OXFORD REVIEW OF ECONOMIC POLICY, VOL. 18, NO. 3

ICT AND PRODUCTIVITY GROWTH IN THE UNITED KINGDOM

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This paper develops new estimates of investment in and output of information and communication technology (ICT). These new estimates imply that GDP growth has been significantly understated, particularly since 1994. A growth-accounting approach is employed to measure the contribution of ICT to the growth of both aggregate output and aggregate input. On both counts, the contribution of ICT has been rising over time. From 1989 to 1998, ICT output contributed a fifth of overall GDP growth. Since 1989, 55 per cent of capital deepening (the growth of capital per hour worked) has been contributed by ICT capital; since 1994 this proportion has risen to 90 per cent. ICT capital deepening accounts for 25 per cent of the growth of labour productivity over 1989–98 and 48 per cent over 1994–8. But even when output growth is adjusted for the new ICT estimates, both labour productivity and TFP growth are still found to slow down after 1994.

I. INTRODUCTION

From 1995 onwards a striking and unexpected increase occurred in the growth rate of labour productivity (GDP per hour worked) in the United States: the average growth rate over 1995–2000 rose by a full percentage point compared to the preceding 5-year period. There now seems general agreement that a large part of the productivity improvement can be accounted for by rapid growth in the stock of information and communications technology (ICT) equipment (Bosworth and Triplett,

[1] This paper is a condensed version of a longer one, Oulton (2001*a*), where fuller explanation and argument plus additional references to the literature and detailed tables may be found. I am grateful to Sushil Wadhwani for much encouragement and numerous helpful discussions and insightful comments. I have also benefited from the comments of Paul Stoneman (Warwick Business School); of colleagues in the Bank of England, particularly Ian Bond, Jo Cutler, Jens Larsen, and Hasan Bakhshi; and of officials of the Office for National Statistics, in particular Prabhat Vaze. I also thank Bruce Grimm of the Bureau of Economic Analysis for advice on US software estimates, Steve Oliner of the Board of Governors of the Federal Reserve for supplying data on semiconductor prices, and Mary O'Mahony (National Institute of Economic and Social Research), for providing data on hours worked. Malte Janzarik provided excellent research assistance. Finally, I thank an anonymous referee and the editors for numerous useful suggestions on the current paper. None of these people should be blamed for any remaining errors which are my responsibility. The views expressed are my own and do not necessarily reflect those of the Bank of England or of its Monetary Policy Committee.

2000; Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; Baily, 2001; DeLong and Summers, 2001). The ICT investment boom in turn was driven by the rapid rate of decline of computer prices, which accelerated in the second half of the 1990s. The fall in computer prices has been mainly due in turn to rapid and, indeed, accelerating technical progress in semiconductors (Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000).

In the United Kingdom, by contrast, the second half of the 1990s saw a decline in labour productivity growth. Since ICT products are widely traded internationally, the benefit of falling prices should be felt in all countries with access to the world market. So was there a comparable investment boom in the UK? If there was, why has it not apparently led to faster labour productivity growth?

This paper seeks to measure the contribution of ICT to the growth of output and productivity in the UK, using a growth-accounting approach. Four types of ICT are studied: computers, software, telecommunications equipment, and semiconductors (chips). Telecommunications equipment is included since in recent years investment in computers and software has been strongly associated with the development of networks, both internal to companies (intranets) and external, in the shape of the Internet. Semiconductors are included since it may well be technical progress in these products which has been fuelling technical progress in computers and telecommunications. This is summed up in the expression 'Moore's Law': the tendency for the density of chips to double every 18 months to 2 years.

This paper takes a wider view than some studies which cover the UK (e.g. Schreyer, 2000; Kneller and Young, 2001) since it includes software as well as hardware.[2] On the other hand, it does not aim to estimate the contribution of the 'New Economy' as a whole.[3] To do that, the scope would have to be extended to study the contributions of the Internet, the digital media, and e-commerce. Nor does the paper cover other aspects of the New Economy, such as changes in the labour market and in product-market competition, as discussed in Wadhwani (2000). Studies which put the New Economy in a wider historical perspective include Gordon (2000) and Crafts (2002).

