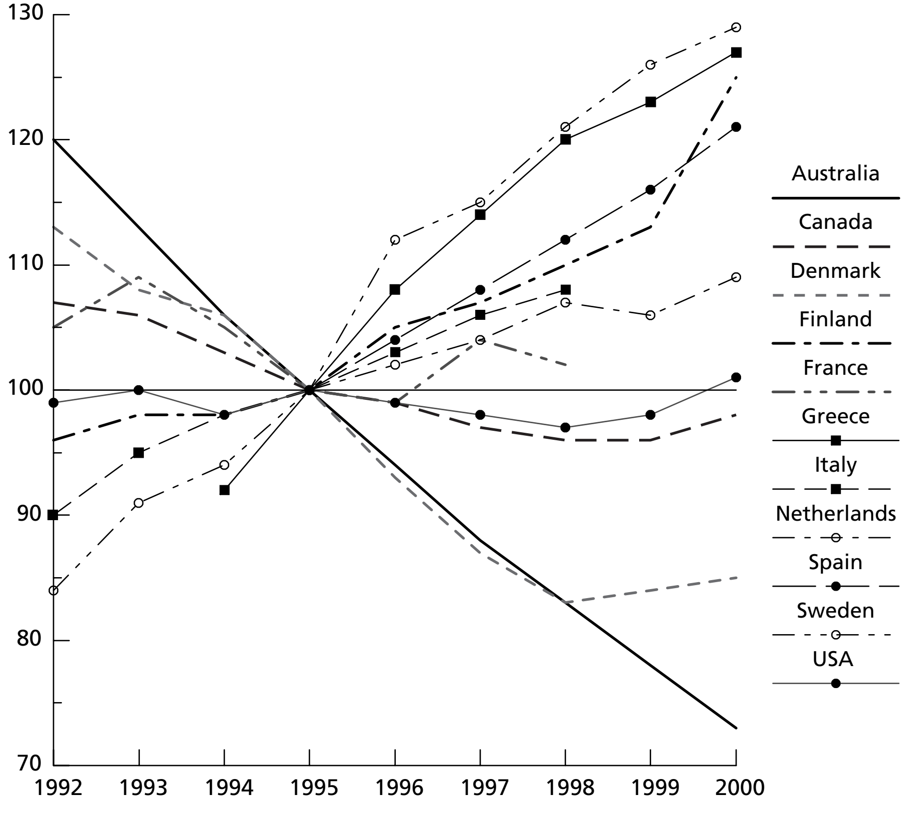
Table 3 - Comparison of software deflators

Country		Own-account	Customised	Pre-packaged
Australia		Prices are assumed to fall by 6% a year.		
Canada		Weighted average (2:1) of programmer labour costs and non-labour inputs to the computer services industry.	Weighted average of own-account and pre-packaged (1:3).	Average of US index for pre-packaged adjusted for exchange rates. A new index is due for release.
Czech Republic		Price indices for the output of the computer services industry.		
Denmark	1993-95	Weighted average of labour costs and PC hardware (1:1).		
	1996-97	Weighted average labour and PC hardware (3:1).		Weighted labour and PC hardware (1:1).
	1998+	Geometric average of labour and hardware (3:1).		
Finland	1975-97	Average earnings index for the computer services industry.		
	1998+	Weighted average of labour costs of the computer services industry and US pre-packaged software index adjusted for exchange rates.		
France	1995 (–)	US price index adjusted for exchange rates.		
	1995+	Labour costs.		
Greece		General (whole inflation) price index.		
Japan		Corporate Service Price Index for "the development of computer software tailored for corporations", based on the labour costs.		
Netherlands		Labour costs of ICT personnel.	Producer price index.	Producer price index.
Spain		Based on producer price index for office machinery and the general consumer price index (excluding renting).		
Sweden		Average earnings index for the computer services industry.		
United Kingdom		Average earnings series adjusted for the computer services industry with 3% productivity adjustment since 1996.		
United States		Weighted average (roughly 1:1) of programmer labour costs and non-labour inputs to the computer services industry.	Weighted average of own-account and pre-packaged (1:3).	Directly collected price index

Source: Ahmad (2003).

It should not come as a surprise that the observed price indices for software exhibit large differences across countries (FIGURE 8). As in the case of hardware, it is unlikely that these differences are exclusively due to true differences in price developments – at least a sizeable part of them is accounted for by differences in the methodology for price indices.

Figure 8 - Price indices for software investment, 1995 = 100



Source: Ahmad, 2003.

A short-term solution: "harmonised deflators"

Schreyer (2000a) and Colecchia and Schreyer (2001) use a "harmonised" deflator for information and communication technology products and for software investment to adjust at least roughly for differences in price index methodology between countries. This remains an approximation, though, and cannot replace more systematic efforts by countries to use similar methodologies in the construction of their price indices. But the adjustment permits a comparison between investment measures constructed with national and those based on "harmonised" deflators.

Thus, one way of assessing the effects of the choice of price index methodologies on measures of investment, output or productivity is to reconstruct the same measure with a different underlying deflator. In particular, it is instructive to replace national price indices by those used in the United States, as comparisons and discussions about measurement issues frequently focus on the comparison with the United States. However, one has to keep in mind that replacing one country's price index by that of another country implies assuming away differences in the composition of ICT production or consumption as well as differences in market structure and competition. Both can have significant impact on the aggregate ICT price index and the use of "harmonised" deflators remains at best an approximation to a lower bound of a true price change. Also, there are several possibilities for transposing the US deflators to other countries' accounts for purposes of such a simulation. Here, three such possibilities are explored.

