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THE CONTRIBUTION OF INFORMATION AND COMMUNICATION TECHNOLOGY TO OUTPUT GROWTH: A STUDY OF THE G7 COUNTRIES

Paul Schreyer

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THE CONTRIBUTION OF INFORMATION AND COMMUNICATION TECHNOLOGY TO OUTPUT GROWTH: A STUDY OF THE G7 COUNTRIES

Paul Schreyer

This paper deals with the contribution of information and communication technology (ICT) to economic growth and to labour and multi-factor productivity. It uses a well-established growth accounting framework to assess the role of ICTs as capital inputs and the contribution of these capital inputs to output growth. The paper provides an international perspective by presenting results for the G7 countries. For this purpose, data on ICT investment expenditure were compiled from several sources, to construct measures of ICT capital stocks and capital services. Special care was taken to account for the methodological differences in price deflators for computers as they exist across OECD countries. For all seven countries, the report finds that ICT capital goods have been important contributors to economic growth, although the role of ICT has been most accentuated in the United States. An important limitation of the study lies in the timeliness of internationally comparable data. Calculations could only be carried out for the years up to 1996 for all G7 countries. The report points to some of the most recent studies for the United States and briefly discusses their results.

Cette étude examine la contribution des technologies de l'information et de la communication (TIC) à la croissance économique, ainsi qu'à la productivité du travail et à la productivité totale des facteurs. Elle s'appuie sur un cadre éprouvé d'analyse causale de la croissance pour évaluer le rôle des TIC en tant qu'apports de capital et la contribution de ces apports à la croissance de la production. L'étude propose un tour d'horizon international en présentant les résultats des pays du G7. A cette fin, des données sur les dépenses d'équipement en TIC ont été recueillies auprès de plusieurs sources et classées de façon à obtenir des mesures du stock de capital sous forme de TIC et des services tirés de ce capital. Les différences méthodologiques entre les pays de l'OCDE en ce qui concerne les coefficients d'ajustement des prix des ordinateurs ont été soigneusement prises en compte. Il apparaît que les biens d'équipement des TIC ont joué un rôle important dans la croissance économique dans l'ensemble des sept pays examinés, même si c'est aux États-Unis que cette contribution a été la plus marquée. La principale imperfection de l'étude tient aux délais de disponibilité de données comparables au plan international. Ainsi, les calculs n'ont pu être effectués que jusqu'à l'année 1996 pour l'ensemble des pays du G7. Le rapport renvoie cependant à certaines des études les plus récentes concernant les États-Unis et examine brièvement leurs résultats.

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1. Introduction and main findings

In recent years, the US economy has grown at a surprisingly fast pace, in a phase of expansion that started nine years ago and constitutes the longest-ever recorded period of sustained growth. Moreover, expansion has been marked by low unemployment and record employment but also by low inflation, and an acceleration of productivity growth in the most recent years. This long period of expansion coincides with significant investment in and the diffusion of information and communication technologies (ICT) and their applications. The term "new economy" has been coined to mark the association of inflation-free growth with computerisation and globalisation, with the implication that information technologies play a major role in explaining sustained growth. The notion of the "new economy" has also been employed to signal that the workings of the economy may have significantly changed, with rules, principles and institutions different from those of the "old economy". A frequently cited example of such new factors is the rising importance of network externalities. Whether a "new economy" in this sense has actually emerged is unclear but the performance of the US economy is uncontested and has been contrasted with growth and employment in many European countries and in Japan.

This Working Paper deals with the contribution of ICTs to economic growth and to labour and multi-factor productivity. It uses a conceptual framework (presented in Section 2). One important distinction which needs to be made is the difference between *ICT industries* and their contribution to growth, and the role of *ICTs as capital inputs* in all parts of the economy. Another distinction is between the effects of ICTs on *labour* and on *multi-factor* productivity. Conclusions about the role of ICT can be quite different, depending on the perspective taken.

From an international perspective, the question of differences across countries arises: if ICTs constitute an important driver of output and productivity growth, why has an extended period of growth been observed in some countries – in particular the United States – and not in others? Investment in and use of information technology has by no means been confined to the United States, and yet average European or Japanese growth experiences have been quite different. The international perspective is at the core of the present study. For the G7 countries, data on ICT investment expenditure were compiled to construct measures of ICT capital stocks and capital services. Special care was taken to account for the methodological differences in price deflators for computers as they exist across OECD countries. Based on these data, this report focuses on the role of ICTs as capital inputs and on their contribution to output growth.

Main findings are:

- ICT capital goods are important contributors to economic growth but there is little evidence that they are inherently different from other capital goods. Over the past decades, technical progress has led to a rapid improvement in the price-performance ratio of ICT capital goods and has thus reduced the user cost of ICT capital goods relative to other types of assets. As a consequence, there has been significant substitution of ICT capital for other types of capital and labour inputs – witness the sustained growth in volume investment in ICTs that has outpaced investment in other types of capital goods. In their role as capital goods and providers of capital services, ICTs have increasingly contributed to output and therefore to labour productivity growth.

- It is sometimes argued that, in addition to their direct (and remunerated) contribution to output growth, ICTs generate spill-overs and "free" benefits that exceed the direct returns to ICT capital. If such effects are large, they should translate into an acceleration of multi-factor productivity (MFP) growth, the overall efficiency with which combined inputs are used in the economy. For the observation period 1985-96, and the group of G7 countries, this study finds few signs of a broad-based uptake in multi-factor productivity growth.

– At the same time, an important limitation of the present study lies in the timeliness of internationally comparable data. MFP calculations could only be carried out for the years up to 1996 for all G7 countries. Yet, over the most recent past (1996-99), several studies, including Oliner and Sichel (2000), Jorgenson and Stiroh (2000), and Council of Economic Advisers (2000) find a significant uptake in the growth rate of MFP in the United States. ICT plays a role here, because a sizeable part of this acceleration in MFP growth is attributable to technological gains and MFP growth in the ICT-producing industries. The remaining part of MFP growth stems from other industries. Although data limitations do not allow one to determine whether, over the period 1996-99, these (other) industries' MFP growth reflects spill-over effects from ICTs, this is certainly a possibility. Further research will be needed to make a more definite statement here.

– There are also several conclusions of a methodological nature. The first concerns the importance of international harmonisation of price indices for ICT products. At present, methodologies vary significantly and may bias international comparisons. Similarly, official sources of internationally comparable data on expenditure on ICT assets still need to be developed. The present study also underlines the importance of conceptually correct measures of capital inputs.

2. Measurement: the growth contribution of ICT

2.1. Three aspects

To provide the context for measurement in this paper, consider several ways in which information technology can influence economic growth.