The next section of the paper sets out the growth-accounting framework. It argues that we must distinguish between the contribution of the ICT sector to the growth of output and its contribution to the growth of input. The contribution to output growth derives from the domestic output of ICT products. The contribution to input growth derives from the growth of the capital services flowing from the accumulated stock of ICT equipment (some of it imported). Section III considers the measurement issues that are particularly acute in this area. It discusses the reasons why US rather than UK price indices are employed to deflate nominal expenditures on ICT and why a large upward adjustment to the level of software investment is justified. Section IV then presents the results. It turns out that ICT has made a large contribution to both output and input growth, despite the fact that ICT output and investment are small proportions of the totals. But even though the measurement adjustments for ICT proposed here lead to GDP growing faster than on the official measure, the growth of labour productivity is still found to slow down after 1995. Section V compares the US and UK experiences directly and suggests some hypotheses to account for the divergence between them. Section VI then asks whether the impact of ICT on UK growth will continue to grow in the future. The answer suggested is yes. The reason is that the relative importance of ICT,

[2] The paper which is closest in coverage to the present one is Davies *et al*. (2000). They present estimates for the UK of the effect of ICT on both aggregate output and input, using a similar methodology to that of the present paper. Their definition of ICT is also similar. But there are some significant differences between their estimates and those presented here. Kodres (2001) employs a similar growth-accounting approach, though she uses capital stocks rather than capital services. Schreyer (2000) includes computers and telecommunications but omits software. He uses proprietary data to estimate ICT stocks. He estimates the contribution of ICT to input but not output. Kneller and Young (2001) estimate the effect of computers on aggregate input but not aggregate output, i.e. they exclude software and telecommunications equipment. Daveri (2000) uses the same database as in Schreyer (2000) to do a growth-accounting analysis for 18 countries, of which 13, including the UK, are in Europe; his comparisons cover software, too.

[3] Computers themselves are, of course, far from 'new'. The year 2001 saw the 50th anniversary of the first computer to be introduced into commercial service in the UK, by J. Lyons and Co. In 1954 there were 12 computers in the UK, by 1964 this had risen to 982, and by 1970 to 5,470 (Stoneman, 1976, p. 69 and Table 2.2, p. 20).

both as an input and as an output, has been growing steadily for five decades and there seems no reason why these long-lasting trends should suddenly be reversed. Section VII concludes.

II. THE GROWTH-ACCOUNTING APPROACH

The framework employed here is growth accounting, based ultimately on Jorgenson and Griliches (1967); Jorgenson and Stiroh (2000) is a more recent example. Broadly the same framework is set out in OECD (2001*a*).[4]

The fundamental equation of growth accounting is:

growth of aggregate output = growth of aggregate input + growth of TFP (1)

where TFP is total factor productivity. In turn, the growth of aggregate output equals the share-weighted average of the growth rates of each type of real final output. Here the shares are the value of each type of output as a proportion of nominal GDP. The growth of aggregate *input* is a share-weighted average of the growth rates of the individual inputs. In this case, the shares are the income attributable to each input as a proportion of nominal GDP. The rationale for weighting by income shares is marginal productivity: inputs are assumed to be paid the value of their marginal products. This implies that the economy is perfectly competitive: firms have no market power in either input or output markets. The assumption that firms have no market power in output markets may seem particularly implausible, but none the less studies that attempt to measure the degree of market power suggest that it is quite small in aggregate, hence the assumption of perfect competition may not be too misleading in the present context.[5]

Labour's share is just the wage bill as a proportion of GDP. In the case of capital input, services are considered to be proportional to the capital stock. The stock of any type of capital is accumulated investment, after allowing for depreciation. Investment is, of course, measured in real terms: nominal investment deflated by a price index. It is important to note that the price index should in principle be corrected for quality change. So the stock of any asset, and consequently the services which it yields, are measured in units of a given quality; that is, under this methodology an increase in the *quality* of the capital stock will show up as an increase in the *quantity* of capital services. At the aggregate level, capital's share is the profit share, i.e. profit before depreciation and tax as a proportion of GDP.

The contribution of any particular type of output, such as computers, to GDP growth is therefore:

share of final output of computers in GDP $\times$ growth rate of final output of computers.

Here final output of computers (or of any other type of output) is defined as:

final output = consumption + investment + exports – imports.

(Government expenditure is potentially included in all these categories.) Note that final output can be smaller than investment to the extent that domestic demand is met from imports. Conceivably, ICT investment might be large while final output is small, and so ICT might make a large contribution to aggregate input, but only a small contribution to aggregate output.

Computers also contribute to aggregate *input* since they are a form of capital. The contribution of computers to aggregate input growth is:

profit attributable to computers as a proportion of GDP $\times$ growth rate of the services of the stock of computers.

The services derived from the stock of computers are assumed to be directly proportional to the stock: one (quality-adjusted) computer, i.e. one unit of computer power, yields one unit of computer

[4] An alternative framework centring on the concept of 'investment-specific technological change' has been proposed by Greenwood *et al*. (1997). The relationship between this framework and growth accounting is discussed in Oulton (2001*b*).

