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ICT Investment and Economic Growth in the 1990s

IS THE UNITED STATES A UNIQUE CASE? A COMPARATIVE STUDY OF NINE OECD COUNTRIES

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ICT INVESTMENT AND ECONOMIC GROWTH IN THE 1990S: IS THE UNITED STATES A UNIQUE CASE?

A COMPARATIVE STUDY OF NINE OECD COUNTRIES

Alessandra Colecchia and Paul Schreyer[1]

Investment in information technologies has by no means been confined to the United States and yet, average European or Japanese growth experience has been quite different. The paper compares the impact of ICT capital accumulation on output growth in Australia, Canada, Finland, France, Germany, Italy, Japan, the United Kingdom and the United States. The analysis uses a newly compiled database of investment in ICT equipment and software based on the System of National Accounts 1993 (SNA93). Over the past two decades, ICT contributed between 0.2 and 0.5 percentage points per year to economic growth, depending on the country. During the second half of the 1990s, this contribution rose to 0.3 to 0.9 percentage points per year. The paper shows that, despite differences between countries, the United States has not been alone in benefiting from the positive effects of ICT capital investment on economic growth nor was the United States the sole country to experience an acceleration of these effects. ICT diffusion plays a key role and depends on the right framework conditions, not necessarily on the existence of an ICT producing sector.

INVESTISSEMENT EN TIC ET CROISSANCE ÉCONOMIQUE DANS LES ANNÉES 1990: LES ÉTATS-UNIS REPRÉSENT-ILS UN CAS UNIQUE?

UNE COMPARAISON DE NEUF PAYS MEMBRES DE L'OCDE

Alessandra Colecchia et Paul Schreyer

L'investissement dans les technologies de l'information n'a pas été confiné aux États-Unis, toutefois la croissance en Europe et au Japon est assez différent. On trouvera dans ce papier une comparaison de l'incidence de l'accumulation de capital de TIC sur la performance économique en Allemagne, en Australie, au Canada, aux États-Unis, en Finlande, en France, en Italie, au Japon et au Rouyame-Uni. Cette étude fait usage d'une nouvelle base de données sur l'investissement en logiciel et en équipement de TIC, fondée sur le Système de comptabilité nationale de 1993 (SCN 93). Au cours des 20 dernières années, les TIC ont contribué à la croissance économique entre 0.2 et 0.5 point de pourcentage par an, selon le pays. Au cours des 5 dernières années (1995-2000), cette contribution a atteint des valeurs annuelles comprises entre 0.3 et 0.9 point. On montre que, malgré les différences qui existent entre les pays, les États-Unis n'ont pas été les seuls a beneficier de l'incidence positive des TIC sur la croissance, ni de l'augmentation de cette incidence. La diffusion de TIC joue un role important et nécessite des conditions économiques et reglementaires favorables, mais pas necessariement de l'existence d'un sectéur producteur de TIC.

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1. OECD Science, Technology and Industry Directorate and Statistics Directorate, respectively. A preliminary version of this work (Colecchia 2001) was prepared in the context of the OECD growth project and is available upon request from the author. This work would have not been possible without the help of National Statistical Offices that provided us with investment series detailed by ICT and non ICT assets. In particular we would like to thank Ludovico Bracci (ISTAT, Italy), Gwennaelle Brilhault (INSEE, France), Gerald Cruse (Federal Statistical Office, Germany), Jukka Jalava (Statistics Finland), Patricia Mahony (Australian Bureau of Statistics), Nick Oulton (Bank of England), Hiromitsu Shimada (Economic Planning Agency, Japan). Opinions expressed in the paper do not necessarily reflect the views of the Organisation for Economic Development and Co-operation or its Member countries.

Introduction

Economic growth can be achieved through increased or improved use of labour and capital or through a rise in multi-factor productivity (MFP). Recently, OECD (2001a) examined sources of and differences in growth patterns between OECD countries and concluded that that none of these factors stands out as being the single most important in all OECD countries. However, a new factor that has been driving growth in some countries is information and communication technology (ICT). This is best exemplified by a well-documented experience in the United States that witnessed strong growth over an unusually long expansion, 1992-00. The present work aims at quantifying the contribution of ICTs to output growth in the United States and in several other OECD countries. In particular, it examines the role of ICT as a source of capital services, delivering inputs to the production process. This is different from an output perspective where the primary concern is the role of ICT-producing industries in the economy.

ICT is often embodied in other, non-ICT capital goods – for example semiconductors are part of assembly lines. Here, ICT plays a role as an intermediate input to capital goods production. While potentially an important source of productivity gains, this contribution to output is not separately identified in the present framework.

Colecchia (2001) updates and extends an OECD study on the contribution of ICT to output growth in the G7 countries (Schreyer, 2000) in several significant ways. First, the study covers software as an ICT asset. This reflects the recognition of software as an intangible investment good in the System of National Accounts 1993 (SNA93). Second, ICT investment series are as far as possible based on official statistics, while Schreyer (2000) had to rely on private source data. Third, the set of countries has been extended to cover two additional countries, Australia and Finland. In addition, the analysis covers the second half of the 1990s which has been a period of significant interest regarding the role of ICT. This paper extends Colecchia (2001) to include the year 2000 for several countries. The calculations thus reflect the most recent revisions in the US National Accounts (NIPA, August 2001) and in the Canadian National Accounts. The paper at hand also defines a consistent measure of net value added and examines its evolution over the 1990s.

Framework

Accounting for output growth

Production theory provides the framework for the present analysis. The methodology follows directly the approach by Oliner and Sichel (1994, 2000), Jorgenson and Stiroh (2000) and Schreyer (2000). It represents an extension to the well-established growth accounting and productivity measurement approach, based on the work by Solow (1958), and Griliches and Jorgenson (1968). A comprehensive discussion of this approach and the ensuing measurement issues can be found in OECD (2001b).

In the decomposition we consider deflated value-added[1] as our output measure and call it *Q*. Associated with the volume measure of output is a price index for the same period, *P*. Inputs comprise the primary inputs labour (*L*) and capital. Capital services are provided by *R* different types of assets, of which *R1* are ICT, and *R2* non-ICT assets (*R=R1+R2).* The present study distinguishes three types of ICT assets: hardware, communication equipment and software but for purposes of theoretical exposition, they are lumped together here as the flow of ICT capital services (K^C) as distinct from the flow of non-ICT capital services (K^N). The well-known growth de-composition is given by:

$$\mathrm{dln}Q = \varepsilon_L \mathrm{dln}L + \varepsilon_{KN} \mathrm{dln}K^N + \varepsilon_{KC} \mathrm{dln}K^C + \mathrm{dln}A \qquad (1)$$

In (1), $\varepsilon_{L,}$ ε_{KN} and ε_{KC} are the elasticities of production of labour, non-ICT and ICT capital, respectively. For a cost-minimising firm and under competitive conditions on factor markets, $\varepsilon_{L,}$ ε_{KN} and ε_{KC} correspond to cost shares of the different factors of production. Under constant returns of scale, total cost equals total revenue, cost shares equal income shares and sum to unity. Call *w* the average compensation per hour of labour input, u^C the user cost of a unit of ICT capital services and u^N the user cost of a unit of non-ICT capital services so that wL/PQ is the income share of labour, and u^CK^C/PQ and u^CK^N/PQ are the income shares of ICT and non-ICT capital. In (1), the rate of change of output is presented as a weighted average of the growth rates of factor inputs, and of a multi-factor productivity (MFP) term, dln*A*. This rate of MFP change is a Hicks-neutral (input-augmenting) shift of a production possibility function over time. The contribution of an input to output growth is evaluated by its cost or income share multiplied by its rate of volume change. In particular, the contribution of ICT capital to output growth is captured by $[u^CK^C/PQ]\text{dln}K^C$.

Quantity of ICT capital services

The rate of change of ICT capital input $\text{dln}K^C$ is a weighted average of the rates of change of its three components: IT equipment, software, communications equipment:

$$\text{dln}K^C = \textstyle\sum_i^{R1} [u^i K^i / \sum_i^{R1} u^i K^i]\, \text{dln}K^i. \qquad (2)$$

Thus, $u^i K^i / \sum_i^{R1} u^i K^i$ is the share of ICT asset *i* in total income of ICT capital at current prices. Typically, ICT and other capital services are not directly observable. The usual assumption here is that, for a particular type of (homogenous) capital good, the flow of capital services is proportional to the productive stock of the same capital good, and that this proportionality factor is constant over time. With this simplification, the rate of change of the productive stock and of the flow of capital services derived from this stock are equal. The productive stock (see OECD 2001b for a fuller discussion) reflects the physical or quantity aspect of a capital good. We construct the productive stock for each asset with the perpetual inventory method that cumulates past investment, corrected for the retirement of assets and corrected for the loss in productive efficiency (see section 0 of the annex for a more detailed description).

Price of capital services

The price of capital services is given by the user cost or rental price expression as initially formulated by Jorgenson (1963). User costs are imputed prices and reflect how much would be charged in a well-functioning market for a one period-rental of a capital good. Ignoring taxes, user costs u^i of an asset *i* are composed of the net rate of return *r* applied to the purchase price of a new asset q^i, of the costs of depreciation, captured by the rate of depreciation *d*, and by the rate of change of the asset price itself, as expressed by the term $\zeta = \text{dln}q^i$.

$$u_,^i = q^i\, [r + d^i - \zeta^i] \qquad (3)$$

The expression in brackets represents the gross rate of return on a new capital asset. For ICT assets, the gross rate of return tends to be higher than for other assets. This reflects rapid obsolescence of ICT assets, which enters the user cost term via changes in purchase prices of new capital goods and via depreciation. Generally, falling purchase prices raise the cost of holding a capital good while making it less expensive to buy.