ICT production. One obvious way to grasp the economic importance of information technologies is to consider the role of ICT producers in an economy's total value added or GDP. Such an approach focuses on the production process of ICT goods. Where comparisons are made, ICT production constitutes between 2.5 and 4.5% of total GDP at current prices (OECD, 2000), depending on the country and on the specific definition of ICT. Even with relatively small shares, however, the contribution to overall output can be significant if ICT industries grow much faster than other parts of the economy. If rapid output growth in ICT industries is due to strong productivity gains in these industries, this contributes to macroeconomic productivity gains. Looking at ICT industries only provides, however, no information about the *use* of ICT in production, *i.e.* the importance of computers and information technology as an *input* in other industries. There may well be countries whose ICT industry is small and yet ICT capital goods – imported and invested – play an important role in producing non-ICT output.

ICT as a capital input. An input-oriented approach would focus on the role of ICT in production. Computers and information equipment can be seen as a specific type of capital good in which firms invest, and which they combine with other types of capital and labour to produce output. The amount of ICT investment is governed by the relative prices and expected marginal revenues of capital goods: when prices of computer assets fall relative to other capital or labour, firms will substitute the latter for the former and change the way in which they combine various inputs in production. Capturing substitution processes is an important aspect of assessing the role of ICT in production. This approach [which features, for example in the work of Jorgenson and Stiroh (1999) and Oliner and Sichel (2000)] treats ICT capital goods like all other types of capital goods – in particular, it is assumed that firms who own ICT assets are able to reap most or all of the benefits that accrue from using new technologies. Only in this case is it possible to observe market income accruing to ICT capital and make inferences about its overall growth contribution. If there are other, unobserved, benefits or income, this contribution would be underestimated. This leads to the point about ICT as a special input.

ICT as a special capital input. Part of the discussion about the "new economy" is based on the claim that ICTs produce benefits that go beyond those accruing to investors and owners. A case in point are network externalities: for example, one of the advantages of Internet transactions between businesses arises because firms are connected to the network – every new investment in a connection is advantageous not only for the investor but also for all other participants. Such externalities, or spillovers, improve overall productivity and aggregate income growth. As such, they are similar to advances in knowledge, the appearance of new blueprints and formulae or organisational innovations that potentially benefit all market participants. As will be shown below in a more formal framework, such effects imply a link between multi-factor productivity (the overall efficiency with which resources are used in an economy) and use of ICT.

2.2. Framework

The three aspects of the role of ICT can be translated into a well-established growth accounting framework.[1] To see this, consider a production function relating an economy's output to labour and capital input and to multi-factor productivity. Capital input comprises the services from different types of capital goods, but for the present exposition only ICT and non-ICT capital are distinguished. The growth contribution of each input is obtained by weighting its rate of change with a coefficient that represents each factor's share in total cost. Mathematically, this can be expressed as:

$$\hat{Q} = s_L \hat{L} + s_{KC} \hat{K}_C + s_{KN} \hat{K}_N + \hat{A} \qquad (1)$$

where Q is output, L is labour input, K_C is ICT capital, K_N is all other capital and A is disembodied technical change (hatted variables indicate percentage rates of change). s_L, etc., denote each factor's share in total cost. Under constant returns to scale, total costs equal total revenue and the weights also represent income shares. How then, can the three views about ICT's contribution to growth be articulated in this framework?

ICT production. To capture the contribution of ICT industries, expression (1) could be split up into value added generated by ICT industries and by non-ICT industries. Equivalently, each of the inputs (labour, ICT and other capital as well as MFP) could be broken down into those inputs employed by the ICT industry and those employed by other industries. The contribution of ICT producers to GDP growth could then be evaluated as the sum of the contribution of labour and capital employed and MFP generated in ICT production. As pointed out earlier, there is no reason to assume that the so-computed contribution of *ICT industries* to output equals the contribution of *ICT capital goods* to output growth. Both are meaningful indicators, but respond to different questions.

ICT as a capital input. In the second approach, ICT is treated like other capital goods. Its contribution to overall output can be measured by $s_{KC}\hat{K}_C$, *i.e.* the rate of change of ICT capital input, weighted by its share in total income. Notes that K_C stands for services from ICT capital goods in all parts of the economy, ICT industries and other sectors. This relation is used to assess the impact of ICT investment on labour productivity, or on output per person. Equation (1) can be rearranged to yield an expression for the rate of change of labour productivity:

$$\hat{Q}-\hat{L}=s_{KN}(\hat{K}_N-\hat{L})+s_{KC}(\hat{K}_C-\hat{L})+\hat{A} \quad (2)$$

The expression shows that labour productivity increases with a rising intensity of non-ICT capital per unit of labour input, with a rising intensity of ICT capital per unit of labour input and with general multi-factor productivity advances. An important point arises from this presentation: if ICT is considered to be an "ordinary" capital input whose revenues accrue entirely to its owners, labour productivity will rise when there is ICT capital deepening, but there is no necessity for multi-factor productivity to rise.

ICT as a special capital input. According to this view, ICT affects not only output and labour productivity in line with its income share but also gives rise to additional effects that translate into gains in overall productivity. Such positive externalities are always characterised by a discrepancy between a private investor's rate of return and the rate of return for society as a whole. In other words, ICT equipment generates benefits above and beyond those reflected in its measured income share. This view is in the spirit of models of economic growth with increasing returns, as developed by a number of authors, in particular Romer (1986) and Lucas (1988). In Romer's model, output depends not only on each producer's capital stock but on the economy-wide capital stock. While Romer motivates this formulation with knowledge spillovers, it can also accommodate the idea of externalities generated by ICTs. Lucas' emphasis is on positive spillovers from human capital but formally the analysis is similar. In expression (1), spillovers can be picked up by a term θ, which adds to the growth effects of ICT capital:

$$\hat{Q}=s_L\hat{L}+s_{KC}(1+\theta)\hat{K}_C+s_{KN}\hat{K}_N+\hat{A} \quad (4)$$

In practice, it is difficult to observe θ directly. Although econometric techniques permit in principle to obtain estimates of the coefficient $s_{KC}(1+\theta)$, obtaining unbiased estimates is difficult and the usually preferred approach to MFP estimation is the non-parametric one (Barro, 1998). What can normally be observed is the income share s_{KC} realised by computer capital. This is also the coefficient that typically enters the computation of MFP. In the presence of externalities, the standard MFP calculation captures both the externality generated by ICT capital and the overall rate of technical change. This can be seen from the following expression that shows the effects of calculating the standard MFP residual in the presence of spillovers:

$$MF\tilde{P}=\hat{Q}-s_L\hat{L}-s_{KC}\hat{K}_C-s_{KN}\hat{K}_N=s_{KC}\theta\hat{K}_C+\hat{A} \quad (5)$$

Thus, if ICT generates positive externalities, these effects should be picked up by a conventionally measured multi-factor productivity residual.