[5] Hall (1988, 1990) suggested that deviations from perfect competition, in the sense of a high ratio of price to marginal cost, were large. But subsequent studies, e.g. Caballero and Lyons (1990, 1992) and Basu *et al*. (2001) for the USA, or Oulton (1996) for the UK, found the deviations to be quite small.

services. The profit attributable to computers is the rental price of computers multiplied by the stock of computers. The rental price is the competitive price for which a computer could in principle be hired, as opposed to the price for which it can be purchased outright, the asset price. As a proportion of the asset price, the rental price of a computer equals the nominal rate of return (assumed the same for all assets), *plus* the rate of depreciation on computers, *minus* the rate of growth of the price of computers (the asset price).[6] Since computers depreciate rapidly (I assume at 31.5 per cent per cent per annum) and their price is *falling* (at around 20 per cent per annum), their rental price is very high in relation to their asset price, around 60 per cent. In other words, if someone were trying to make money by renting out computers, then he or she would have to charge an annual rental equal to about 60 per cent of the price of a new computer. By contrast, the rental price of a building is a small proportion of its asset price, since buildings depreciate slowly and their asset price rises over time. This means that when we come to measure the growth of aggregate capital services, computers will get a much higher weight, and buildings a much lower weight, than if we were measuring the growth of the capital *stock*.[7]

The contributions of software and telecommunications equipment, which are also investment goods, are defined analogously to that of computers. Semiconductors are an intermediate product for which, by definition, consumption and investment are zero. In a closed economy, their contribution to either output or input would be zero, using the present approach. But the UK is an open economy and so their contribution to *output* (in an arithmetic sense) is measured as exports net of imports and hence may be negative. Of course, domestically produced semiconductors do contribute indirectly to output if they are incorporated into other ICT products. But it would be double counting to count both the semiconductors and the computers (and telecommunications equipment) of which the semiconductors form a part.[8]

Semiconductors make no direct contribution to aggregate input. Their contribution is measured implicitly as part of the contributions of the other ICT categories.

(i) Labour Productivity and TFP

The 'fundamental equation' above can be rewritten in terms of the growth of labour productivity (output per hour):

growth of output per hour = 'capital deepening' + TFP growth (2)

where capital deepening is the share of capital (profit share) times the growth rate of capital services per hour. Our aim is to quantify the elements of this equation.

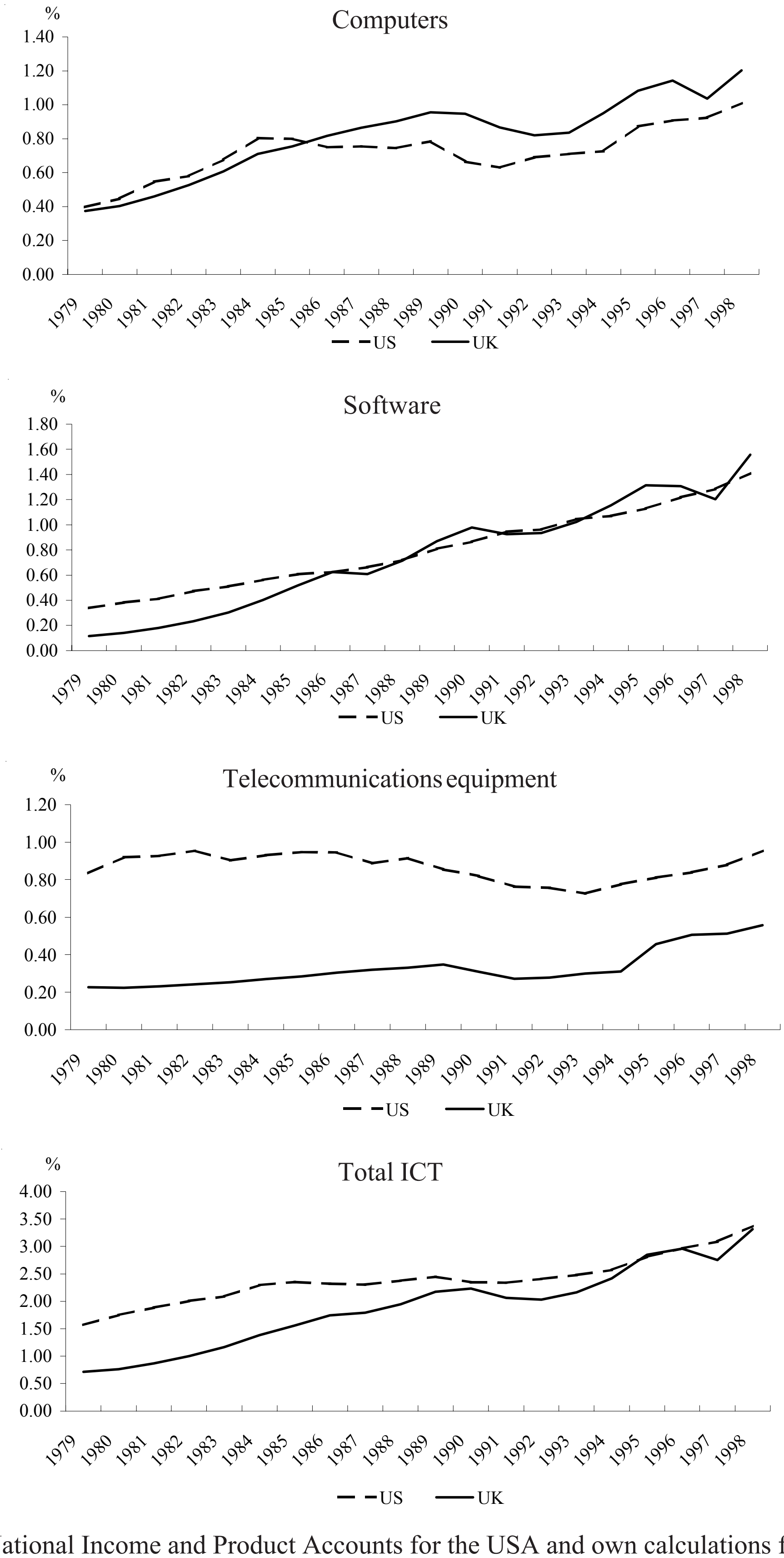
Growth accounting is only a framework and cannot by itself be used to prove any hypothesis. To say that the contribution of some input to GDP growth is x percentage points per annum (p.p.p.a.) does not imply that GDP growth would have been lower by exactly that amount had the input not grown at all. But the framework can be used to establish what factors are quantitatively important in the growth process over a particular period. It can also be used as a diagnostic tool, helping to distinguish between alternative hypotheses and to suggest new ones (see section V below).