We determine the net rate of return *r* in the user cost expression as the ex-post rate (Griliches and Jorgenson 1967) that will just make the user costs exhaust the gross operating surplus of the sector under consideration[2].

Depreciation rates d^i reflect the relative loss of an asset's value due to ageing[3]. Note that the entire change in an asset's value comprises not only the ageing effect d^i but also the value change implied by a rise or fall of the asset price. Often, the term 'depreciation' is used to denote both the ageing and the price effect. To avoid semantic confusion, we follow Hill (2000) and Diewert (2001) and call the value loss associated with ageing *cross section depreciation* and the value loss due to both ageing and expected obsolescence (which would incoporate part of the price effect) *time series depreciation*. Conceptually, the latter corresponds approximately to the notion of "consumption of fixed capital" as defined in the System of National Accounts[4]. The total amount of depreciation considered in the present paper corresponds to cross section depreciation and is given by $d^i q^i K^i$.

Gross and net output

In the present set-up, cross section depreciation is instrumental for the derivation of measures of net value-added. They measure income, net of the resources that have to be set aside to keep capital services intact. Net value-added traces measures of disposable income for consumption more closely than gross value-added. While not an appropriate point of departure for modelling producer behaviour, it provides a bridge to a welfare perspective of economic growth. The specific interest in this paper is in the effects of ICT investment on the volume change in time series depreciation as the latter determines largely by how much the volume change in gross value-added differs from the volume change in net value-added.

In terms of the present accounting framework, the level of current-price cross-section depreciation is captured by $\sum_i^R d^i q^i K^i$. Current-price net value-added ($P^N N$) is current-price gross value-added minus depreciation or

$$PQ = P^N N + \sum_i^R d^i q^i K^i \qquad (4)$$

The volume rate of change of net value added is obtained implicitly by differentiating (4) with respect to time and presenting the volume rate of change of gross value added as a weighted average of the volume rate of change of depreciation and of net value-added. this gives rise to the following expression:

$$\mathrm{dln}Q = v_D \sum_i^R x^i \mathrm{dln}K^i + (1-v_D)\mathrm{dln}N \qquad (5)$$

where $v_D \equiv \sum_i^R d^i q^i K^i / PQ$ is the share of depreciation in total income and where $x^i \equiv \{d^i q^i K^i / \sum_i^R d^i q^i K^i\}$ is each asset's nominal share in total cross-section depreciation. The first expression on the right hand side of (5) is the volume change of depreciation multiplied by v_D, its share in total income. The volume rate of change of net value-added is obtained by solving (5) for dln$N$. To measure the impact of ICT capital accumulation on the difference between the rates of net and gross value-added, two effects have to be considered. The first one is the direct effect on volume depreciation and income, as captured by $v_D \sum_i^{R1} x^i \mathrm{dln}K^i$. The second one is the contribution to gross output growth associated with ICT capital services. These effects are operating in different directions. Whereas a shift towards short-lived, high-depreciation assets such as ICT will raise volume depreciation and therefore increase the wedge between net and gross value-added, it also raises gross output. Both effects must be taken into account when examining the consequence of a structural change in investment and capital services. Using (5), we can express the difference between the volume change of gross and net value-added as:

$$\mathrm{dln}Q - \mathrm{dln}N = \{v_D/(1-v_D)\}\{\sum_i^R x^i \mathrm{dln}K^i - \mathrm{dln}Q\} \qquad (6)$$

Next, the growth accounting equation (1) is inserted into (6) to account for the effects of capital on gross output growth. After some rearrangement, one obtains:

$$\mathrm{dln}Q - \mathrm{dln}N = \{v_D/(1-v_D)\}\{\sum_i^R (x^i - v_K v^i)\mathrm{dln}K^i - v_L \mathrm{dln}L - \mathrm{dlnA}\} \qquad (7)$$

To isolate the effects of ICT capital services, K^i (i=1,2,..*R1*), we set the effects of labour, MFP and non-ICT capital goods to zero. This yields

$$\textit{Effects of ICT capital services on } \mathrm{dln}Q\text{-}\mathrm{dln}N = \{v_D/(1-v_D)\}\{\textstyle\sum_i^{R1}(x^i - v_K v^i)\mathrm{dln}K^i\} \qquad (8)$$

where $v_K \equiv \sum_i^R u^i K^i / PQ$ is the capital income share. From (8) it is apparent that the effect of ICT capital services on the wedge between volume growth of gross and net value-added is zero when the volume growth of depreciation due to ICT equals the volume contribution of ICT to gross output growth. The gap widens if the depreciation effects prevail and narrows if the output contribution prevails. We examine the evolution of the net effect in section 0.

Empirical implementation for nine OECD countries

Data

Several statistical issues arise in an international comparison of the role of ICTs in economic growth. They concern availability and comparability of current price investment series of ICT capital goods, and the choice of deflators. In addition, comparable methodologies have to be used to compute capital service series, and productive and wealth capital stocks.

Current-price investment. There are significant differences in the availability and the level of detail at which statistical offices in OECD countries compile and publish data on gross fixed capital formation by type of asset or by type of investment good. The present study distinguishes 7 types of capital goods, of which three are ICT capital goods (IT hardware, communications equipment and software). This remains a high level of aggregation, given that every asset category is implicitly considered as a homogenous type of capital good – an assumption that appears difficult to justify in several cases. At the same time, the bias from using aggregate data is large only when relative prices of the components of an aggregate evolve significantly differently. This is in particular the case for ICT assets and those have been considered separately.

Whereas Schreyer (2000) and Daveri (2001) use a private data source to assess the size of ICT investment at the international level, the present study is based on data that has recently become available in statistical offices national accounts. Estimates were still necessary, in particular to obtain long time series. Also, certain differences in the coverage of asset classification remain but on the whole, the data set is more consistent than the one used in Schreyer (2000).

Some countries (for example the United States) publish official investment data by detailed type of asset only for private investment. In a number of other countries (for example Germany, Italy or the United Kingdom), the available asset breakdown of investment relates to the entire economy. Estimates had to be made to construct series for both the entire economy and the business sector for all countries under consideration. Table 1 provides an overview of data availability and coverage.

Table 1: Current price ICT investment series available in official statistics and used in this study

	Available aggregates	Software	IT equipment	Communications equipment	Time period
Australia	Private, public enterprise and general government	Purchased and own-account software	Computer equipment and peripherals + OECD estimate of office and accounting equipment	*OECD estimate based on OECD telecommunication database*	1960-2000
Canada	Total economy, business sector and government	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment	1981-2000
Finland	Total economy, business sector and government	Purchased and own-account software	*OECD estimate based on production and trade data from the OECD STAN database and investment data from the SNA database*	*OECD estimate based on production and trade data from the OECD STAN database and investment data from the SNA database*	1960-1999
France	Total economy and major institutional sectors	Purchased and own-account software	Computers, office and accounting equipment ('machines de bureau et matériel informatique', GE31)	Communications equipment ('appareils d'émission and de transmission', GE33)	1959-2000
Germany	Total economy *OECD estimate for the business sector*	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment (including radio and television sets)	1991-2000
Italy	Total economy *OECD estimate for the business sector*	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment	1982-99
Japan	Total economy *OECD estimate for the business sector*	Purchased software	Electric computing equipment and accessory devices	Wired and radio communications equipment	1990-99
United Kingdom	Total economy *OECD estimate for the business sector*	Purchased and own-account software: estimates by Oulton (2001) (*lower bound estimate used*)	Computers, office and accounting equipment (*estimate of computers only by Oulton 2001 used*)	Communications equipment	1948-99
United States	Private sector	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment	1948-00

Notes: (1) In this table, *business sector* is used for data classified by institutional sectors or units. In national accounts terminology, this corresponds to the *corporate sector*, i.e., financial and non-financial corporations including quasi-corporations.
Source: OECD STI/STD.

Software. The System of National Accounts 1993 (SNA93) stipulates that software purchases by firms should be considered investment expenditure, incurred to build up an intangible asset, the stock of software available in the production process. With the implementation of the SNA93 in most OECD countries, the first set of estimates of software expenditure has become available in countries' national accounts. A number of important measurement issues arise in this context. Some of them are briefly described in Annex section 0. Unlike hardware, whose current price investment can be assessed with reasonable confidence, the measurement of software expenditure at current prices is subject to many uncertainties and estimation methods differ across countries. For example, Lequiller (2001) found significant cross-country differences in the allocation of software expenditure between fixed capital formation and intermediate consumption. This may be as indicative of differences in methodologies as it may reflect truly different investment patterns across OECD countries[5]. In addition, the problem of finding the appropriate price index for software is similar to the one for hardware investment. Consequently, comparisons of software investment across countries have to be treated with considerable care.

Price indices. Price indices are key in measuring volume investment, capital services and user costs. Accurate price indices should be constant quality deflators that reflect price changes for a given performance of ICT investment goods. Thus, observed price changes of 'computer boxes' have to be quality-adjusted for comparison of different vintages. Wyckoff (1995) was one of the first to point out that the large differences that could be observed between computer price indices in OECD countries were likely much more a reflection of differences in statistical methodology than true differences in price changes. In particular, those countries that employ hedonic methods to construct ICT deflators tend to register a larger drop in ICT prices than countries that do not. Schreyer (2000) used a set of 'harmonised' deflators to control for some of the differences in methodology. We follow this approach and assume that the ratios between ICT and non-ICT asset prices evolve in a similar manner across countries, using the United States as the benchmark. A comparison of the growth contributions of ICT based on national and harmonised deflators produces a sensitivity analysis with regard to the choice of deflators.