For the purpose at hand, then, the vehicle of analysis will be equations (4) and (5): in a first instance, the contribution of ICT capital to output growth is evaluated. This entails estimates for the growth rate of ICT capital and for its income share. In a second instance, contributions from all other inputs are evaluated to permit computation of a multi-factor productivity residual. If the performance of MFP has improved over time, this could be interpreted as the sign of an additional growth contribution from ICT. Nonetheless, this remains only a possibility. A rise in MFP growth is neither a necessary nor a sufficient condition to show positive externalities of ICT capital. Many factors influence MFP growth and can compensate positive effects from ICT (in which case the absence of MFP growth would be wrongly interpreted as an absence of positive effects from ICT). Alternatively, other factors can raise MFP growth and this would be wrongly interpreted as a positive effect from ICT capital. In particular, one such factor is the ICT industry itself: if the production of ICT is accompanied by large MFP gains, this will feed through to the aggregate MFP measure $\hat{A}$. While this may be an interesting result from the production perspective of ICT, it should not be confused with spillovers generated by ICTs in their *use* as capital goods.

2.3. The importance of ICT in the capital stock

Oliner and Sichel (1994) and Sichel (1997) noted that computers make up a relatively small share of the entire capital stock – they find a share of about 2% in the US nominal net capital stock during the early 1990s. This was the basis for their argument that the overall growth contribution of computers should not be expected to be large. For more recent years (1996-98), they find a much larger role of computers in the capital stock and in its growth contribution. However, already in their earlier work, they demonstrated that a definition of ICT that encompasses computers and other information equipment as well as computer software and corresponding labour inputs significantly raise ICT's contribution to output. A first and important point is therefore the specification of information and communication technology. For the present purpose of evaluating the growth contribution of ICT, the notion should cover computers, peripheral equipment and other information-related office equipment (photocopiers, cash registers, calculators), communications equipment, and instruments. As will presently be seen, such data is only partly available at the international level.

An important omission in this coverage of ICT assets is software. The 1993 System of National Accounts recognises software as an investment good, and some countries have started to implement this recommendation in their national accounts. At present, however, it is too early to obtain software-related information at the international level and, consequently, the current paper limits itself to the hardware component of ICT. Recent studies concerning the United States by Oliner and Sichel (2000) and Jorgenson and Stiroh (2000) incorporate software as an ICT asset and find that it plays an important role. For example, Oliner and Sichel attribute 0.23 of a percentage point per year of US non-farm business output growth over the first half of the 1990s to software – about as much as the contribution of hardware.

Measuring ICT investment

Most of the research on the importance of ICT has been carried out for the United States where national income and product accounts provide detailed and long time series of different types of ICT investment, quality-adjusted price indices and measures of the respective capital stock. Such rich data sets are not always available for other countries and where they are, differences in national statistics reduce international comparability. Empirical analysis at the international level has to refer to a number of sources and use simplifying assumptions for purposes of comparison between countries. For current price expenditure on ICT goods, the present study draws on a private source (International Data Corporation, 1998). While IDC data may not always be identical to official national data (where such data exist), it has the advantage of a symmetric treatment of all countries. Two IDC series enter the study at hand:

- *IT hardware*, comprising servers, personal computers, workstations data communication equipment (LAN hardware) and peripherals purchased by a corporation, household, school or government agency from an external agent or corporation. From a national accounts perspective, all but the expenditure of private households qualifies as investment and thus as part of an ICT capital stock. In this sense, the IDC series overestimate IT investment. However, IT expenditure of unincorporated enterprises are excluded – and in this sense IT investment is underestimated. For the present purpose, it was assumed that the two effects roughly cancel out. A comparison for the United States, where both official and IDC series are available, shows that this approximation is not unreasonable.

- *Telecommunications spending* brings together expenditures on public and private network equipment and telecommunication services. While equipment expenditures qualify as investment, telecommunication services do not. Based on a comparison with official sources in the United States,[2] it was found that a 30% share would constitute a lower bound for the investment expenditure part in total telecommunications spending.

An issue of considerable importance is the choice of the appropriate deflator for ICT capital goods. Productive services of ICT capital vary in proportion to the ICT capital stock and one important determinant of its rate of growth or decline is the amount of volume investment in every period. Volume investment is obtained by dividing current-price expenditure by a price index. Two specificities arise for ICT capital goods.

The first is that certain ICT capital goods, in particular computers, have undergone significant quality change, witnessed by the rapid succession of ever more powerful computer models at stagnant or falling prices per "computer box". In constant quality terms (*i.e.* taking into account the improvement in performance), computer prices have fallen very rapidly and computer quantities (quality-adjusted) have risen at rates outstripping those of other capital goods.

The second specificity is that methodologies to measure the price change in ICT capital goods vary greatly across OECD countries. Some statistical agencies (*e.g.* in the United States, Canada, Japan, partly in France) apply "hedonic" techniques to capture price change in various types of ICT capital goods, mainly computers – others apply more traditional techniques to price ICT goods. Results from the various methods can be vastly different, rendering direct international comparisons difficult. To carry out meaningful analysis of the economic effects of ICT investment, a common methodology for deflation was applied. In the present study, a harmonised deflator is used for all countries under investigation. This harmonised price index is based on the assumption that the differences between price changes for ICT capital goods and non-ICT capital goods are the same across countries (Box 1). There is no doubt that such a procedure introduces other biases[3] – in particular, it ignores all cross-country differences in real ICT prices that reflect different structures in the composition of ICT investment as well as all differences that are real in the sense that relative ICT prices in some countries have fallen more rapidly than in others, due to market barriers, effects of government regulation or differential regimes of taxation. To date, the extent of these biases cannot be established. However, it was felt that they were smaller than the biases incurred by choosing national deflators that were manifestly based on very different methodologies. Further support for this approach comes from the fact that ICT goods are produced and traded on a global scale with few international barriers to trade. This creates a presumption of similar rather than divergent price movements across economies.

Table 1 is largely based on the above sources. It shows that in all G7 countries, the share of IT capital goods in total investment expenditure has steadily increased and now accounts for about 10% of total non-residential gross fixed capital formation or about 20% of total producer durable equipment expenditure. The share of communication equipment has risen less rapidly, but accounts for another 5 to 10% of total non-residential investment. All shares are expressed in current prices. At constant prices, volume growth rates of ICT capital investment have progressed at a rate of about 20% and are outstripping all other kinds of assets. IT price indices draw the "dual" picture: they decline at rates of around 10% per year, reflecting rapid quality improvements and technical progress embodied in these capital goods.