[6] This is the Hall–Jorgenson formula for the cost of capital (Hall and Jorgenson, 1967); corporate tax and investment subsidies were also taken into account in the empirical results. All the elements of the cost of capital are known under the methodology used here, except for the nominal rate of return. But the sum across all assets of the profit attributable to each asset must equal total profits. Total profits are observed, so we can back out the nominal rate of return that makes this equation hold.

[7] The distinction between the capital stock and capital services is a fundamental feature of Jorgensonian growth accounting (Jorgenson, 1989). For a recent discussion of this issue, see OECD (2001*b*) and Oulton (2001*c*).

[8] We must distinguish between the contribution of semiconductor products to output growth and the contribution of the semiconductor industry to output growth. The latter would be measured as the growth rate of real value-added in semiconductors multiplied by the share of value-added in the semiconductor industry in GDP. The value-added share would normally be positive (unless profits were very negative, a situation which could not persist). Hence, as long as real value-added in semiconductors is growing, the industry would be making a positive contribution to GDP growth. By contrast, the contribution of semiconductor final output could be persistently negative. This does not mean that the semiconductor industry is in some way reducing GDP. Rather it should be seen, as the text indicates, as a statistical correction necessary to make the contribution of the ICT sector as a whole add up properly. Without this correction, we would be overestimating ICT output growth since some of what we measure as growth of domestic output is in reality contributed by imports.

Figure 1
Investment in ICT as a proportion of GDP (current prices)



Sources: US National Income and Product Accounts for the USA and own calculations for the UK (see section IV below).

(ii) The Scale of Investment in ICT: A USA–UK Comparison

By way of motivation, we start by comparing the scale of investment in the UK and the USA in the three categories of ICT investment and in total. We make the comparison in terms of shares of GDP at current prices.

The UK's total investment in ICT is now rather more than 3 per cent of GDP and is as large as that of the USA. In computers, the UK invests relatively more and in software about the same. In both cases, the UK achieved convergence by the mid-1980s. Only in telecommunications does there still remain a substantial gap, though this may be affected by incompatibilities between the two countries' systems of industrial classification. Two caveats should, however, be noted. First, the UK's performance in software is obviously strongly affected by the large correction to the official figure—multiplication by three—which I argue below is justified. Second, since US GDP per capita is substantially larger (by 44 per cent on a purchasing-power-parity basis according to the World Bank), the result would be less flattering to the UK if investment *per capita* were being compared.

III. MEASURING ICT

My estimates make two main adjustments to the underlying data, which come from the UK's Office for National Statistics (ONS):

- I use US producer price indices for ICT, adjusted for exchange-rate changes, to deflate UK investment and output;
- I argue that the level of software investment in current prices is at least three times higher than the official figure; I treat this as an addition to total investment.

In principle, official price indices in both the USA and the UK seek to measure price change net of quality improvement. But US producer price indices for computers and software have been falling much more rapidly than the corresponding UK price indices which are used by the ONS to deflate output and investment. So employing US indices is bound to raise the growth rates of output and investment.[9]

The argument for using US price indices is threefold.