Note a difficulty with using the harmonised deflator. From an accounting perspective, adjusting the price index for investment goods for any country implies an adjustment of the volume index of output. In most cases, such an adjustment would increase the measured rate of volume output change. For practical reasons, these effects had to be ignored in the present analysis[6].

ICT investment

The economic expansion in the United States in the 1990s was led by large and sustained growth in business investment, albeit from very low levels at the beginning of the decade. Remarkably, the rate of capital accumulation in the US business sector almost doubled in the second part of the decade, mainly because of strong investment in ICT capital. In 2000, and measured at current prices, ICT investment accounted for nearly a third of overall non-residential investment, and similar high rates are found in Finland, followed by Canada and Australia (Table 2). When comparing these trends across countries, one has to bear in mind business cycles. For example in the early 1990s, when the United States started its expansion phase, Finland went through a deep economic recession. More recently, when investment in Finland has been surging, Japan has been experiencing an economic downturn.

Table 2 Percentage share of ICT investment in total non-residential investment

Current prices, 1980-2000[1]

		Australia	Canada	Finland	France	Germany	Italy	Japan	United Kingdom	United States
IT equipment	1980	2.2	3.9	2.0	2.5	4.6	4.1	3.3	2.9	5.1
	1990	5.5	4.5	3.6	3.5	5.5	4.2	3.8	6.0	7.0
	1995	8.4	5.7	4.0	3.9	4.6	3.5	4.6	8.6	8.7
	2000	7.2	7.9	2.9	4.4	6.1	4.2	5.2	8.4	8.3
Communications equipment	1980	4.0	3.0	3.2	2.9	3.9	4.0	3.4	1.6	7.1
	1990	3.8	3.8	3.9	3.2	4.8	5.7	4.0	2.0	7.5
	1995	4.7	4.0	9.3	3.5	4.2	6.7	5.3	3.6	7.3
	2000	5.6	4.2	15.3	3.9	4.3	7.2	6.9	3.6	8.0
Software	1980	1.1	2.2	2.6	1.3	3.6	1.7	0.4	0.3	3.0
	1990	4.6	4.9	5.2	2.6	3.7	3.8	3.1	2.1	8.0
	1995	6.4	7.1	9.2	3.5	4.5	4.3	4.0	3.5	10.1
	2000	9.7	9.4	9.8	6.1	5.7	4.9	3.8	3.0	13.6
ICT equipment and software	1980	7.3	9.1	7.8	6.8	12.2	9.7	7.0	4.8	15.2
	1990	13.9	13.2	12.7	9.4	13.9	13.7	10.8	10.1	22.5
	1995	19.5	16.8	22.5	10.8	13.3	14.4	13.8	15.6	26.1
	2000	22.5	21.4	28.0	14.4	16.2	16.3	16.0	15.0	29.9

Note: 1) 1999 for Finland, Italy and Japan.

In spite of different positions in the business cycle, it is apparent from Table 3 that all nine OECD countries under consideration witnessed a rapid increase of constant price ICT investment. The growth rate even accelerated in the second part of the 1990s, with the exception of Japan. The rate of growth in IT equipment in the United States in the 1990s doubled with respect to the 1980s and accelerated in the 1995-99 period to reach 34 per cent per year on average. Similar rates of increase were registered in France for all three types of ICT assets. While communications equipment was the most dynamic component in Finland, it was hardware in Japan and software in Australia. Overall, and despite different positions in the business cycles, the growth of investment in the 1990s has been largely driven by growth in ICT investment in all nine countries. This is particularly evident in the case of the United States, Australia and Finland where ICT investment accounted for over 50 per cent of non-residential investment growth in the most recent years.

Volume growth in IT investment has been so significant because of a steady decline in its relative price, giving rise to substitution between different types of capital and between ICT capital and labour. The rapid price decline for computers and office equipment accelerated further in the late 1990s with respect to earlier years. This drop in prices has been much less pronounced for communications equipment and software. Software has nonetheless been a major driver of ICT investment growth in the late 1990, contributing 25-40 percent of overall investment growth.

One likely reason for rapid software investment is its complementarity with IT capital goods. Consider a general-purpose technology such as the Internet that offers an infrastructure for new forms of business. Their development typically entails investment in communication infrastructure first, followed by investment in applications (software). The development of on-line activities, which often follows, generates demand for new technology infrastructure and applications. For instance, new multimedia applications require continuous improvements in circuit technology and software enabling the use of real-time media data-types such as video, speech, animation and music. Another, more short-lived reason for a steep rise in software investment towards the end of the 1990 was the anticipation of the "Y2K bug" even though it remains difficult to give even approximate indications about the size of this investment effect.

Table 3 Average annual percentage growth of volume investment
Business sector, 1980-2000

National price index

		Australia	Canada	Finland	France	Germany	Italy	Japan	United Kingdom	United Sta
IT equipment	1980-90	31.9	23.2	12.1	18.8	8.5	5.6	13.1	20.7	18.9
	1990-00	22.9	27.2	-7.6	15.4	10.1	4.2	8.1	12.7	27.5
	1990-95	21.3	19.6	-11.3	9.1	4.1	-2.4	5.5	11.9	22.5
	95-2000	24.5	34.8	-2.9	21.7	16.0	12.4	11.3	13.5	32.4
Communications equipment	1980-90	5.5	4.8	8.6	4.6	6.8	8.5	11.8	9.6	3.9
	1990-00	8.1	8.3	10.7	7.3	5.4	5.7	9.4	10.8	11.2
	1990-95	6.4	5.2	4.9	3.3	4.1	5.0	3.4	11.3	6.2
	95-2000	9.8	11.5	17.9	11.2	6.7	6.6	16.8	10.4	16.2
Software	1980-90	28.8	13.6	8.5	11.6	4.2	11.6	7.9	20.6	14.6
	1990-00	17.4	10.9	4.3	9.4	9.5	3.5	-0.3	4.6	14.1
	1990-95	13.8	8.1	1.2	4.7	8.7	1.6	0.2	7.2	11.6
	95-2000	20.9	13.7	8.1	14.0	10.3	5.8	-0.9	2.0	16.6

Harmonised price index

		Australia	Canada	Finland	France	Germany	Italy	Japan	United Kingdom	United Sta
IT equipment	1980-90	30.2	19.3	25.4	22.5	20.1	18.4	24.8	28.2	18.9
	1990-00	23.0	30.1	15.1	23.5	22.9	20.1	20.1	25.4	27.5
	1990-95	23.9	21.2	9.4	15.4	14.6	11.5	16.6	22.8	22.5
	95-2000	22.0	38.9	22.3	31.6	31.2	30.9	24.4	28.0	32.4
Communi-cations equipment	1980-90	7.1	6.6	8.6	7.3	7.4	8.6	12.0	9.9	3.9
	1990-00	9.7	8.2	18.4	7.9	5.6	8.3	8.1	13.4	11.2
	1990-95	8.7	3.7	12.2	4.3	2.4	5.5	5.5	14.9	6.2
	95-2000	10.7	12.7	26.2	11.4	8.7	11.7	11.3	11.9	16.2
Software	1980-90	24.8	14.8	14.4	15.0	6.9	14.3	32.8	27.3	14.6
	1990-00	11.7	12.1	10.0	12.1	9.7	7.5	3.0	9.9	14.1
	1990-95	9.3	9.6	6.9	5.7	8.6	4.6	4.6	12.7	11.6
	95-2000	14.1	14.6	13.9	18.6	10.9	11.0	1.1	7.1	16.6

Table 4 Average annual percentage change in ICT price indices

Business sector, 1980-2000[1]

National price index

		AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
IT equipment	1980-90	-10.8	-16.5	4.3	-7.1	-1.2	6.0	-3.1	-3.7	-10.2
	1990-2000	-17.2	-13.3	4.0	-10.5	-4.8	-0.2	-6.5	-6.2	-17.8
	1990-95	-12.2	-14.2	4.1	-9.3	-3.1	1.7	-5.4	-4.6	-12.7
	95-2000	-22.2	-18.3	3.8	-11.7	-6.5	-2.4	-7.8	-8.1	-22.8
Communi-cations equipment	1980-90	5.5	2.9	3.9	4.9	0.7	6.2	-1.6	2.1	2.2
	1990-2000	-0.5	-1.6	3.7	-2.8	-2.2	1.1	-5.1	-0.8	-2.2
	1990-95	0.6	-3.0	3.8	-1.5	-2.1	1.3	-1.3	1.1	-1.5
	95-2000	-1.5	-1.4	3.6	-4.1	-2.3	0.8	-9.8	-3.1	-2.9
Software	1980-90	-1.3	1.1	8.6	4.3	1.6	7.5	21.9	7.2	0.8
	1990-2000	-6.5	0.5	2.7	0.6	-0.9	3.6	0.6	3.3	-1.1
	1990-95	-5.9	0.3	2.5	-1.2	-0.2	4.2	1.3	3.4	-1.4
	95-2000	-7.1	0.5	3.0	2.4	-1.6	2.9	-0.3	3.2	-0.9

Harmonised price index

		AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
IT equipment	1980-90	-9.1	-12.5	-9.2	-11.0	-12.8	-7.1	-15.0	-11.2	-10.2
	1990-2000	-17.3	-17.1	-18.4	-18.4	-17.6	-15.8	-18.1	-18.5	-17.8
	1990-95	-14.8	-15.8	-16.0	-15.0	-13.5	-11.6	-15.9	-15.6	-12.7
	95-2000	-19.8	-22.3	-21.3	-21.7	-21.7	-21.0	-20.9	-21.4	-22.8
Communi-cations equipment	1980-90	3.8	1.2	4.0	2.2	0.2	6.1	-1.8	1.8	2.2
	1990-2000	-2.0	-1.5	-3.9	-3.3	-2.4	-1.3	-3.7	-3.3	-2.2
	1990-95	-1.7	-1.5	-3.3	-2.4	-0.4	1.1	-3.2	-2.5	-1.5
	95-2000	-2.4	-2.6	-4.6	-4.3	-4.3	-4.3	-4.3	-4.0	-2.9
Software	1980-90	2.6	-0.1	2.6	0.8	-1.1	4.7	-3.2	0.6	0.8
	1990-2000	-0.8	-0.2	-3.0	-2.2	-1.1	-0.4	-2.8	-2.2	-1.1
	1990-95	-1.3	-1.2	-3.3	-2.3	-0.1	1.1	-3.2	-2.1	-1.4
	95-2000	-0.2	-0.4	-2.7	-2.1	-2.2	-2.3	-2.3	-1.9	-0.9

Note: 1) 1999 for Finland, Italy and Japan.