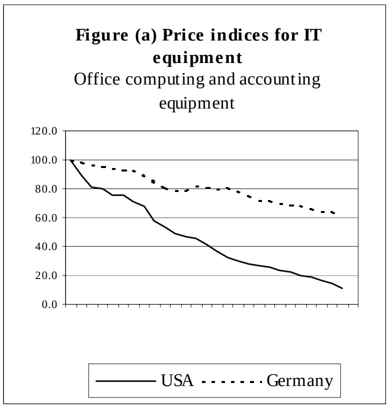
ICT capital stock

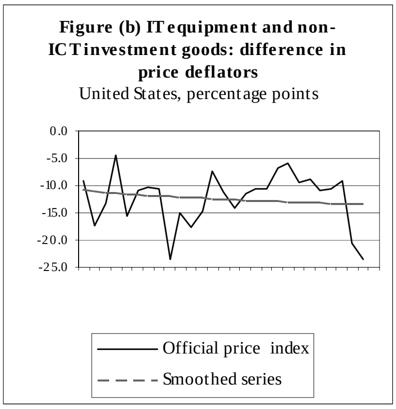
Capital goods provide productive services, and the quantity of these services is usually taken to be proportional to the capital stock. Capital stocks are not directly observable and time series have to be constructed by cumulating real investment over time. Weights are then attached to each vintage investment to reflect the fact that older capital goods provide fewer productive services than new ones. The so-derived series is the productive capital stock. It has to be distinguished from the net capital stock, which reflects a wealth concept. The distinction can be important in the case of ICT capital goods:

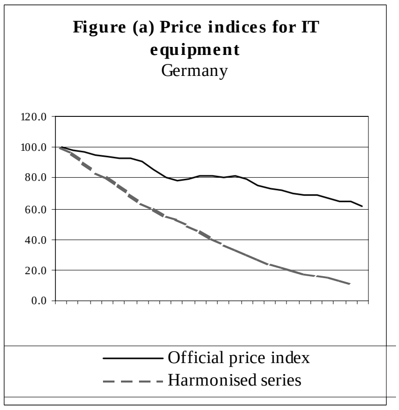
Box 1. **Measurement of prices and quantities**

A discussion of the *productivity slowdown*, the *productivity paradox* or the *new economy* has to address the issue of price and quantity measurement, and the role of information technology [see also OECD (1996)]. For the present analysis, two aspects are important: *i)* what is the correct measure for prices and quantities of ICT capital goods? *ii)* is there unmeasured output in industries that are important ICT users?

Point *i)* is about the right way to break down observations on the value of computer investment expenditure into their price and quantity components. How much of money value is inflation (or deflation), how much is "real"? Traditionally, statisticians identify price changes by comparing the price of the same product across two periods. For ICT products, this has become difficult because their technical characteristics have changed rapidly. The same computer may not be on the market one year after its appearance, or may have become obsolete because a new type with improved performance has been introduced. One way to cope with this situation is based on hedonic methods, where computer characteristics are priced instead of computer "boxes". This helps to make "boxes" comparable and permits price-quantity splits. Price indices based on hedonic functions deviate dramatically from those based on other methods and there is an apparent issue of international comparability. A study of the contribution of ICT capital to economic growth cannot ignore this point, and ICT deflators are "harmonised", albeit imperfectly, for purposes of analysis. To illustrate, consider Figure (a) below which plots the official US price index for office, computing and accounting machinery (OCAM, based on hedonic methods) against the closest equivalent component of the German producer price index (not based on hedonic methods). Differences are striking. The methodology for harmonisation starts with Figure (b). It plots the difference between the US OCAM price index and the price index of all other US investment goods. The difference is always negative, indicating that IT prices rose much less rapidly (fell by more) than prices of non-IT goods. To eliminate large annual variations; a smoothed series is constructed. This smoothed time series is then used to calculate the harmonised IT deflator: the same differential growth pattern between IT and non-IT price indices is applied to all countries under consideration. In the case of Germany, the outcome is shown in Figure (c). A similar procedure exists for communication equipment.







Source: Statistisches Bundesamt and US Bureau of Economic Analysis, OECD estimates.

While the first measurement point is about constructing price indices for observed values of output and expenditure, point *ii)* concerns the possibility that ICT has allowed producers to develop new products or features of customer convenience that are not picked up by the official statistics – there is unmeasured *value*, in nominal terms. Computer-intensive industries are concentrated in the service sector (finance, insurance, real estate, trade, communication services) and it is well known that the output of some of these industries is hard to measure (Griliches, 1994). Negative numbers of productivity growth in the United States have been pinpointed as an indicator of difficulties in measuring output. At the same time, an additional aspect comes into play: much of the output of computer-using industries is intermediate, not final. Even if unmeasured output was measured; this would shift the allocation of productivity growth *between* industries, but not change the *aggregate* rate of output and productivity growth. Because the analysis at hand is conducted at the aggregate level, it is unaffected by unmeasured output that serves as intermediate input. It is, however, affected by unmeasured final output, be it to investors or consumers.

Table 1. **ICT investment**

Total industries, percentages

	Canada	France	Western Germany	Italy	Japan	United Kingdom	United States
Share in non-residential GFCF							
IT equipment							
1985	6.9	6.1	3.4	3.4	3.4	5.2	6.3
1990	7.3	5.0	3.5	4.1	3.8	7.5	8.7
1996	10.1	6.0	6.1	4.2	4.6	11.7	13.4
Communication equipment							
1985	4.2	4.0	3.7	2.4	0.8	5.2	5.8
1990	5.3	3.8	3.7	3.6	1.5	5.8	7.0
1996	6.1	4.9	4.8	5.4	3.5	6.6	6.5
Average annual rate of growth of constant price expenditure on:							
IT equipment[1]							
1985-90	17.2	16.2	18.8	20.8	23.6	25.5	19.6
1990-96	17.6	11.0	18.6	12.9	14.5	17.6	23.8
Communication equipment[1]							
1985-90	20.6	19.0	18.4	25.6	34.7	20.3	16.7
1990-96	4.3	2.1	3.4	9.2	15.0	2.2	5.1
Price deflator[2]:							
IT equipment							
1985-90	-9.4	-10.2	-10.3	-8.1	-12.0	-6.7	-10.4
1990-96	-11.1	-9.2	-10.7	-9.1	-12.5	-9.1	-11.5
Communication equipment							
1985-90	1.3	0.5	0.4	2.7	-1.3	4.0	0.3
1990-96	-0.7	1.2	-0.4	1.3	-2.2	1.2	-1.1
Share of ICT in nominal productive capital stock:							
1985	4.3	2.4	2.9	1.3	1.2	3.6	6.2
1996	5.0	3.2	3.0	2.1	2.3	5.2	7.4

1. For definition see text.
2. Harmonised deflator - see text for description.

Source: OECD STI/EAS estimates.

Computers are often quoted as examples for capital goods whose productive efficiency hardly declines over their lifetime. Their rate of decay is low as long as they are in use, and this has led researchers (*e.g.* Jorgenson and Stiroh, 1995) to use a profile where capital services remain fully intact over a computer's service life. ICT capital goods, however, show rapid rates of losses in value – their rate of economic depreciation is high and it is this rate that shapes the net (wealth) stock of computers. The pronounced distinction between decay and depreciation (see also Triplett, 1996) for ICT assets lends specific importance to the choice of the capital stock formulation.