First, it is possible to use the United States deflator, unadjusted for domestic inflation. This constitutes the most direct way of transposing a price index from one country to another. The underlying hypothesis is that nominal prices of ICT products change at the same rate in different countries: for example, a 20% fall of computer prices in the United States translates into a 20% decline of the same price index in Italy. However, this simple transposition ignores that countries may experience different changes in the overall price level.

The second measure adjusts for this issue, as it uses the United States deflator adjusted for domestic inflation. To control for domestic inflation in the construction of a harmonised price index, the following assumption is made: the relative price change of the ICT product under consideration should be the same across countries. Thus, if ICT prices in the United States rise by 10 percentage points per year less than prices for non-ICT goods, this carries over to other countries and makes the "harmonised" deflator independent of the overall price level that prevails in the different countries. The implicit assumption is that the movements in relative price structures are the same across countries which may or may not be the case empirically.

A third way of constructing a "harmonised" deflator includes an exchange rate adjustment. This is a plausible approach if the ICT product is internationally traded and/or imported into the country under consideration. One problem is that shifts in exchange rates are not always fully passed on to domestic consumers. To the extent that this is not the case, exchange rate adjustments may under- or overstate the price change in domestic currencies. The exchange rate adjustment implicitly reflects cross-country differences in overall inflation, as long as exchange rates are floating and responsive to changes in a country's price level. In some countries (for example Australia) this method is used to "import" the United States' price index for personal computers into the national accounts.

TABLE 4 compares the methods. It shows the average annual growth rate of volume investment in the business sector of several OECD countries. Alternative measures reflect different price indices for the three ICT capital goods that form part of aggregate investment: software, information technology hardware and communication technology. Three types of "harmonised" deflators were used in the comparison; they have in common that they all are based on the national United States deflator for these products.

Table 4 - Private non-residential gross fixed capital formation with alternative deflators for ICT assets

Tornqvist volume index, percentage change at annual rate, 1990-99

	Based on:			
	National deflator	United States deflator, adjusted for domestic inflation	United States deflator, unadjusted for domestic inflation	United States deflator, adjusted for exchange rate movements
Australia	4.2%	3.9%	4.0%	3.6%
Canada	4.0%	4.0%	4.1%	3.9%
Finland	– 1.8%	– 0.1%	– 0.4%	– 1.0%
France	0.9%	1.1%	1.1%	1.0%
Germany*	2.4%	2.8%	2.9%	2.7%
Italy	1.8%	2.8%	3.0%	2.2%
Japan	– 2.2%	– 1.8%	– 1.9%	– 1.8%
United Kingdom	3.4%	4.5%	4.5%	4.4%
United States	7.6 %	–	–	–

*1991-1999.
Source: Author's calculations, based on Colecchia and Schreyer (2001).

Future prospects

Many difficulties continue to persist in the computation of reliable, accurate and internationally comparable price series for ICT investment goods. This is a reflection of the conceptual and practical difficulties that statisticians face with these rapidly-changing goods and markets. For ICT investment goods, international comparability is inhibited by the use of different statistical methodologies to adjust for quality change. In particular, countries that use hedonic methods for quality adjustment of ICT prices tend to show more marked declines in prices than those countries that do not rely on hedonic methods. 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. Short-run solutions such as the "harmonised" deflators discussed above exist but true improvements can only be achieved by reviewing and improving methods for every country.

Whereas the focus here has been on price indices for ICT investment goods, it is worth pointing out that price measurement is probably even more difficult in the field of ICT-related services, for example communication services. The picture is not all bleak, though. New work has been carried out for service sectors, for example by Magnien (2003) on pricing mobile phone services. Fraumeni (2001) also points to several areas of progress in ICT-related statistics. Several countries have recently started to adopt hedonic methods (*e.g.* Germany) and this will help to improve international comparability. Several new international handbooks and manuals on price indices will facilitate implementation of new methods in other countries.[13] Also, ICT itself will further facilitate price measurement, for example through the availability of scanner data, internet quotes or other new sources of information that can be exploited by price statisticians.

Concluding remarks

The measurement and impacts of ICT investment have been discussed in several recent studies, *e.g.* Colecchia and Schreyer (2001), Van Ark, *et al.* (2002), Ahmad (2003) and Schreyer, *et al.* (2003). A considerable body of work has also examined the broader measurement of ICT diffusion (OECD, 2002; 2003*a*). This work suggests that a number of problems still affect the measurement of ICT investment.

These include:

1. Measures of ICT investment are not yet fully comparable across countries. Measures of software investment are particularly problematic (Ahmad, 2003), and have been the subject of an OECD/Eurostat Taskforce that has produced a range of recommendations to improve measurement; these are currently being implemented by statistical offices in OECD countries. Further efforts will be needed to improve the existing measures; this should include work to settle on a definition of ICT goods as well as work to improve business surveys of capital expenditure.
2. Adjustment for quality change remains difficult. Hedonic deflators 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 use hedonic deflators that reflect their own national context. An OECD Handbook on Hedonic Price Measurement is due for publication in 2004, and may be followed by further steps to implement its findings in national statistical practices.
3. A great deal has been achieved over the past years and measures of ICT investment and the economic impacts of ICT are currently much improved from what they were only a few years ago. The more solid evidence is, is important for policy, as it helps underpin evidence-based policies. Further improvements in ICT measurement at the aggregate, sectoral and firm level offer a great potential for future analysis, with potentially important policy implications. Given the continuing diffusion of ICT, better measurement remains an important challenge.

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13. In particular, OECD (forthcoming) as well as the new international manuals on producer price and consumer price indices.

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