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THE CONTRIBUTION OF INFORMATION AND COMMUNICATION TECHNOLOGIES TO ECONOMIC GROWTH IN NINE OECD COUNTRIES

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INTRODUCTION

Recently, OECD (2001a) examined sources of and differences in growth patterns between OECD countries and concluded that one factor that has become increasingly important is information and communication technology (ICT). Some of the effects of ICT, in conjunction with macroeconomic policies are well-documented for the United States which 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.

This paper is based on Colecchia (2001) which 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.

FRAMEWORK

Accounting for the contribution of ICT to output growth

The methodology employed here 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 (1957), and Jorgenson and Griliches (1967). 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 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 a set R of different types of assets, of which a subset R1 is ICT and another subset R2 is non-ICT assets. 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 $u^C K^C$/PQ and $u^N K^N$/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, dlnA. 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 $[u^C K^C/PQ]\mathrm{dln}K^C$.

For purposes of empirical implementation, $\mathrm{dln}K^C$ will be approximated by a logarithmic rate of change of ICT capital services $[\Delta \ln K_t^C = \ln(K_t^C/K_{t-1}^C)]$ and its income share $u^C K^C$/PQ by a two-period average: $0.5(u_t^C K_t^C/P_t Q_t + u_{t-1}^C K_{t-1}^C/P_{t-1} Q_{t-1})$.

The rate of change of ICT capital input $\mathrm{dln}K^C$ is a weighted average of the rates of change of its three components: IT equipment, software and communications equipment. A Törnqvist index is used in its empirical implementation with weights $v_t^i \equiv [u_t^i K_t^i / \Sigma_{i\in R1}\, u_t^i K_t^i]$ that stand for the share of ICT asset i in total income of ICT capital at current prices:

$$\Delta \ln K_t^C = \Sigma_{i\in R1}\, 0.5(v_t^i + v_{t-1}^i)\, \Delta \ln K_t^i \qquad (2)$$

Measuring the volume of capital services

Typically, volume changes of ICT and other capital services are not directly observable. The same holds for their user costs that are needed to aggregate flows of capital services. Concerning the flow of capital services, the usual assumption is that, for a particular type of (homogenous) capital good, it 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.

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. λ can be set to equal unity as its size does not affect the rate of change of the productive stock. Based on volume investment series and assumptions about their service lives, age-efficiency functions and retirement distributions, 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:

$$K_t^i = S_{t-1}^i = \Sigma_{\tau=0}^{T} g_\tau^i I_{t-1-\tau}^i \quad i \in R \qquad (3)$$

g_τ^i is a function that combines the effects of retirement and efficiency loss of an asset. 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 life, determined as T = 1.5*average service life. Truncation avoids the situation where some assets of a cohort have an infinite service life.

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 ($h_{T+1}^i = 0$). Following the practice at the United States Bureau of Labor Statistics (BLS, 1983), a hyperbolic age-efficiency function was used. 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.[1]

The formulation in (3) 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 intra-annual data, it is not possible to introduce a lag structure differentiated by type of asset.

Measuring the price of capital services

The price of capital services is given by the user cost or rental price expression as 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_t^i of an asset i are composed of the net rate of return r_t applied to the purchase price of a new asset q_t^i, of the costs of depreciation, captured by the rate of depreciation d_t^i, and of the rate of change of the asset price itself, as expressed by the term ζ_t^i. 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.

$$u_t^i = q_{t-1}^i[r_t + d_t^i - \zeta_t^i(1 - d_t^i)] \quad (4)$$

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_t in the user cost expression as the *ex post* rate (Jorgenson and Griliches, 1967) that will just make the user costs exhaust the gross operating surplus of the sector under consideration.[2] Depreciation rates d_t^i reflect the relative loss of an asset's value due to ageing.[3] The rates of depreciation d_t^i for the user cost expression were derived in a consistent manner from age-efficiency profiles and expected asset price changes (see OECD, 2001b for a full statement).

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:

$$\text{Non-labour income} = P_tQ_t - w_tL_t = \Sigma_{i\in R}\, u_t^iK_t^i = r_t\Sigma_{i\in R}\, q_{t-1}^iS_{t-1}^i + \Sigma_{i\in R}[d_t^i - \zeta_t^i(1 - d_t^i)]q_{t-1}^iS_{t-1}^i \quad (5)$$

DATA

Current-price investment

There are significant differences in the availability and the level of detail at which statistical offices compile and publish data on gross fixed capital formation by type of asset or by type of investment good. The present study distinguishes seven types of capital goods,[4] of which three are ICT capital goods (IT hardware, communications equipment and software) and four are 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. 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 (2000) 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.

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. 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. 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.