For the present analysis, then, a productive capital stock for computers has been calculated with an age-efficiency pattern that declines slowly in the early years of an ICT capital good's service life and rapidly at the end. Parallel to this age-efficiency pattern, a consistent age-price pattern has been derived to measure depreciation (value losses) at different years. Although measures of depreciation are not needed to produce *quantity* series of capital services, they are needed as an input to the corresponding *price* component of capital services, the user costs of capital as described below. Figure 1 shows the annual growth rate of the productive ICT capital stock at constant prices and confirms the observed rapid growth in earlier studies of the United States. All the G7 countries have been adding to their IT capital stock at two-digit rates over the past decades. However, only in the United States, Canada and the United Kingdom has the rate of IT capital-build up accelerated in the second half of the 1990s.

Non-ICT capital stock

The present study distinguishes six types of assets: non-residential structures, other non-residential construction, transport equipment, IT hardware, communication equipment and other non-transport equipment (Table 2). These categories correspond directly to those used in the OECD's *Annual National Accounts*, with the exception of IT hardware and communication equipment whose sources are described above.

In productivity analysis, the total flow of capital services is best measured with a bottom-up approach, starting with the most detailed differentiation: for each type of asset, an asset-specific capital stock should be computed. Total capital services are obtained by aggregating the rates of growth of the stock of each type of asset, where user costs of capital should be used as weights. User costs are designed to account for differences in service flows of assets of different types. When user cost weights are allowed to change every period, the resulting aggregate index takes account of substitution processes between different types of capital.

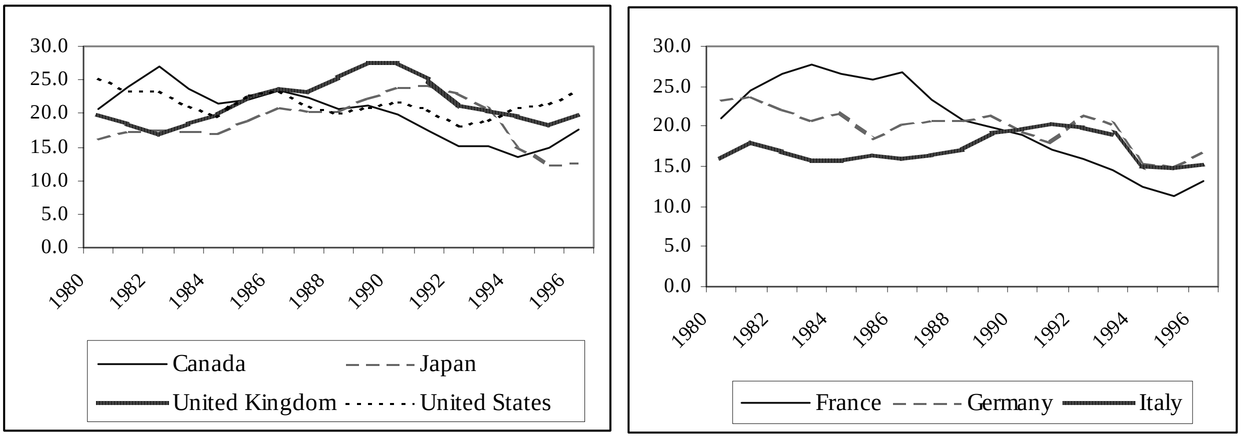
Table 2. **Types of capital assets**

Asset type	**Source**	**Category**
Non-residential structures and equipment	OECD ANA*	
Structures:		
Non-residential structures	OECD ANA*	Non-ICT
Other construction	OECD ANA*	Non-ICT
Producer durable equipment		
Transport equipment	OECD ANA*	Non-ICT
Non-transport equipment	OECD ANA*	
IT hardware	IDC	ICT
Communication equipment	IDC	ICT
Other non-transport equipment	By deduction	Non-ICT

Note: * = OECD, *Annual National Accounts* (1999).

Figure 1. **IT productive capital stock**

Percentage change over preceding year



Source: OECD STI/EAS estimates.

The six categories of capital available in this study are at best an approximation of the much greater level of detail from which capital aggregates are ideally constructed, but the six asset types already constitute an improvement over a single aggregate. Also, the present study distinguishes ICT from non-ICT capital goods – the categories between which arguably the greatest shift in relative prices has taken place.[4] The substitution bias between ICT and non-ICT assets is thereby avoided.

2.4. User cost of capital

The price for capital services is given by their user costs or rental price. Ignoring taxes and fiscal incentives, user costs for a particular type of asset are $q(r+d-\hat{q})$ where *q* is the acquisition price of a new capital good, *r* is the internal rate of return, *d* captures economic depreciation and $\hat{q}$ is the rate of change of the investment goods price. The user cost of capital expression is the price that would be charged if capital was rented for one period: such a rental price has to cover opportunity costs of investing elsewhere (represented by the interest rate *r*), the loss in market value of the capital good due to ageing (captured by the depreciation rate *d*), and the capital gains or losses because of asset price inflation $\hat{q}$. The term $(r+d-\hat{q})$ is the gross rate of return that a capital good has to earn in a well-functioning market.

User costs for ICT capital goods are noteworthy in several ways:

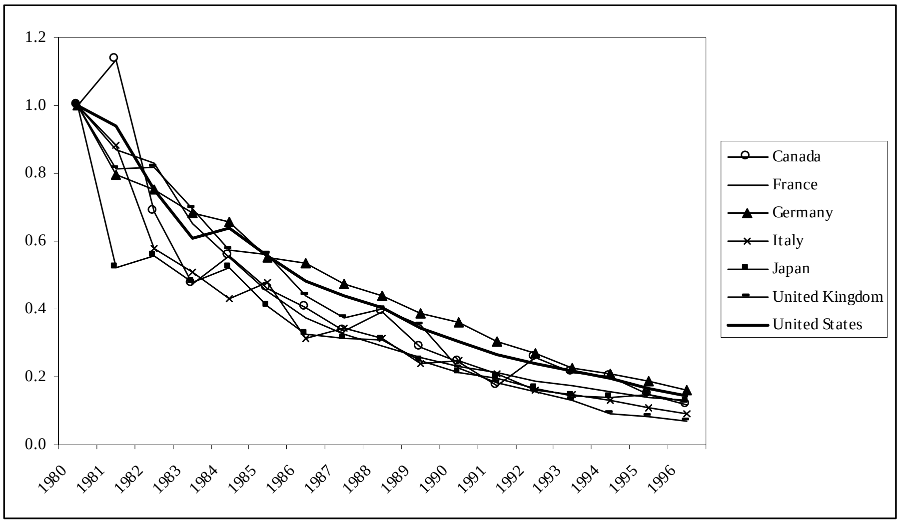
– Gross rates of return for ICT capital goods tend to be much higher than those of other capital goods because of the rapid obsolescence of ICT assets. Obsolescence enters the user cost expression via the capital gains (or better, capital losses) term $\hat{q}$: rapidly falling computer prices raise the cost of holding and using a computer. At the same time, falling prices make it cheaper to buy ICT capital goods. Thus, falling prices raise the required gross rate of return on capital goods while reducing the cost of acquiring them. As will be shown below, user costs of ICT capital (the product of acquisition price and gross rate of return) have been falling in comparison to other capital inputs, causing firms and households to substitute ICT capital for other types of capital and for labour.