Capital services

To present the evolution of ICT capital services, the theoretical framework in section 0 has to be re-formulated in discrete time. The capital service flow derived from asset *i* is given by $K_t^i=\lambda S_{t-1}^i$. Here, S_{t-1}^i stands for the productive stock of asset *i*, at the end of period *t-1*. λ is a constant parameter that links the productive stock to the flow of capital services. For simplicity, and without loss of generality, we set $\lambda=1$. Based on volume investment series and assumptions about their service lives, age-efficiency functions and retirement distributions (see Annex section 0), we compute productive capital stocks for each type of asset.

More specifically, letting I_t^i be the flow of constant price investment expenditure during period t, the productive services of capital good i are:

$$K_{,t}^i = S_{t-1}^i = \sum_{\tau=0}^T g_{,\tau}^i I_{t-1-\tau}^i \qquad i=1,2,..R \qquad (9)$$

g_τ^i is a function that combines the effects of retirement and efficiency loss of an asset. The formulation in (9) implies that investment in period t translates into capital services of the following year. For longer-lived assets such as machinery or non-residential structures, this is a suitable assumption. For short-lived assets such as ICT capital, this may be less plausible. However, in the absence of infra-annual data, it is not possible to introduce a lag structure differentiated by type of asset.

A volume index of ICT capital services is obtained by aggregating across capital services of individual ICT asset by way of a Törnqvist index number formula: $\Delta\ln K_t^C = \sum_i^{R1} 0.5(v_t^i + v_{t-1}^i)\Delta\ln K_t^i$ with $v_t^i \equiv [u_t^i K_t^i / \sum_i^R u_t^i K_t^i]$ as each asset's share in total user costs. Our empirical formulation of the user cost expression is consistent with (9): $u_{,t}^i = q_{t-1}^i [r_t + d_t^i - \zeta_t^i (1-d_t^i)]$, where $\zeta_t = (q_t^i / q_{t-1}^i) - 1$ and $d_t^i - 1 = q_{t,1}^i / q_{t,0}^i$ is the price of a one-year old asset in period t relative to that of a new asset in the same period t.

A look at the overall rate of capital services growth in Table 5 shows that a good deal of the dynamics of ICT capital services translates into overall capital input. Two elements account for this. First, the rapid rate of growth of the volume of individual ICT capital services, as discussed in the preceding paragraph. Second, the weights by which ICT capital services enter the overall measure of capital services. These weights are current-price capital income shares of each type of asset where capital income is defined as the product of user costs and the level of capital services. More formally, capital income is given by $u_{,t}^i K_t^i = [r_t + d_t^i - \zeta_t^i (1-d_t^i)] q_{t-1}^i S_{t-1}^i$, or the gross rate of return $[r_t + d_t^i - \zeta_t^i (1-d_t^i)]$ times the current-price capital stock of each asset. Given the large decline in ICT asset prices, these gross rates of return have to be large to compensate for the loss of holding a capital good that becomes rapidly cheaper. But high rates of return reflect high marginal rates of productivity of ICT assets. Thus, the capital income shares $(u_{,t}^i K_t^i / \sum_i^R u_{,t}^i K_t^i)$ by which ICT assets enter overall measures of capital services have tended to rise, and this added weight accounts for part of the overall increase in the quantity of capital services.

Jorgenson (2001) presents estimates of capital quality for the United States. He defines a quality index of capital services as the ratio between an index of capital services and the capital stock. We adopt his methodology and define the latter as the share-weighted index of the productive stocks of individual assets where weights are based on purchase prices of capital goods rather than on user costs. Put differently, the weights attached to each capital services index are the shares of each capital good in the value of the productive stock at current prices as opposed to the share of each capital good in the capital income of each period. These purchase price weights $(q_{t-1}^i S_{t-1}^i / \sum_i^R q_{t-1}^i S_{t-1}^i)$ miss out precisely the gross rate of return that plays a distinctive role in user-cost based weights. Empirically, we measure the rate of compositional change of capital services as follows:

$$\textit{Rate of compositional change} = \Delta\ln K_t - \Delta\ln S_{t-1} =$$

$$= \sum_i^R 0.5\,(v_t^i + v_{t-1}^i)\,\Delta\ln K_t^i - \sum_i^R 0.5\,(z_t^i + z_{t-1}^i)\,\Delta\ln K_t^i, \text{ where} \qquad (10)$$

$$v_t^i \equiv [u_t^i K_t^i / \sum_i^R u_t^i K_t^i] \text{ and } z_i^t \equiv [q_{t-1}^i S_{t-1}^i / \sum_i^R q_{t-1}^i S_{t-1}^i]$$

Table 5 shows indices of capital services and of their compositional change. With the exception of Finland, capital services grew more rapidly than measures of capital stock, implying a quality improvement of capital input or a shift of capital input towards more short-lived, high productivity assets. The same table, based on our set of harmonised deflators reinforces this picture. Over time, and independent of the choice of price indices, the relative importance of capital quality in total capital input increased. However, only in the United States did the capital composition component double between the second and the first half of the nineties – a development not followed by other countries.

Table 5 Capital services and compositional change

Average annual percentage change, based on national deflators, 1980-2000 or latest available year

National price index

		AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
Capital services	1980-90	4.9	4.1	2.4	2.6	2.3	2.8	5.3	3.1	3.7
	1990-95	3.7	2.7	0.8	2.2	3.4	2.2	5.5	2.9	2.8
	95-2000	4.3	3.2	0.1	1.9	2.5	1.9	3.1	3.4	4.5
Capital stocks	1980-90	4.2	3.6	2.4	2.1	2.2	2.4	5.2	2.8	3.2
	1990-95	3.1	2.2	0.6	2.0	3.0	2.0	5.4	2.6	2.3
	95-2000	3.4	2.4	0.6	1.5	2.3	1.9	3.1	3.0	3.3
Composi-tional change	1980-90	0.7	0.5	0.0	0.5	0.1	0.4	0.1	0.3	0.5
	1990-95	0.7	0.5	0.3	0.2	0.3	0.2	0.1	0.3	0.5
	95-2000	1.0	0.8	-0.6	0.4	0.2	0.0	0.1	0.4	1.2

Harmonised price index

		AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
Capital services	1980-90	4.9	4.1	2.7	2.7	2.6	3.1	5.8	3.3	3.7
	1990-95	3.7	2.7	1.4	2.3	3.6	2.5	6.2	3.3	2.8
	95-2000	4.1	3.4	1.0	2.1	2.9	2.5	4.0	4.0	4.5
Capital stocks	1980-90	4.2	3.6	2.4	2.1	2.3	2.5	5.3	2.8	3.2
	1990-95	3.1	2.2	0.7	2.0	3.1	2.1	5.6	2.7	2.3
	95-2000	3.3	2.5	0.8	1.6	2.4	2.0	3.4	3.2	3.3
Composi-tional change	1980-90	0.6	0.5	0.3	0.6	0.3	0.6	0.5	0.5	0.5
	1990-95	0.7	0.5	0.7	0.3	0.5	0.4	0.6	0.6	0.5
	95-2000	0.8	0.9	0.2	0.5	0.5	0.5	0.6	0.9	1.2

Contribution of ICT capital to output growth

To measure the contribution of ICT to output growth empirically, we approximate the theoretical formulation in equation (1) by a Törnqvist index number formula and estimate the ICT contribution as

$$\sum_i^{R1} 0.5(v_{K,t}^i + v_{K,t-1}^i)\Delta \ln K_t^i, \text{ where } v_{K,t}^i \equiv u_t^i K_t^i / P_t Q_t. \qquad (11)$$

Table 6 shows that over the past twenty years the contribution of ICT equipment and software to output growth of the business sector has been between 0.2 and 0.5 percentage points per year, depending on the country. Over the period 1995-2000, the contribution of IT and software jumped to a range from 0.3

to 0.9 per cent. In relative terms, ICT capital accounted for between one third and close to 100 percent of the overall contribution of capital services to output growth. The contribution of ICT equipment to output growth was highest in the United States (0.87 percentage points on average over the years 1995-00), followed by Australia, Canada and Finland. As the first panel of Table 6 is based on national price indices for ICT, some of the differences in growth contributions may be due to methodological rather than actual discrepancies in price changes. One of these methodological differences lies in the type of price indices. The second panel therefore reproduces the results based on a harmonised price index. A comparison of the tables yields major differences in the ICT contribution to output growth for Finland (up by over 0.4 percentage points in the second half of the 1990s) and a more moderate increase in the measured contributions of Germany, Italy and the United Kingdom. This brings them in line with France and Japan where national IT deflators are based on hedonic models and differ much less from the harmonised set. However, the use of harmonised deflators does not close the apparent gap between ICT contributions in the United States and the large European countries.