- ICT products are widely traded in highly competitive markets, so their prices should fall at about the same rate in all countries.[10]
- US agencies, such as the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS), not to mention the Fed and the academic community, have done a considerable amount of research on this topic (e.g. Cole *et al*., 1986; Aizcorbe *et al*., 2000).
- The UK *retail* price of computers (which is part of both the Harmonized Index of Consumer Prices and the Retail Price Index) is falling at about the same rate as its US counterpart, but considerably faster than the UK *producer* price index. This suggests that there may be a problem with the producer price index.

For software, two alternative price indices are used. The first is the official US index, which is conservative. The second is the pre-packaged component of the official index which falls more rapidly. This gives rise to two sets of estimates, called below the 'low' and 'high' variants respectively.

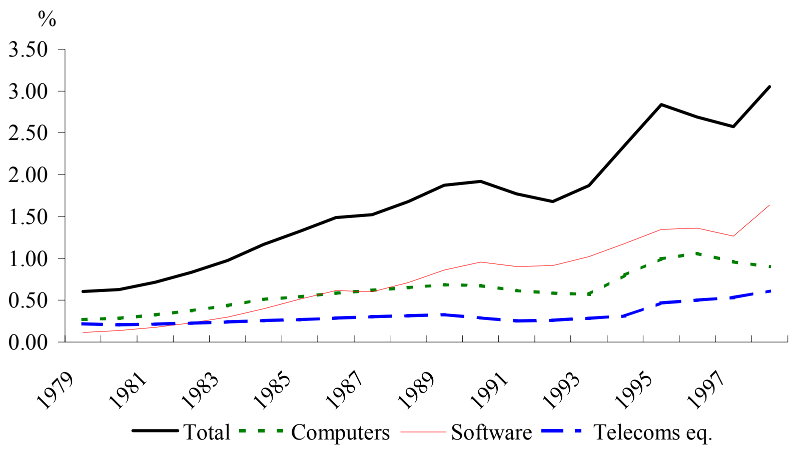
The argument for tripling the level of software investment is again threefold:

- In the UK, software investment was about 39 per cent of computer investment in the 1990s

[9] The US price index for telecommunications equipment diverges from its UK counterpart to a much smaller extent. Arguably, quality change has been highly significant in telecommunications equipment. But telecommunications has not been the subject of nearly as much research as computers.

[10] It is often asserted on the basis of anecdotal evidence that ICT equipment is more expensive in the UK than in the USA, because the UK market is less competitive. This is quite compatible with prices falling at the same rate in both countries. But the UK market has quite likely become more competitive over time. If so, ICT prices in the UK will have been falling more rapidly than in the USA.

Figure 2
Share of ICT Output in GDP (current prices)



Note: Semiconductors included in total from 1992 onwards, but not shown separately.

using the official figures, while in the USA software investment was 140 per cent of computer investment. Such a large discrepancy is implausible.

- There is also a striking discrepancy in the proportion of the sales of the computer services industry that are classified as investment in the two countries. In the USA this proportion was about 60 per cent in 1996, while in the UK it was only 18 per cent.[11]

- A re-examination of the survey which was the basis for the official software series plus the application of US methods to estimating so-called 'own account'[12] software supports at least a tripling.

My methodology for measuring capital services differs from that currently used by the ONS and this affects the results significantly, too. The capital stock of each asset is estimated by cumulating investment, with depreciation assumed to be geometric at the rates used by the BEA. To get the aggregate stock, assets are weighted together using rental prices, not asset prices.

IV. THE CONTRIBUTION OF ICT

(i) The ICT Share in Output

The share of ICT output in GDP in current prices was 0.6 per cent in 1979, but has risen fairly steadily since then and by 1998 had reached 3.1 per cent of GDP (see Figure 2). The computer share has fallen a bit since 1996, but recall that the output share is influenced by the net trade position, which has deteriorated. Software output was 1.6 per cent of GDP in 1998. Recall that this proportion is three times larger than the ONS one. The semiconductor share is included in the total from 1992 onwards, but not shown separately in the figure. It was, in fact, very small, averaging –0.1 per cent over 1992–8 (negative because it is measured as exports less imports as a proportion of GDP).

(ii) The ICT Adjustment to GDP Growth

The first question is, by how much do the new estimates of ICT output change the official estimates of GDP? Table 1 shows that the size of the adjustment has been rising. In 1994–8, the effect is to increase GDP by, on average, between 0.26 and

[11] The UK also appears to be out of line with other European countries. Lequiller (2001) has compared France with the USA. He finds that the ratio of software investment to IT equipment investment was about the same in the two countries in 1998 (his p. 25 and chart 5). He also finds that the ratio of software investment to intermediate consumption of IT services is substantially lower in France than in the USA (pp. 26–7). This ratio is exceptionally high in the USA, but equally his chart 6 shows that it is exceptionally low in the UK. In fact, the reported UK ratio is substantially lower than in France, the Netherlands, Italy, and Germany.
[12] Own-account software is software developed within a firm for its own use, not for sale to an external buyer. In the USA it constitutes about one-third of total software investment.