– Depreciation rates – the loss in an asset's value due to ageing – are not necessarily constant over time, nor is their time profile necessarily identical to an asset's age-efficiency profile. Depreciation rates are governed by the age-price profile of computer equipment, which tends to show rapid value losses in early years and slower ones in later years of an asset's lifetime. This is the age-price pattern used in the present study.

– The net (marginal) rate of return, or internal rate of return for ICT capital should in principle not be different from that of other assets. If it was, the question would arise why firms have not invested more in ICT capital assets – efficient allocation of resources requires that all assets yield the same marginal net rate of return. The present study makes the assumption of a common marginal net rate of return between different types of assets. Consequently, it cannot test whether ICT capital has yielded supra-normal returns to its owners.[5] However, if such supra-normal returns were present, this methodology would allocate them to the multi-factor productivity residual. As long as the latter shows no signs of an upward trend reversal, there is little reason to suspect that supra-normal returns to owners or positive externalities are present, or if they do exist, they are small.

Figure 2. **User costs of ICT relative to non-ICT capital**

Based on harmonised price index for ICT capital goods, 1980 = 1

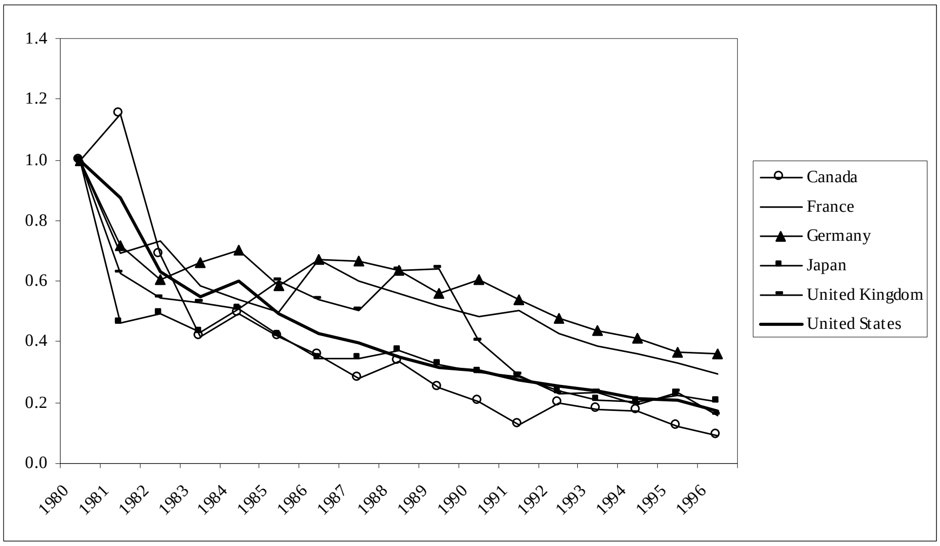


Source: OECD STI/EAS estimates.

Given the various elements, it is possible to construct an index of user costs for ICT capital services and one for non-ICT capital services and to compare their time profiles. Such relative user costs between pairs of inputs are of interest because theory shows that they provide the signals for substitution between inputs: a fall in user costs of ICT capital relative to user costs of other types of capital, for example, incites producers to substitute computers for other types of capital inputs. Similarly, a fall in ICT user costs relative to wages provides signals to substitute ICT capital for labour input. Patterns of relative user costs between ICT assets and non-ICT assets as shown in Figure 2 are indeed suggestive of strong substitution effects. Figure 3 presents the same relative user cost series but based on national deflators for ICT capital goods. Although there are much greater differences across countries, the overall picture of continuous decline of user costs for IT and communication equipment is pervasive, as are the induced substitution processes between different types of capital.

Figure 3. **User costs of ICT relative to non-ICT capital**

Based on national price index or closest approximation for ICT capital goods, 1980 = 1



Source: OECD STI/EAS estimates.

Along with user costs, total capital cost or capital income for ICT assets can be computed and compared to total income on all assets. The result of this comparison is the income share of ICT capital, *i.e.* the weighting factor by which ICT enters the growth accounting equations (1) – (5). Because this income share plays a key role in accounting for the growth contribution of ICT capital, it is worth breaking out its different components:

$$Income\ share\ of\ ICT\ capital = \left(\frac{Total\ capital\ income}{Total\ income\ (all\ inputs)}\right) \cdot \left(\frac{ICT\ capital\ income}{Total\ capital\ income}\right) \qquad (6)$$

Two ratios determine the income share of ICT capital: the first term is the share of all types of capital in total income. Total income to factors of production equals total value added. This capital share in value added, which – at the aggregate level of the economy – is around 0.3 for most countries, has been fairly stable over time. The second term is the share of ICT capital in total capital income. This ratio has been comparatively small, although it is rising. To explain the small income share, recall that capital income is the product of user cost per unit of capital and the productive capital stock. In relation (7), user costs are designated as μ_i where *i=1,2,…6* stands for the six asset types considered in this study, including μ_{ICT}, the user costs of ICT capital.

$$\frac{ICT\ capital\ income}{Total\ capital\ income} = \frac{\mu_{ICT} K_{ICT}}{\sum^{6} \mu_i K_i} \qquad (7)$$

This relation shows that two movements drive the ICT income share: *i)* the relative user costs between ICT capital and other types of assets (this ratio has declined rapidly as can be seen from Figure 2); and *ii)* the initial size and the relative growth of ICT and non-ICT capital stocks. The ICT capital stock has grown much more rapidly than other types of capital (Figure 1). Overall, the two movements partly compensate each other and so lead to a small but rising income share of capital as shown in Table 3.

Table 3. **ICT income shares**

Percentages

	Canada	France	Western Germany	Italy	Japan	United Kingdom	United States
ICT share in total capital income							
1980	2.1	1.3	1.0	1.5	2.2	1.4	2.4
1990	4.5	2.6	1.7	2.1	2.6	3.0	3.8
1996	4.6	2.4	1.9	2.1	2.8	4.3	4.9
ICT share in total income							
1980	0.7	0.3	0.3	0.5	0.5	0.4	0.8
1990	1.4	0.9	0.7	0.8	0.7	1.0	1.3
1996	1.5	0.9	0.8	0.9	0.8	1.5	1.7

Source: OECD STI/EAS estimates.