In the 1995-2000 period, software capital accumulation accounted for about 20 to 30 percent of the overall contribution of ICT capital to output growth. It is remarkable that this result holds across all OECD countries in the sample, with the exception of Japan and the United Kingdom. However, software expenditure data for Japan excludes own-account software and this may well explain the discrepancy. For the United Kingdom, Oulton (2001) suggested that the official data under-estimate software expenditure. Also, some researchers (Jorgenson and Stiroh 2000) have observed that price indices of own-account software may not fully reflect quality improvements and in this sense, the contribution of software to economic growth as computed here may constitute a lower bound. More generally, however, statistical methodologies to capitalise software are still under development, and a definite statement about upward or downward biases is difficult to make.

Our results are broadly consistent with those of other studies relating to individual countries, in particular Oliner and Sichel (2000) and Jorgenson and Stiroh (2000) for the United States, Cette et al. (2000) for France, Niininen (1999) for Finland, Oulton (2001) for the United Kingdom, Schreyer (2000) for the G7, Daveri (2000) for eighteen countries. Other studies for the United States use a different framework with somewhat different results like in Whelan (2000), or significantly different results as in Kiley (1999)[7]. A more specific comparison can be found in Annex section 0.

Time profiles of the contributions from ICT in different countries are shown in Figure 1. It clearly emerges that the United States have not been alone in benefiting from rising growth contributions of ICT. Yet, differences in the size of contributions are also apparent. Without claiming to explain the underlying causes for differences in ICT contributions to growth across countries, we offer a few points for consideration.

Role of ICT producing industry. There is no immediate reason why a country with a small or without any ICT producing industry should not benefit from the growth impulses of the *use* of ICT as a capital input. Yet, the question of the role of the ICT producing sector has been debated, in particular from a perspective of comparing European economies with the United States[8].

The present analysis shows that for the period under consideration, the existence of a large ICT producing industry is neither a necessary nor a sufficient condition for countries to benefit from growth effects of ICT. This is demonstrated by the examples of Australia and Japan: whereas the former has a very small ICT producing sector and benefited markedly from ICT capital services, the latter has the largest IT hardware producing sector of the nine countries analysed, and did not exhibit above-average growth contributions from ICT equipment.

Table 6 Percentage point contribution of ICT to output growth

Business sector, national price index[1], 1980-2000 or latest available year

National price index

		Australia	Canada	Finland	France	Germany	Italy	Japan	United Kingdom	United States
growth of output	80-85	3.39	2.66	2.80	1.48	1.13	1.54	3.31	2.59	3.35
	85-90	3.79	2.90	3.42	3.46	3.59	3.04	5.14	3.90	3.31
	90-95	3.37	1.79	-0.70	0.97	2.22	1.44	1.33	2.12	2.64
	95-99	4.72	4.09	5.62	2.60	1.73	1.93	1.10	3.48	4.43
	95-2000	**4.62**	**4.20**		**2.81**	**2.06**			**3.55**	**4.40**
contribution (percentage points) from:										
IT and communications equipment	80-85	0.22	0.28	0.14	0.11	0.09	0.11	0.08	0.10	0.36
	85-90	0.35	0.27	0.18	0.15	0.13	0.13	0.16	0.20	0.32
	90-95	0.31	0.21	0.00	0.11	0.16	0.10	0.14	0.13	0.29
	95-99	0.57	0.36	0.11	0.19	0.14	0.12	0.29	0.25	0.61
	95-2000	**0.56**	**0.38**		**0.19**	**0.15**			**0.25**	**0.62**
software	80-85	0.05	0.04	0.04	0.03	0.01	0.02	0.00	0.01	0.07
	85-90	0.16	0.09	0.08	0.05	0.03	0.06	0.02	0.03	0.11
	90-95	0.16	0.08	0.01	0.02	0.06	0.01	0.00	0.02	0.14
	95-99	0.21	0.11	0.09	0.08	0.07	0.04	0.00	0.03	0.25
	95-2000	**0.23**	**0.12**		**0.08**	**0.07**			**0.02**	**0.25**
total ICT	80-85	0.27	0.32	0.18	0.14	0.10	0.13	0.09	0.12	0.44
	85-90	0.51	0.36	0.25	0.21	0.16	0.20	0.18	0.23	0.43
	90-95	0.47	0.28	0.01	0.13	0.22	0.10	0.14	0.15	0.43
	95-99	0.78	0.47	0.20	0.26	0.21	0.16	0.29	0.28	0.86
	95-2000	**0.79**	**0.51**		**0.27**	**0.22**			**0.27**	**0.87**
total capital services	80-85	1.63	1.14	0.68	0.69	0.58	0.72	1.01	0.70	1.25
	85-90	1.97	1.15	0.83	0.91	0.80	0.86	1.38	1.10	1.10
	90-95	1.35	0.63	0.03	0.73	0.99	0.62	1.33	0.74	0.97
	95-99	1.74	0.92	0.15	0.75	0.81	0.82	0.97	1.05	1.69
	95-2000		**0.97**		**0.78**	**0.83**			**1.04**	**1.71**

Harmonised price index

		Australia	Canada	Finland	France	Germany	Italy	Japan	United Kingdom	United States
growth of output	80-85	3.39	2.66	2.80	1.48	1.13	1.54	3.31	2.59	3.35
	85-90	3.79	2.90	3.42	3.46	3.59	3.04	5.14	3.90	3.31
	90-95	3.37	1.79	-0.70	0.97	2.22	1.44	1.33	2.12	2.64
	95-99	4.72	4.09	5.62	2.60	1.73	1.93	1.10	3.48	4.43
	95-2000	**4.62**	**4.20**		**2.81**	**2.06**			**3.55**	**4.40**
contribution (percentage points) from:										
IT and communications equipment	80-85	0.24	0.25	0.21	0.13	0.18	0.21	0.16	0.16	0.36
	85-90	0.34	0.24	0.30	0.17	0.23	0.23	0.23	0.25	0.32
	90-95	0.37	0.21	0.17	0.16	0.24	0.18	0.25	0.23	0.29
	95-99	0.53	0.39	0.46	0.23	0.28	0.29	0.36	0.42	0.61
	95-2000	**0.53**	**0.43**		**0.25**	**0.30**			**0.43**	**0.62**
		0.20	0.23	0.26	0.30	0.20	0.18	0.05	0.10	0.29
software	80-85	0.05	0.04	0.07	0.05	0.03	0.02	0.02	0.02	0.07
	85-90	0.12	0.09	0.12	0.05	0.04	0.08	0.07	0.04	0.11
	90-95	0.12	0.09	0.07	0.02	0.06	0.02	0.06	0.04	0.14
	95-99	0.13	0.12	0.16	0.10	0.07	0.07	0.02	0.05	0.25
	95-2000	**0.15**	**0.13**		**0.10**	**0.07**			**0.04**	**0.25**
total ICT	80-85	0.29	0.30	0.28	0.18	0.20	0.23	0.18	0.18	0.44
	85-90	0.46	0.33	0.42	0.22	0.27	0.31	0.30	0.29	0.43
	90-95	0.48	0.30	0.24	0.18	0.30	0.21	0.31	0.27	0.43
	95-99	0.66	0.51	0.62	0.33	0.35	0.36	0.38	0.47	0.86
	95-2000	**0.68**	**0.57**		**0.35**	**0.38**			**0.48**	**0.87**
total capital services	80-85	1.66	1.11	0.77	0.72	0.69	0.82	1.10	0.76	1.25
	85-90	1.93	1.13	1.00	0.92	0.91	0.97	1.50	1.15	1.10
	90-95	1.37	0.65	0.26	0.78	1.08	0.73	1.49	0.85	0.97
	95-99	1.63	0.96	0.57	0.82	0.95	1.01	1.07	1.23	1.69
	95-2000		**1.03**		**0.87**	**0.98**			**1.25**	**1.71**

This does not mean that ICT producing industries have not played a role in recent growth patterns. This emerges from analyses of the sectoral sources of macro-economic MFP growth. For the United States, Oliner and Sichel (2000) and Jorgenson and Stiroh (2000) find that a sizeable part of overall MFP growth can be traced back to the ICT producing industries[9] (computers, semiconductors and communications equipment). Pilat and Lee (2001) examine contributions of ICT and non-ICT industries to economy-wide labour productivity growth and find notable contributions of the ICT industries[10] in a number of countries. Gordon (2000) attributes the entire acceleration of trend MFP growth to MFP advances in the computer and computer-related semiconductor manufacturing, although this result depends critically on the specific methodology to adjust for cyclical swings in productivity. Thus, it is certainly the case that technological advances, for example in the semiconductor industry, translate into MFP growth of this industry and consequently contribute to economy-wide MFP growth. Technical advances also translate into lower equipment prices and capital deepening in other industries. While this second effect is not tied to the existence of an ICT producing industry, the first effect is, and in this sense the presence of an ICT producing industry can be beneficial for overall advances in MFP. In an analysis of ten OECD countries, van Ark (2001) finds that productivity growth differentials between the United States and several European countries are at least partly explained by a larger and more productive ICT producing sector in the United States. Note, however, that this is *not* an occurrence of spill-overs, from producing to other industries. It is a simple statement of the fact that MFP grew rapidly in ICT industries.