Table 1. **Availability of current price ICT investment series in official statistics**

	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 et 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	1982-1999
Japan	Total economy OECD *estimate for the business sector*	Purchased software	Electric computing equipment and accessory devices	Wired and radio communications equipment	1990-1999
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 used by* Oulton, 2001)	Communications equipment	1948-1999
United States	Private sector	Purchased and own-account software	Computers, office and accounting equipment	Communications equipment	1948-2000

Note: 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.

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 firms' 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.

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.

Table 2 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.[5]

Schreyer (2000) used a set of "harmonised" deflators to control for some of the differences in methodology. "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 $k = 1,2,\ldots 8$ countries other than the United States.

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]

Table 2. **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

Source: OECD.

RESULTS

ICT investment

The economic expansion in the United States in the second half of the 1990s was led by large and sustained growth in business investment, following 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 3).

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. Yet, in spite of different positions in the business cycle, it is apparent from Table 4 that all nine OECD countries under consideration witnessed a rapid increase of constant price ICT investment. The growth rate even

Table 3. **Share of ICT investment in non-residential investment**
Percentages

		Australia	Canada	Finland[1]	France	Germany	Italy[1]	Japan[1]	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

1. 1999 instead of 2000.
Source: Authors' calculations.

Table 4. **Volume investment**
Percentage change at annual rates, business sector

		Australia	Canada	Finland[1]	France	Germany	Italy[1]	Japan[1]	United Kingdom	United States
National price index										
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
	1995-00	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
	1995-00	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
	1995-00	20.9	13.7	8.1	14.0	10.3	5.8	–0.9	2.0	16.6
Harmonised price index										
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
	1995-00	22.0	38.9	22.3	31.6	31.2	30.9	24.4	28.0	32.4
Communications 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
	1995-00	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
	1995-00	14.1	14.6	13.9	18.6	10.9	11.0	1.1	7.1	16.6

1. 1999 instead of 2000.
Source: Authors' calculations.

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 1995-00 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, the growth of investment in the 1990s was 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 second half of the 1990s.

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 per cent 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 1990s was the anticipation of the "Y2K bug" even though it remains difficult to give even approximate indications about the size of this investment effect.

Contribution of ICT capital to output growth

Table 5 shows the contribution of ICT equipment and software to output growth in the business sector of the countries under review. In the first half of the 1990s, and based on the harmonised price index, this contribution ranged between 0.18 percentage point per year and 0.48 percentage point, depending on the country. Over the period 1995-2000, the contribution of IT and software jumped to a range from 0.33 to 0.86 percentage point. In relative terms, ICT capital accounted for between one-third and close to 100 per cent of the overall contribution of capital services to output growth. The contribution of ICT equipment to output growth was highest in the United States (0.86 percentage point on average over the years 1995-99), followed by Australia, Canada and Finland. As the first panel of Table 5 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. 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 point 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

Table 5. **Contribution of ICT to output growth**
Percentage points, business sector

		Australia	Canada	Finland[1]	France	Germany	Italy[1]	Japan[1]	United Kingdom	United States
National price index										
% change at annual rate										
Output	1980-85	3.39	2.66	2.80	1.48	1.13	1.54	3.31	2.59	3.35
	1985-90	3.79	2.90	3.42	3.46	3.59	3.04	5.14	3.90	3.31
	1990-95	3.37	1.79	–0.70	0.97	2.22	1.44	1.33	2.12	2.64
	1995-99	4.72	4.09	5.62	2.60	1.73	1.93	1.10	3.48	4.43
	1995-00	4.62	4.20	. .	2.81	2.06	. .	. .	3.55	4.40
Contribution (% points) from:										
IT and communications equipment	1980-85	0.22	0.28	0.14	0.11	0.09	0.11	0.08	0.10	0.36
	1985-90	0.35	0.27	0.18	0.15	0.13	0.13	0.16	0.20	0.32
	1990-95	0.31	0.21	0.00	0.11	0.16	0.10	0.14	0.13	0.29
	1995-99	0.57	0.36	0.11	0.19	0.14	0.12	0.29	0.25	0.61
	1995-00	0.56	0.38	. .	0.19	0.15	. .	. .	0.25	0.62
Software	1980-85	0.05	0.04	0.04	0.03	0.01	0.02	0.00	0.01	0.07
	1985-90	0.16	0.09	0.08	0.05	0.03	0.06	0.02	0.03	0.11
	1990-95	0.16	0.08	0.01	0.02	0.06	0.01	0.00	0.02	0.14
	1995-99	0.21	0.11	0.09	0.08	0.07	0.04	0.00	0.03	0.25
	1995-00	0.23	0.12	. .	0.08	0.07	. .	. .	0.02	0.25
Total ICT	1980-00	0.51	0.37	0.16	0.19	0.17	0.15	0.17	0.19	0.54
	1980-85	0.27	0.32	0.18	0.14	0.10	0.13	0.09	0.12	0.44
	1985-90	0.51	0.36	0.25	0.21	0.16	0.20	0.18	0.23	0.43
	1990-95	0.47	0.28	0.01	0.13	0.22	0.10	0.14	0.15	0.43
	1995-99	0.78	0.47	0.20	0.26	0.21	0.16	0.29	0.28	0.86
	1995-00	0.79	0.51	. .	0.27	0.22	. .	. .	0.27	0.87
Total capital services	1980-85	1.63	1.45	0.68	0.69	0.58	0.72	1.01	0.70	1.25
	1985-90	1.97	1.25	0.83	0.91	0.80	0.86	1.38	1.10	1.10
	1990-95	1.35	0.72	0.03	0.73	0.99	0.62	1.33	0.74	0.97
	1995-99	1.74	1.04	0.15	0.75	0.81	0.82	0.97	1.05	1.69
	1995-00	1.73	1.09	. .	0.78	0.83	. .	. .	1.04	1.71