Table 1
Effect of ICT Adjustment on GDP Growth (percentage points per annum)

	'Low' software		'High' software	
Software level adjustment (x3 factor)?	Yes	No	Yes	No
1979–89	+0.09	+0.03	+0.14	+0.04
1989–98	+0.21	+0.12	+0.30	+0.15
1989–94	+0.18	+0.12	+0.27	+0.15
1994–8	+0.25	+0.13	+0.33	+0.16

Note: The 'low' software estimates use the official US software deflator. The 'high' software estimates use one component of the official US deflator, the price index for packaged software, to deflate all software (packaged, custom, and own-account); this price index falls much more rapidly than the official deflator.

Table 2
Contributions of ICT and Non-ICT Output to GDP Growth: Annual Averages (high software variant)

	Non-ICT		ICT		Growth of GDP
Period	Contribution p.p.p.a.	Proportion of GDP growth %	Contribution p.p.p.a.	Proportion of GDP growth %	% p.a.
1979–89	2.18	86.7	0.33	13.3	2.52
1989–98	1.75	79.3	0.46	20.7	2.21
1989–94	1.08	74.8	0.36	25.2	1.44
1994–8	2.59	81.8	0.57	18.2	3.16

Notes: The contribution of a sector (ICT or non-ICT) to GDP growth in absolute terms is measured as the growth rate of the sector multiplied by the share in current prices of that sector in GDP; the share is measured as the average of its value in the first and last years of the period. These contributions are also shown in the table as percentages of GDP growth; p.p.p.a.: percentage points per annum.

0.33 p.p.p.a. The contributions of computers and software to the adjustment are roughly equal, while that of telecommunications is small. About half of the total effect is due to the software levels adjustment—see Oulton (2001*a*) for more detail on this.[13]

(iii) The ICT Contribution to Aggregate Output

A second and different question is this: conditional on these new ICT output estimates being accepted, how much in fact has ICT output contributed to the growth of aggregate output? This question is answered in Table 2 for the high software variant; results are similar for the low case. Table 2 shows that despite its small share in GDP, ICT accounted for 13 per cent of output growth in 1979–89 and 21 per cent in 1989–99. In absolute terms, the ICT contribution is clearly on a rising trend. Over 1994–8, ICT added, on average, 0.57 p.p.p.a. to GDP growth. The rising level of the ICT contribution is not due to ICT output growing more rapidly in the 1990s—in fact, output was growing more rapidly in the 1980s—but rather to the steadily rising ICT share (Figure 2).

Because of the phenomenal rate at which their prices are falling, semiconductors have the potential to make a major contribution to output growth. In

[13] Vaze (2001) finds somewhat smaller effects, but he does not make the software levels adjustment.

fact, from 1994 to 1998, exports of semiconductors grew at an extraordinary 41.8 per cent p.a. Taken by themselves, exports of this one small sector would have contributed 0.38 p.p.p.a. to annual growth over this period. But imports were growing at a still more extraordinary 60.4 per cent p.a., which reduced GDP growth by 0.49 p.p.p.a. So the net effect of semiconductors was to reduce GDP growth (in an arithmetic sense) by 0.11 p.p.p.a.

(iv) The ICT Contribution to Aggregate Input

The contribution of ICT capital to the growth rate of aggregate capital services is the share of aggregate profits attributable to ICT capital multiplied by the growth rate of ICT capital. Let us consider these two elements in turn. Figure 3 shows profits attributable to ICT capital as a share of total profits. In 1998 this share was 15 per cent. It has tripled since 1979. The share of total profit in GDP has not changed very much, so the profit attributable to ICT capital as a share of gross domestic income (= GDP), the income share of ICT, has also tripled since 1979 and now stands at about 3 per cent. The income share is very similar to the share of ICT *output* in gross domestic *product* (see Figure 2), though this is something of a coincidence. The income share of ICT is relevant when we come to measure the contribution of ICT capital to aggregate input growth.

Figure 4 shows the growth rates of ICT and non-ICT capital services. ICT growth is much higher and considerably more volatile. Recall that the growth of capital services is inclusive of quality improvements in capital goods. Figure 5 shows the effect of incorporating these adjustments into a measure of aggregate capital services. The ICT-adjusted estimates have a similar profile but lie uniformly above the baseline estimate, which makes no adjustment for ICT. The adjustment clearly has a substantial effect on the aggregate growth rate. As Table 3 shows, ICT capital (high software variant) was growing at 21.49 per cent p.a. over 1989–98, while non-ICT capital grew at only 2.34 per cent p.a. The result was that, compared to the baseline estimate of 3.13 per cent p.a., the high software variant of aggregate capital services grew at the substantially faster rate of 4.76 per cent over the same period.