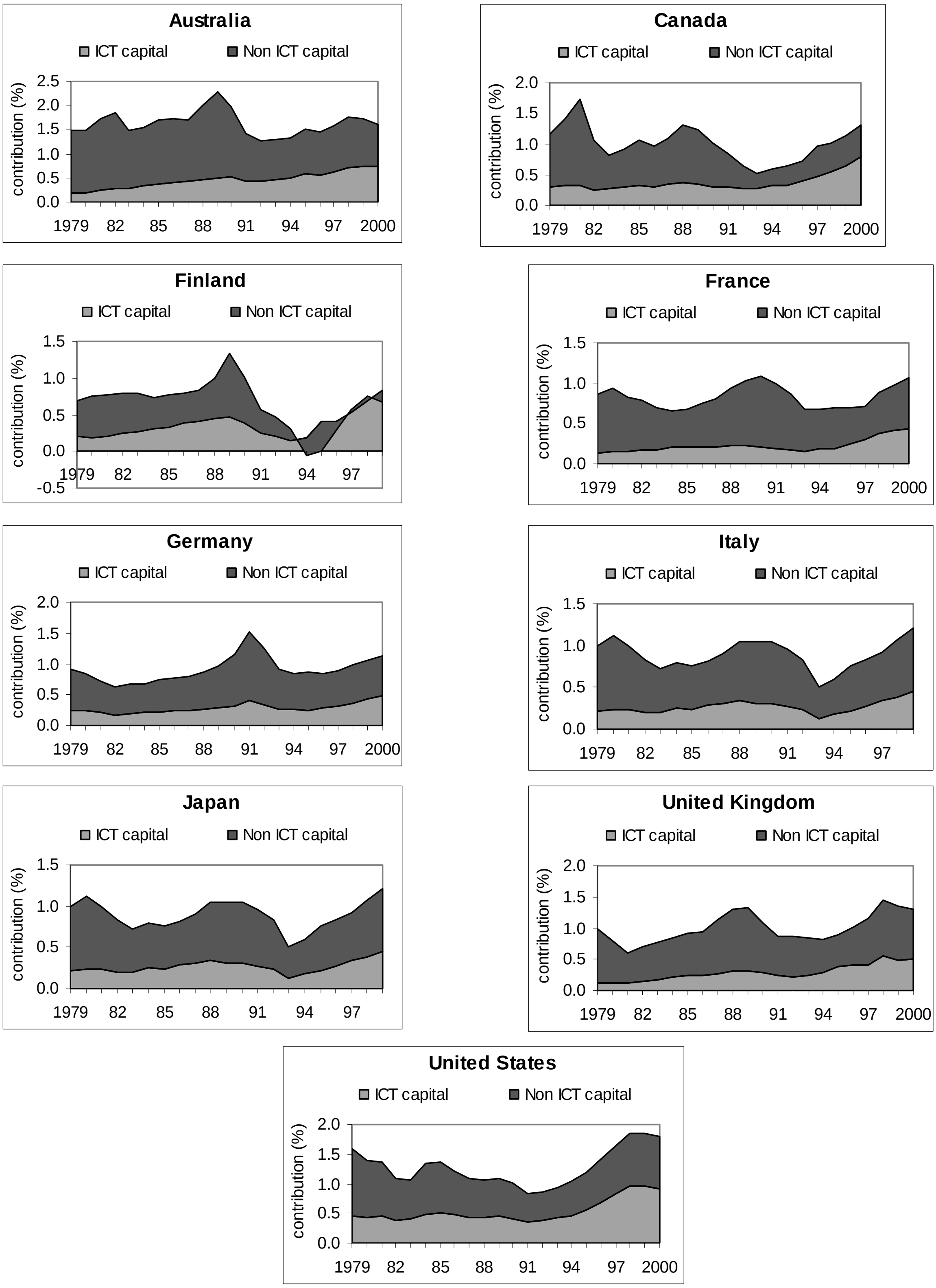
Flexibility and absorptive capacity. Technological advances in ICT are available universally. However, the degree of uptake and use of ICT in production has varied across OECD countries. It is unlikely that this simply reflects a slower decline of relative prices of ICT equipment as perceived by economic actors[11]. With broadly similar changes in relative prices, what other explanations are there? Apart from simple differences in economic structure (different shares of ICT-intensive industries, different shares of ICT producing industries), recent work by OECD (2000, 2001a) points to differences in flexibility of product and labour markets and the business environment as explanatory factors behind differences in the uptake and diffusion of new technologies between some OECD countries.

We make no attempt to summarise the analysis in OECD (2000, 2001a), but instead take a brief look at two countries that are useful examples and that are part of the set of countries in the present analysis, Finland and Australia. Both countries featured above-average MFP growth over the 1990s and both countries' growth performance benefited significantly from ICT capital services. Finland underwent major structural changes that resulted in a shift of its producing and export sector toward ICT industries, in particular telecommunication equipment. However, the importance of ICT for Finland only partly resides in ICT production. ICT using services have accounted for just over one-third of the pick up in MFP growth in the 1995-99 period (Pilat and Lee, 2001). Widespread diffusion of ICT as well as the development of the ICT producing industry are closely linked to a tradition of open and competitive markets for telecommunication services but also the liberalisation of other product markets. OECD (2001a) shows that countries that moved early to liberalise their telecommunications industry now have much lower communications costs, and consequently, a wider usage and diffusion of ICT technologies than those that followed later on.

OECD (2001a) finds that firms in the United States and Canada have enjoyed considerably lower costs of ICT investment goods in the 1990s than firms in European countries and in Japan. Barriers to trade, in particular non-tariff barriers related to standards, import licensing and government procurement, may partly explain cost differentials. Higher price levels in other OECD countries may also be associated with a lack of competition within countries. For example, Nicoletti et al. (1999) find that countries with a high relative price level of ICT investment tend to have a lower degree of competition, as measured by indicators of economic regulation. Over time, however, international trade and competition should erode some of these cross-country differences.

Figure 1 ICT contribution to output growth

Business sector, based on harmonised price index



Contrary to Finland, the ICT producing industry plays a negligible role in Australia. We find a direct and significant impact of ICT on Australian output growth. One explanation of this large impact is again in the complementarity between micro-economic reforms and ICT. Regulatory reforms and open market policies brought about rationalisation and restructuring of business processes and ICT is likely to have been instrumental in this process[12]. We conclude from the – admittedly partial – evidence from Finland and Australia that microeconomic reforms have helped ICT adoption, and that ICT diffusion is interacting with organisational and innovation factors in generating a positive impact on productivity.

Gross and net output

This section considers the impact of ICT investment on overall rates and on volume changes of depreciation. Following the framework in section 2.4, we set out by calculating the average rates of (cross-section) depreciation in nine OECD countries. The level of cross-section depreciation in current prices for a single asset is given by $d_t^i q_{t-1}{}^i S_{t-1}{}^i$, and the average rate of cross-section depreciation can be defined as $\sum_i^R[(q_{t-1}{}^i S_{t-1}{}^i / \sum_i^R q_{t-1}{}^i S_{t-1}{}^i) d_t^i\,]$, where each asset's depreciation rate is weighed by its share in the nominal productive capital stock. Table 7 below shows trends for the nine OECD countries. For all of them, the average rate of depreciation has increased over the past decade, although not dramatically. Despite the important growth of ICT assets in volume terms, the average rate of depreciation, i.e., the value loss due to the rapid ageing of ICT assets has remained moderate as these assets continue to occupy a comparatively small share in the current-price productive capital stock.

Table 7 Average percentage rate of cross-section depreciation[1]

Business sector, based on national ICT price indices, 1980-2000 or latest available year[2]

	AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
					All assets				
1980-1990	2.0	1.4	2.5	1.7	1.9	2.4	1.9	2.6	3.1
1990-95	2.0	2.0	2.1	1.5	2.0	1.6	2.0	2.2	3.5
95-2000	2.5	2.5	2.3	2.0	2.0	1.5	2.6	2.2	3.9
					Machinery and equipment				
1980-1990	3.7	3.6	4.7	3.8	4.7	4.3	4.4	4.1	6.7
1990-95	4.1	4.4	4.5	3.8	4.5	3.8	4.5	4.2	7.5
95-2000	4.5	4.9	4.3	4.4	4.7	4.2	5.7	4.1	7.7

Notes: 1). As described in the text, the rate of cross-section depreciation is the percentage difference in value of a one-year old asset over a new asset at a given point in time. 2) 1999 for Finland, Italy and Japan.

Turning to volume measures of depreciation, the rate of change of gross (*Q)* value added is a weighted average of the rate of change of net (*N*) value-added and the rate of change of depreciation:

$$\Delta \ln Q_t = \sum_i^R 0.5(v_{D,t}{}^i + v_{D,t-1}{}^i)\Delta \ln K_t^i + 0.5(v_{N,t} + v_{N,t-1})\,\Delta lnN_t \qquad (12)$$

where $v_{D,t}{}^i \equiv [d_t^i q_{t-1}{}^i S_{t-1}{}^i]/P_t Q_t$ is asset *i*'s share of nominal depreciation in total factor income (gross value-added) and $v_{N,,t}$ is the current price share of net value-added in total income. The difference between the volume index of gross and of net value added is given by the expression below where derivation has been laid out in section 2.4 on the conceptual framework.