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 per cent 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

Table 5. **Contribution of ICT to output growth** (*cont.*)
Percentage points, business sector

		Australia	Canada	Finland[1]	France	Germany	Italy[1]	Japan[1]	United Kingdom	United States
Harmonised price index										
% change at annual rate										
Output	1980-85	3.39	2.66	2.80	1.48	1.13	1.54	3.31	2.59	3.35
	1985-90	3.79	2.90	3.42	3.46	3.59	3.04	5.14	3.90	3.31
	1990-95	3.37	1.79	–0.70	0.97	2.22	1.44	1.33	2.12	2.64
	1995-99	4.72	4.09	5.62	2.60	1.73	1.93	1.10	3.48	4.43
	1995-00	4.62	4.20	. .	2.81	2.06	. .	. .	3.55	4.40
Contribution (% points) from:										
IT and communications equipment	1980-85	0.24	0.25	0.21	0.13	0.18	0.21	0.16	0.16	0.36
	1985-90	0.34	0.24	0.30	0.17	0.23	0.23	0.23	0.25	0.32
	1990-95	0.37	0.21	0.17	0.16	0.24	0.18	0.25	0.23	0.29
	1995-99	0.53	0.39	0.46	0.23	0.28	0.29	0.36	0.42	0.61
	1995-00	0.53	0.43	. .	0.25	0.30	. .	. .	0.43	0.62
Software	1980-85	0.05	0.04	0.07	0.05	0.03	0.02	0.02	0.02	0.07
	1985-90	0.12	0.09	0.12	0.05	0.04	0.08	0.07	0.04	0.11
	1990-95	0.12	0.09	0.07	0.02	0.06	0.02	0.06	0.04	0.14
	1995-99	0.13	0.12	0.16	0.10	0.07	0.07	0.02	0.05	0.25
	1995-00	0.15	0.13	. .	0.10	0.07	. .	. .	0.04	0.25
Total ICT	1980-00	0.48	0.37	0.39	0.23	0.29	0.28	0.29	0.30	0.54
	1980-85	0.29	0.30	0.28	0.18	0.20	0.23	0.18	0.18	0.44
	1985-90	0.46	0.33	0.42	0.22	0.27	0.31	0.30	0.29	0.43
	1990-95	0.48	0.30	0.24	0.18	0.30	0.21	0.31	0.27	0.43
	1995-99	0.66	0.51	0.62	0.33	0.35	0.36	0.38	0.47	0.86
	1995-00	0.68	0.57	. .	0.35	0.38	. .	. .	0.48	0.87
Total capital services	1980-85	1.66	1.43	0.77	0.72	0.69	0.82	1.10	0.76	1.25
	1985-90	1.93	1.23	1.00	0.92	0.91	0.97	1.50	1.15	1.10
	1990-95	1.37	0.74	0.26	0.78	1.08	0.73	1.49	0.85	0.97
	1995-99	1.63	1.08	0.57	0.82	0.95	1.01	1.07	1.23	1.69
	1995-00	1.63	1.15	. .	0.87	0.98	. .	. .	1.25	1.71

1. 1999 instead of 2000.
Source: Authors' calculations.

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), Jorgenson and Stiroh (2000) and Jorgenson (2001) 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 18 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]

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 accounted for about one-third of total non-residential investment in the United States, and somewhat less 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.
- In the first half of the 1990s, ICT contributed between about 0.2 and 0.5 percentage point 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 point 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.

NOTES

1. More specifically, the formula employed for the hyperbolic function is $(T - t)/(T - \beta t)$ where T is the maximum service life, t is an index of time passing and the parameter β which shapes the form of the hyperbolic function, has been set to 0.8.

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 OECD (2001b) for a discussion. Based on current practice in OECD countries, we chose the following average service lives: software (three years), IT equipment (seven years), communications equipment (15 years), transport equipment (15 years), other equipment (15 years), non-residential buildings (60 years) and other structures (20 years).

4. 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.

5. 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.

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).

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