3. Results: the growth contribution of ICT

3.1. ICT as a capital input

Equipped with the information on the rate of growth of ICT capital input and on the share of income that accrues to this type of capital, its contribution to output can be approximated over time. During the 1980s and the first half of the 1990s, the overall contribution of ICT capital to output growth of the private sector has been between 0.1 and 0.4 of a percentage point per year, depending on the country (Tables 4 and 5). Over the observation period 1980-96, this contribution has been relatively stable. Several additional points have to be noted:

- Sichel (1999) and Oliner and Sichel (2000) report a major increase in the contribution of computer hardware to output growth in the United States in the most recent past (1996-98). Data limitations at the international level do not permit to bring the present analysis up to the year 1998; it is too early too tell whether other countries have followed a similar pattern, and whether the latter is durable.

- The present study is limited to ICT capital (hardware). It can be argued that neglecting software implies a substantial underestimation of the contribution of ICT to output growth. If software is treated as an intermediate input, as in the current study, it does not contribute directly to output. Another neglected item is the growth contribution of labour associated with ICT investment, such as computer services. In this sense, the results provide a lower rather than an upper bound for the contribution of ICT to output growth.

- Contributions can be expressed in at least in two ways: as percentage points, adding to the overall growth of business sector output – in this sense ICT has only moderately raised its contribution. The other way to express the same result is in terms of a share in total output growth. From this perspective, the relative importance of ICT capital as a contributor to output has risen steeply during the 1990s.

Overall, the contribution of ICT capital to output growth has been significant and rising in relative terms. In the United States, the growth contribution of ICT equipment amounts to about half of the entire growth contribution of fixed capital. In Canada and the United Kingdom, ICT represents about 0.3 of a percentage point of output growth of all industries, or roughly 40% of the entire contribution of fixed capital to output growth. In France, Germany, Italy and Japan, the contribution of ICT capital to output growth has been smaller. This is due not so much to a slower rate of investment in ICT capital goods in these countries as to a lower income share of ICT capital goods. The lower income share, in turn, reflects the smaller share of ICT assets in the total capital stock (last panel of Table 1). One explanation for this is that ICT investment has been concentrated in service industries that occupy a relatively smaller role in some European countries and in the Japanese economy than they do in the United States or the United Kingdom.

Table 4. **ICT contribution to output growth**
Total industries, based on harmonised ICT price index

		Canada	France	Western Germany	Italy	Japan	United Kingdom	United States
Growth of output:	1980-85	2.8	1.7	1.4	1.4	3.5	2.1	3.4
	1985-90	2.9	3.2	3.6	3.0	4.9	3.9	3.2
	1990-96	1.7	0.9	1.8	1.2	1.8	2.1	3.0
Contributions (percentage points) from:								
ICT equipment	1980-85	0.25	0.17	0.12	0.13	0.11	0.16	0.28
	1985-90	0.31	0.23	0.17	0.18	0.17	0.27	0.34
	1990-96	0.28	0.17	0.19	0.21	0.19	0.29	0.42
Total capital	1980-85	1.3	1.0	1.0	0.9	0.8	0.8	1.1
	1985-90	1.1	1.3	1.2	0.9	1.3	1.1	1.0
	1990-96	0.7	1.0	1.0	0.7	1.0	0.8	0.9

Source: OECD STI/EAS estimates.

Table 5. **ICT contribution to output growth**
Total industries, based on national price index or closest approximation

		Canada	France	Western Germany	Italy	Japan	United Kingdom	United States
Growth of output:	1980-85	2.8	1.7	1.4	1.4	3.5	2.1	3.4
	1985-90	2.9	3.2	3.6	3.0	4.9	3.9	3.2
	1990-96	1.7	0.9	1.8	1.2	1.8	2.1	3.0
Contributions (percentage points) from:								
ICT equipment	1980-85	0.29	0.16	0.09	0.13	0.09	0.13	0.28
	1985-90	0.35	0.22	0.12	0.18	0.15	0.27	0.30
	1990-96	0.31	0.17	0.15	0.21	0.20	0.31	0.41
Total capital	1980-85	1.4	1.0	1.0	0.9	0.8	0.8	1.1
	1985-90	1.1	1.3	1.2	0.9	1.2	1.1	0.9
	1990-96	0.7	1.0	1.0	0.7	1.0	0.9	0.9

Source: OECD STI/EAS estimates.

3.2. ICT as a special type of capital good

Finally, it is instructive to examine trends in multi-factor productivity: it was pointed out earlier that if ICT capital goods generate positive spillovers or network effects in the economy, these effects should show up as MFP growth. Unfortunately, MFP is a residual measure combining a myriad of factors and it is difficult to disentangle them. Nonetheless, if MFP growth is persistently slow, this creates a strong presumption against the presence of large spill-over effects caused by ICT. Conversely, an upward reversal in trend MFP growth would at least be consistent with the hypothesis of significant positive externalities generated by the use of IT and communication technology.

As shown in equation (3), rates of changes in MFP are obtained residually by deducting the growth contributions of capital and labour from the rate of output growth.[6] Figure 4 presents the results. Overall, and for the group of G7 countries, there is no convincing sign of a broad-based acceleration in MFP growth. In the first half of the 1990s, MFP productivity growth increased quite significantly in Japan, although this movement would appear to be a cyclical recovery back to trend growth rather than a reversal of trend productivity growth itself. However, recent developments in the United States – although not directly covered by the present study – merit specific attention.

MFP growth in the United States since 1996

Towards the end of the observation period used in this paper, MFP growth accelerated in the United States. Calculations for the years 1996-99 by Oliner and Sichel (2000) point to a continuation and strengthening of the productivity recovery. According to this research, MFP growth rates more than doubled, from about 0.6% over the period 1991-95 to 1.25 % in the years 1996-99. Work by Jorgenson and Stiroh (2000) bears out these results. An interesting question is whether the rise in MFP growth is largely due to a rise in MFP in the ICT industry or whether it reflects a more broad-based pick-up in MFP throughout different industries. The latter case would support the possibility of spill-overs from ICT use throughout the economy, the former would point to a much more narrowly-based MFP uptake – one that is carried by technological change in the *ICT-producing industry*, rather than in *ICT-using* sectors. A widely-quoted paper by Gordon (1999) pointed in the direction of a singularly strong role of the computer industry in the US productivity uptake, although Gordon’s results changed somewhat after incorporating revisions to the US National Income and Product Accounts in October 1999. Oliner and Sichel find a smaller, but still substantive, contribution of the ICT industry in the acceleration of aggregate MFP.