Effects of ICT capital services on $\Delta\ln Q$-$\Delta\ln N$ =

$$= \{0.5(v_{Dt}+v_{Dt-1})/[1-0.5(v_{Dt}+v_{Dt-1})]\}\{\sum_i^{R1}[0.5(x_t^i+x_{t-1}^i)-0.5(v_{Kt}^i+v_{Kt-1}^i)]\mathrm{dln}K^i\} \quad (13)$$

As earlier, x^i denotes each asset's share in total depreciation and v_K^i each asset's share in total factor income[13]. Table 8 presents empirical results. One observes, for example, that during the 1980s, ICT assets accounted for 0.09 percentage points of the difference between the volume rates of growth of gross and net output in Australia. Over the 1990s, this difference grow to 0.14 and 0.16 percentage points, thus somewhat widening the gap between the volume rate of change in net and in gross value added. This should not come as a surprise: a compositional shift in capital services towards highly productive but short-lived capital goods implies an accelerating rate of volume depreciation and consequently an accelerated rate of replacement investment to maintain the overall quantity of capital services. Patterns are hardly more pronounced when harmonised deflators enter the calculation, as shown in the lower panel of Table 8. Overall, the magnitude of the effect remains small, in particular when *both* the effects on volume depreciation and on volume gross value-added are taken into account which at least partly offset each other.

Table 8 Average annual ICT contribution to difference between volume change in gross and net value-added

Percentage points, business sector based on national ICT price index, 1980-2000[1]

	AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
1980-1990	0.09	0.07	0.10	0.05	0.05	0.07	0.05	0.06	0.11
1990-95	0.14	0.09	0.00	0.03	0.07	0.02	0.05	0.05	0.13
95-2000	0.16	0.13	0.09	0.08	0.08	0.06	0.04	0.07	0.19

Percentage points, business sector based on harmonised ICT price index, 1980-2000[1]

	AUSTRALIA	CANADA	FINLAND	FRANCE	GERMANY	ITALY	JAPAN	UK	USA
1980-1990	0.09	0.07	0.11	0.05	0.05	0.07	0.07	0.05	0.11
1990-95	0.12	0.09	0.08	0.03	0.07	0.04	0.08	0.06	0.13
95-2000	0.14	0.13	0.13	0.08	0.07	0.07	0.06	0.06	0.19

Notes: 1) 1999 for Finland, Italy and Japan.

Conclusions

This paper examines the contribution of ICT capital to economic growth in nine OECD countries. It does so by looking at investment trends in ICT equipment and software and at the role played by ICT in overall capital accumulation. Contributions to growth are quantified in a growth accounting framework. Because data issues loom heavily in the ICT area and even more so in international comparisons, measurement and statistical points are discussed at some length. Main findings are:

– Despite different positions in the business cycle, all nine countries underwent a marked increase in the rate of investment in ICT capital goods. IT equipment and software have been the most dynamic ICT components, and grew at two-digit real rates in nearly all nine countries. While ICT investment has been growing everywhere, cross-country differences persist. In the year 2000 and measured in nominal terms, ICT investment has accounted for about one third of total non-residential investment in the United States, and at similar rates in Finland, Canada and Australia.

– Concurrent with the rise in demand for IT investment, prices for IT capital goods have fallen in relative and absolute terms. This led to substitution effects towards IT capital goods and away from other factors of production. Software prices fell by less than IT equipment prices but this did not prevent rapid accumulation of software capital. One notable expression of substitution effects between different types of assets is the observed compositional change of capital services, towards capital goods with higher returns per period.

– Over the past two decades, ICT contributed between 0.2 and 0.5 percentage points per year to economic growth, depending on the country. During the second half of the 1990s, this contribution rose to 0.3 to 0.9 percentage points per year. Thus, the United States has not been alone in benefiting from the positive effects of ICT capital investment on economic growth and it has not been alone in experiencing an acceleration of these effects. However, effects have clearly been largest in the United States, followed only by Australia, Finland and Canada. Of the nine countries considered, Germany, Italy, France and Japan registered the lowest contribution of ICT to economic growth. There is evidence that new potential driving forces of growth such as ICT, require suitable framework conditions. Many of the same policy prescriptions that may allow the traditional factors of growth to work better are likely to be useful to improve framework conditions conducive to ICT and related technologies.

– This analysis which examines the impact of the use of ICT on output growth indicates that the existence of a large ICT producing industry is neither a necessary nor a sufficient condition to successfully experience the growth effects of ICT. ICT diffusion plays a key role and depends on the right framework conditions, not on the existence of an ICT producing sector.

– Rapid accumulation of capital goods with high marginal productivity but comparatively short service lives implies a rise in the average rates of depreciation. More output needs to be set aside for investment so that the flow of capital services is kept intact. The implication is that ICT capital has a smaller effect of advancing the volume growth of net output than that of gross output. Because net output traces disposable income for consumption more closely than gross output, this observation is interesting from a welfare perspective. However, the positive effect on volume depreciation has to be set against the growth contribution of ICT capital in the first instance, to obtain a fuller picture of the welfare-related implications of ICT capital accumulation. It turns out the net effect on the volume change of net value-added has been modest, though increasing in a number of countries.

ANNEX METHODOLOGICAL AND DATA ISSUES

1. Measuring current price investment

IT and telecommunications equipment. An overview of available data is presented in Table 1. Differences between countries relate to the availability of sectoral detail and the possibility to separately identify computers as part of computers and office equipment.

Customised software. Countries estimate customised software purchases either by using information from business surveys or by applying a 'commodity-flow method'. The former aims at directly measuring software investment, the latter uses statistical data on the domestic production and imports of packaged software and then proceeds to split this overall supply into a final demand and intermediate consumption component. There is no guarantee that the two methods yield the same result, however, and there are advantages and drawbacks associated with both methods. For example, the commodity-flow method has the advantage of starting from fairly reliable data on overall supply but requires assumptions about the share of final demand in total supply. The company survey method directly inquires about firm's capital spending but may face other problems; for example firms may understate their software investment because they record software purchases as current expenditure. International comparisons of the split of total supply into a final demand (investment) and an intermediate demand component do reveal significant differences. For an in-depth discussion see Ahmad (2001). Presently, commodity-flow methods are used in Finland, Italy and the United States whereas France, Australia, and the United Kingdom use the company survey method.

Standardised, reproduced software. Separate estimates of reproduced software investment expenditure are difficult to obtain when standardised software is bundled with other commodities in particular computers. Separation of standardised and customised software is also difficult when investment data are based on business surveys as they do not normally distinguish the two types of software.

Own-account software. Estimating own-account software is another difficult issue. In many countries, it suffers from a weak statistical basis and there are considerable cross-country differences in estimation methods. Generally, estimation proceeds by evaluating the compensation for labour input by software engineers involved in the development of own-account software. International differences arise in the definition and measurement of the relevant occupational group ('software developer'); estimates of hours worked in development, and average compensation per hour. There are also conceptual issues such as whether all own-account software should be treated as an investment good or whether some of it (such as own-account software that is subsequently embedded in a product) should be treated as intermediate delivery.

Choice of deflators. Table 9 identifies countries' usage of hedonic methods in constructing price indices for software, IT equipment and communications equipment. Several countries employ hedonic techniques to deflate IT equipment expenditure. Presently, only the United States uses a hedonic pricing model for pre-packaged software. Other countries apply either an input-based deflator (such as a wage index for programmers) or use other investment price series (e.g., for hardware) as approximations. The input-based deflation method is more likely to overstate the price change of software because it cannot reflect quality improvements. Applying the hardware-related deflator could mean overstating the price change of software: where price indices for hardware and software have been established separately, software price indices fell less rapidly than price indices for hardware. We use the United States' overall software deflator to construct harmonised price indices for software. This implies an assumption of similar composition (own-account, standard reproduced and customised) of software investment across countries which may not be accurate[14].

Table 9 Use of hedonic deflators

	Software	IT Equipment	Communications equipment
Australia	No	Hedonic price index linked to US-BEA computer price index, exchange rate-adjusted	No
Canada	Adjusted version of US-BEA price index for pre-packaged software (hedonic) and for customised software (partly hedonic)	Hedonic price index for PCs, portable computers and peripheral equipment	No
Finland	Weighted average (50/50) of average earnings index in computer industry and US-BEA hedonic price index for pre-packaged software	n.a.	n.a.
France	No	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	No	No	No
Italy	No	No	No
Japan	No	Hedonic price index for computers	No
United Kingdom	No	No	No
United States	Hedonic deflator for pre-packaged software; for customised software average of deflators for own-account software (not based on hedonic method) and pre-packaged software	Hedonic deflators for computers and peripheral equipment	Hedonic deflators for telephone switching equipment

2. Capital services and user costs[15]

Asset types. This study distinguishes three ICT assets (IT equipment, communications equipment, software) and four non-ICT assets (non-residential buildings, other construction, transport equipment and other non-residential, non-ICT assets). No account was taken of residential assets, land, inventories and intangibles other than software. Data sources for current and constant-price investment are *OECD Annual National Accounts* for broad asset categories and national sources or specific communications from statistical offices for a more detailed breakdown, in particular regarding ICT assets. Own estimates were added, in particular for early years.

Service lives. Based on current practice in OECD countries, we chose the following average service lives: software (3 years), IT equipment (7 years), communications equipment (15 years), transport equipment (15 years), other equipment (15 years), non-residential buildings (60 years) and other structures (20 years).