(v) ICT and TFP growth

The ICT adjustments increase the growth rates of both output and capital services. It turns out that these effects are of fairly similar size. Hence the impact on TFP growth, relative to an estimate which does not make adjustments for ICT, is also fairly small: TFP growth is reduced by 0.11 p.p.p.a. over 1989–98. Including the adjustments, TFP growth has been below its 1979–98 average from 1995 onwards.[14]

(vi) Labour Productivity Growth: The Contributions of ICT and Non-ICT Capital and of TFP

We can now assess the contribution of ICT to capital deepening and, hence, to the growth of labour productivity (output per hour worked), using equation (2). Table 4 shows the absolute amounts contributed by capital deepening and TFP to the growth of labour productivity on an hours basis. We concentrate on the high software variant since results are similar for the low software case (and also for labour productivity on a heads basis).

It is a remarkable fact that, since as early as 1979, ICT has contributed around half of all capital deepening: 45 per cent in 1979–89, 55 per cent in 1989–98, and no less than 90 per cent in 1994–8. Capital deepening owing to ICT has accounted for 15 per cent of labour productivity growth in 1979–89, 25 per cent in 1989–98, and no less than 48 per cent in 1994–8. The contribution of TFP has been shrinking in both proportional and absolute terms.

Does the ICT adjustment alter the received picture of a slowdown in labour productivity growth from 1995 onwards? The answer is no. Over these last 4 years, labour productivity has been growing at below its average rate since 1979 (as has TFP, too).

[14] Kodres (2001), using a similar growth-accounting approach, also found that TFP growth fell in the second half of the 1990s, despite a rising contribution from ICT.

Figure 3
Profits Owing to ICT Capital: Proportion of Total Profit (current prices)