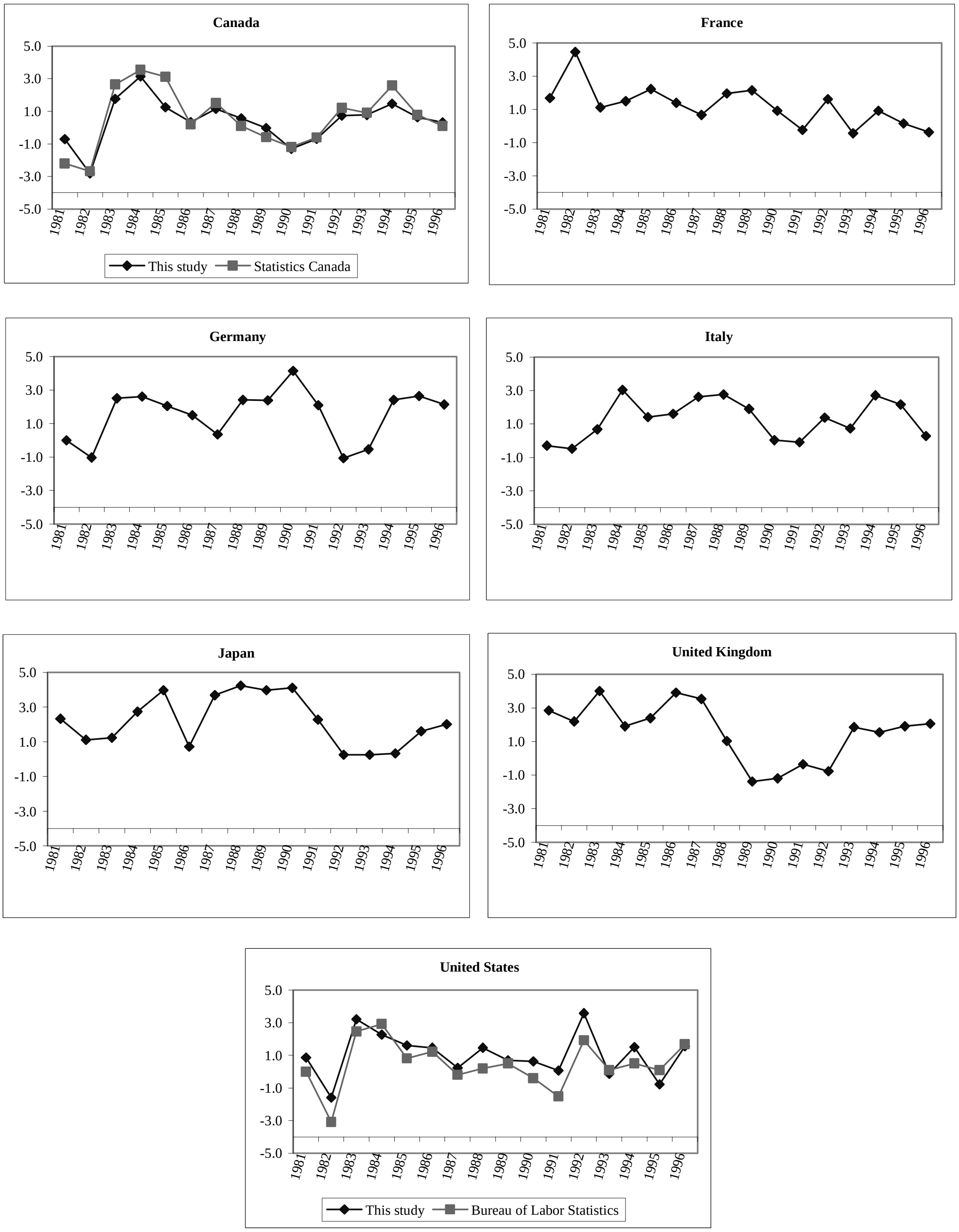
Similarly, the Council of Economic Advisors (2000) estimates that 0.39 of a percentage point of the total 1.04% growth in US MFP is attributable to the computer industry – an important share, but by no means a full explanation. The implication is that other industries outside the ICT producing sector contributed to the MFP uptake. The degree to which this contribution is due to ICTs remains open.

The contribution of the computer industry to US multi-factor productivity growth: Examples from two recent studies

	Oliner and Sichel (2000)	Council of Economic Advisors (2000)
Period and coverage	Non-farm business sector, 1996-99	Total economy, 1995-99
Multi-factor productivity growth	1.25% per year	1.04% per year
Contribution from computer industry	0.62% per year (computer sector plus semiconductor sector)	0.39% per year
Contribution from other industries	0.63% per year	0.65% per year

Figure 4. **Multi-factor productivity growth**

Total industries, percentage changes over preceding year



Source: OECD STI/EAS estimates.

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NOTES

[1]. Jorgenson and Griliches (1967) and Denison (1974), using Solow's (1957) approach to modelling economic growth, have pioneered growth accounting. A large body of literature has developed since.

[2]. For 1996, the US national income and product accounts give a value of USD 99 096 million for office computing and accounting machinery equipment plus photocopy and related equipment of the private sector – this is roughly in line with the IT hardware expenditure figure derived from the IDC source (USD 105 606 million). The official private business sector expenditure on communications equipment was USD 64 025 million; that derived from IDC sources, USD 51 622 million. Similar relations hold for other years of comparison between 1992 and 1996.

[3]. When national price indices for ICT capital goods are changed to improve international comparability, this should in principle also translate into modified measures of output growth. Because the present study makes no effort to adjust volume growth rates of production, there is a potential bias. Note, however, that the size of this bias depends on the relative importance of the ICT-producing industry, and on the extent to which its output is used in investment or in final consumption. The adjustment of price indices for ICT products that are used as intermediate goods affects the distribution of output and productivity growth across industries, but does not affect aggregate output.

[4]. A recent revision of capital input measures by the US Bureau of Labor Statistics (1998) puts a question mark to this statement. As BLS showed, there is a surprising amount of substitution within the relatively narrow category of office, computing and accounting machinery – roughly the same aggregate as the IT hardware component in the present study.

[5]. A test requires econometric analysis, for examples of such work see Brynjolfsson and Hitt (1994).

6. It should be noted that the calculation of labour input and its growth contribution raises additional statistical issues. At least two should be mentioned here: first, labour input should be measured in total hours, not as total persons employed. Only the former measure accounts for shifts in average hours per person, caused, for example by a changing share of part-time employees. A second issue is the quality of labour input. It has been shown that the composition of the labour force in most OECD countries has undergone structural shifts, typically towards higher-skilled labour and away from low-skilled workers. Labour input has thus changed, but an input measure that aggregates total hours or total persons without differentiation will not reflect such changes. For the present study, neither adjustment could be made and labour was measured as the number of persons engaged. Consequently, MFP growth rates are somewhat different from those obtained in national statistics where allowance is sometimes made for average hours and labour composition. Differences may also arise due to the relatively aggregate treatment of capital input and due to common assumptions about asset service lives which may differ from national sources but which ensure consistent treatment across countries. For purposes of comparison, then, for the United States and Canada, time profiles of MFP growth as obtained by national statistical offices are shown next to those evaluated in the present study. It is easy to see that in spite of some differences in the level of MFP growth, movements over time are closely correlated and for the purpose of identifying an acceleration or deceleration of MFP growth this is sufficient.