Retirement function. The survival or retirement function indicates how many of the capital goods purchased in a particular period are still at work after τ years. It was chosen as the cumulative function of a normal distribution of retirement with the average service life as its mean and a spread of two standard deviations. In addition, the retirement function was truncated at the maximum service live, determined as T=1.5*average service life. Truncation avoids the situation where some assets of a cohort have an infinite service life. Denote the retirement function for asset i by F_τ^i.

Age-efficiency function. The age-efficiency function reflects the change in productive efficiency of an asset as it ages, conditional on survival. Call the age-efficiency function for asset i h_τ^i. At the beginning of a cohort's life, this coefficient takes the value of one ($h_0^i=1$), it declines over the service life of an asset and becomes zero when the maximum service life T of the asset is reached ($h_T^i=0$). Following the practice at the United States Bureau of Labor Statistics (BLS 1983), we chose a hyperbolic age-efficiency function. Under a hyperbolic function, an asset loses relatively little of its productive efficiency in the early years of service life and relatively much towards the end of its service life. More specifically, the formula employed for the hyperbolic function is $(T-t)/(T-ßt)$ where T is the maximum service life, t is an index of time passing and the parameter ß which shapes the form of the hyperbolic function, has been set to 0.8.

Productive capital stock. Given a time series of deflated investment and age-efficiency as well as retirement functions, we use the perpetual inventory method to construct measures of the productive capital stock by asset according to $S_t^i = \sum_{\tau=0}^{T} g_{,\tau}^i I_{t-\tau}^i \quad (i=1,2,..R.)$, where $g_\tau^i=h_\tau^i F_\tau^i$ is the combined age-efficiency/retirement function.

Harmonised price indices. "Harmonised" price indices for ICT capital goods were calibrated around the United States ICT price indices. In a first step, the percentage point difference between the price index for IT equipment ($\Delta\ln q_t^{IT,US}$) and the price index for non-ICT equipment was calculated for the United States ($\Delta\ln q_t^{N,US}$). To eliminate short-term fluctuations, the resulting series was regressed against a polynomial trend and predicted values were generated. Call the predicted values from this regression $\lambda_t^{IT}=f(\Delta\ln q_t^{IT,US}-\Delta\ln q_t^{N,US})$. The same procedure was applied to software (SW) and communications equipment (CE) and yielded the series λ_t^{SW} and λ_t^{CE}. To construct the set of harmonised price indices, we applied these factors to non-ICT price indices of other countries: $\Delta\ln q_t^{IT,k}=\Delta\ln q_t^{N,k}+\lambda_t^{IT}$, $\Delta\ln q_t^{SW,k}=\Delta\ln q_t^{N,k}+\lambda_t^{SW}$, $\Delta\ln q_t^{CE,k}=\Delta\ln q_t^{CE,k}+\lambda_t^{CE}$, where $k=1,2,..8$ countries other than the United States.

Time series depreciation. Rates of depreciation d_t^i for the user cost expression were derived in a consistent manner from age-efficiency and survival profile and expected asset price changes (see OECD 2001b for a full statement). No distinction was made between realised and expected asset price changes. Thus, ζ_t^i corresponds to the observed rate of change of the investment good deflator of asset i.

Rates of return. We calculated the net rate of return, r_t,, as the ex-post rate that exhausts all non-labour income in the production account. This was obtained by solving the following relationship for r_t:

$$\textit{Non-labour income} = P_tQ_t - w_tL_t = \sum_i^R u_t^i K_t^i = r_t \sum_i^R q_{t-1}^i S_{t-1}^i + \sum_i^R [d_t^i - \zeta_t^i (1-d_t^i)] q_{t-1}^i S_{t-1}^i.$$

3. Comparison with country-specific studies

The estimates obtained in this study are in the range of those obtained with similar methods and official statistics for the United States, France and the United Kingdom. Table 10 compares contributions of ICT to output growth and points to some of the differences in data and methodologies that help explain the variations in the point estimates.

Table 10 Comparison with country-specific studies

	Data source	Periods	ICT contribution to output growth (percentage points)			Main methodological differences
			Software	IT Equipment	Communi-cations equipment	
United States						
This study	NIPA (BEA) July 2001 revision	1990-95 1995-00	0.14 0.25	0.20 0.47	0.08 0.15	Hyperbolic age-efficiency profile Assets do not include land and inventories 7 types of assets
Oliner and Sichel (2000)	NIPA (BEA) and BLS	1991-95 1996-99	0.25 0.32	0.25 0.63	0.07 0.15	Hyperbolic age-efficiency profile 58 types of assets
Jorgenson and Stiroh (2000)	NIPA (BEA) and BLS with extensions	1990-95 1995-98	0.15 0.21	0.19 0.49	0.06 0.11	Output includes service flows from owner-occupied housing and consumer durables Geometric age-efficiency profile
France						
This study	INSEE August 2001	1990-95 1995-00	0.02 0.08	0.07 0.11	0.04 0.08	
Cette et al. (2001)	INSEE	1989-95 1995-99	0.05 0.09	0.09 0.13	0.03 0.05	Based on exchange rate-adjusted BEA deflator for IT equipment, software
Heckel et al. (2001)	INSEE	1987-98		0.32		Not based on national accounts as statistical source for capital data
United Kingdom						
This study	Oulton (2001)	1990-95 1995-99 1999-00		0.31 (total ICT equipment) 0.51 (total ICT equipment)		Current price software expenditure follows the 'low software' option presented by Oulton.
Oulton (2001)	ONS and Bank of England estimates	1990-95 1995-98		0.34 (total ICT equipment) 0.41(total ICT equipment)		Geometric age-efficiency profile Exchange rate adjusted US-BEA deflators for ICT investment

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NOTES

1. This is only one, albeit convenient, way of presenting the production process. Other formulations are feasible, in particular approaches that recognise both primary and intermediate inputs and that use a concept of gross output. For an overview discussion, see Schreyer and Pilat (2001), for a more extensive treatment see OECD (2001b).

2. This is the most widely-used method based on an assumption of perfect foresight. It fits well with the general equilibrium assumption implied by growth accounting models and has the clear advantage of simplicity. However, it will be subject to measurement errors of gross operating surplus and it is an ex-post measure that may not reflect the conditions facing producers at the beginning of the period. An alternative method is to choose an exogenous expected rate of return instead of an endogenous realised rate of return. It makes capital measures independent of measures of output and does not have to make the strong assumption that all observed price changes have been fully anticipated by economic actors. Such alternative models were studied by Harper, Berndt and Wood (1989), and more recently by Diewert (2001).

3 . In the present study, the age-price profile, which forms the pattern of cross-section depreciation rates, is distinguished from the age-efficiency profile which reflects the productive efficiency of an asset over its service life. See Annex and OECD (2001b) for a discussion.

4. The formulation here uses the actual, ex-post, price change of the asset to determine revaluation, some of which may be due to obsolescence. Implicitly, no distinction is made between expected or normal obsolescence and unexpected obsolescence. The 1993 System of National Accounts, on the other hand, stipulates that expected obsolescence should be part of time series depreciation or consumption of fixed capital. In this sense, there is a conceptual difference between the present formulation and the SNA definition of consumption of fixed capital. See OECD (2001b), Hill (2000) and Diewert (2001) on this point.

5 . An OECD Task Force has been set up in 2001 to review statistical issues related to software measurement in the National Accounts.

6 . However, for many countries, the effects of such an adjustment are likely to be small (Schreyer 2001, Lequiller 2001).

7. Whelan (2000) analyses the growth contribution within a vintage model of production. Kiley (1999) uses an adjustment cost model and thereby obtains a negative short-term contribution of computers to growth. These results are extensively compared in Oliner and Sichel (2000)..

8 . For example, the issue was debated at length at a seminar of the Banque de France in January 2001.

9 . Oliner and Sichel (2000) attribute 0.65 percentage points of an overall 1.16 percent MFP growth over the period 1996-99 to MFP advances in the computer and semiconductor sectors. Jorgenson and Stiroh (2000) identify a 0.5 percentage point contribution from the ICT sector to an overall 0.75 percent MFP growth over the period 1995-99.

10 . Bearing in mind, however, that an analysis of the sectoral sources of labour productivity growth does not permit to distinguish between effects of capital deepening (the use of ICT capital goods) input and effects of MFP growth (the production of ICT).

11 . In which case, the working hypothesis behind our “harmonised deflators” would be wrong.

12 . The use of new technologies in Australian business has increased very rapidly in this last decade. Between 1997/98 and 1999/00, the proportion of businesses with Internet access has almost doubled (29% to 56%) and the use of the Internet to facilitate business processes is remarkably high in traditional sectors such as the gas, electricity and water supply that have undergone extensive reforms. A study by the Australian Productivity Commission explains that the Australian economy “appears to be operating differently in the 1990s. The surge in productivity growth has reversed two long-term trends: Australia’s poor productivity performance, compared with other high-income countries, and a secular decline in capital productivity … this implies that the nation’s capital stock is being better utilised” (Productivity Commission, 1999). The Productivity Commission’s main explanation for this surge in productivity growth is related to extensive microeconomic reforms.

13 . This calculation is an integral and consistent part of the growth accounting model. However, results may be different from those in published national accounts due to differences in methodologies for the computation of current and constant price depreciation and consumption of fixed capital.

14 . United States deflators for the three types of software fall at different rates because the deflator for own-account software is based on an input-price index. Jorgenson and Stiroh (2000) made adjustments for this discrepancy. No adjustments were made in the study at hand.

15 . For a more extensive treatment of capital services measurement, see OECD (2001b).