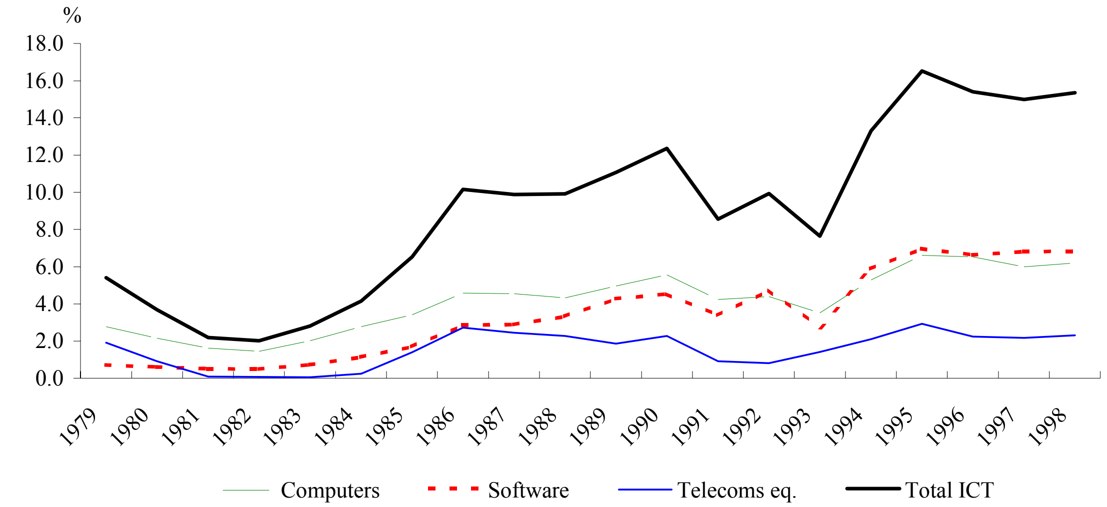


Figure 4
Growth Rates of Capital Services, 1980–99: ICT and Non-ICT

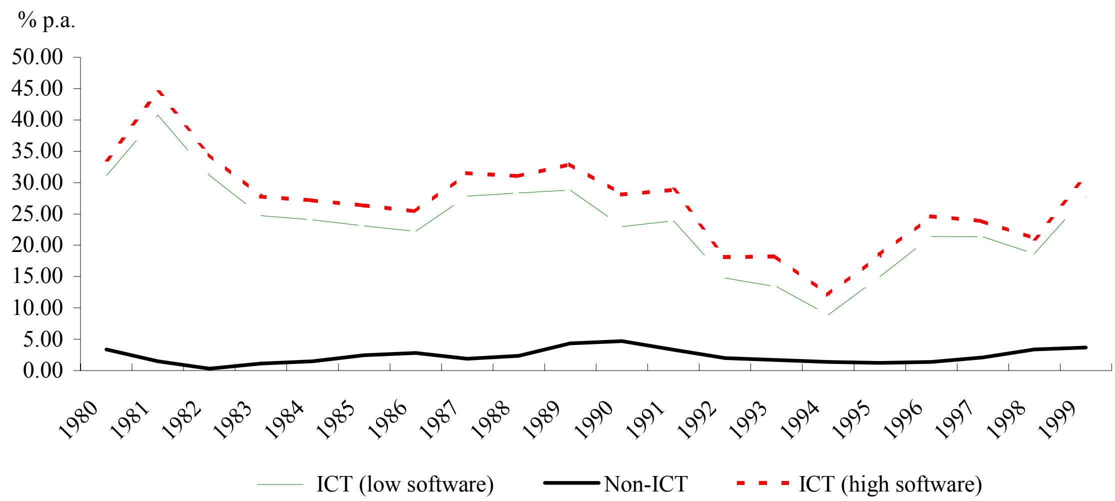


Figure 5
Growth of Capital Services, 1980–99, With and Without ICT Adjustment

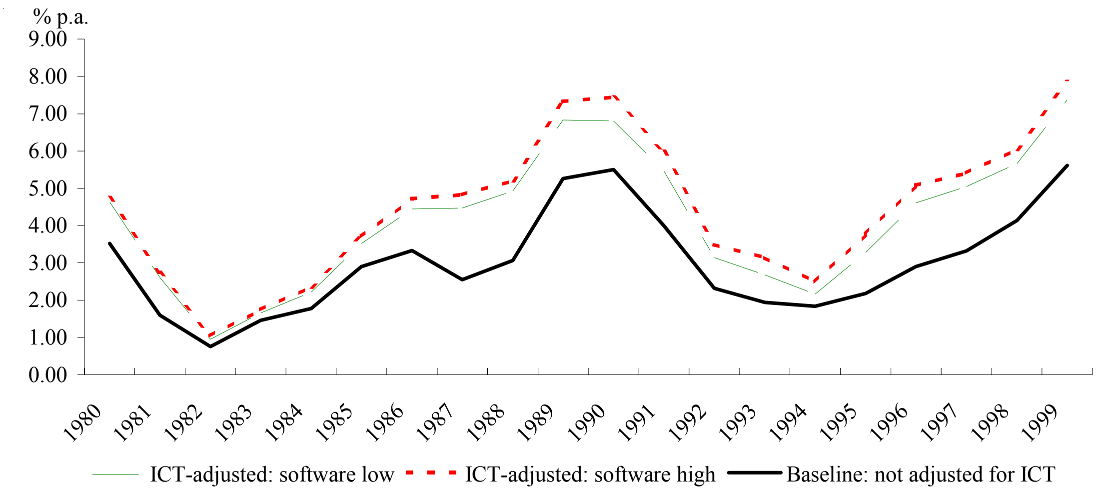


Table 3
Growth of Capital Services: ICT, Non-ICT, and Total

Period	Non-ICT % p.a.	ICT (low software) % p.a.	ICT (high software) % p.a.	Aggregate capital services (low software) % p.a.	Aggregate capital services (high software) % p.a.	Aggregate capital services (baseline) % p.a.
1979–89	2.16	28.19	31.46	3.63	3.84	2.62
1989–98	2.34	17.82	21.49	4.32	4.76	3.13
1989–94	2.62	16.78	21.07	4.05	4.51	3.12
1994–8	2.01	19.11	22.01	4.65	5.08	3.14

Notes: Dwellings are excluded from all these series. The growth of non-ICT capital services is a weighted average of the growth rates of the stocks of plant and machinery (excluding computers and telecommunications equipment), buildings, and vehicles; the weights are the shares of each type of asset in the profits attributable to non-ICT assets as a whole. The growth of ICT capital services is a weighted average of the growth rates of the stocks of computers, software, and telecommunications equipment; the weights are the shares of each type of asset in the profits attributable to ICT assets as a whole. Aggregate capital services (low and high software) are a weighted average of ICT and non-ICT capital services, where the weights are the shares of ICT and non-ICT assets in total profits. The profit attributable to an asset is its rental price (calculated by the Hall–Jorgenson cost-of-capital formula) multiplied by the asset stock. The baseline aggregate capital services estimates include, but do not distinguish separately, ICT assets; implicitly, they employ UK rather than US deflators and they do not make the 'times 3' adjustment for software.

Table 4
Contributions of Capital Deepening and TFP to Growth of Output Per Hour, 1979–98
(by period: absolute amounts)

		Capital deepening			
Period	Growth of output per hour % p.a.	ICT p.p.p.a.	Non-ICT p.p.p.a.	Dwellings p.p.p.a.	TFP p.p.p.a.
Low software					
1979–89	2.75	0.37	0.51	0.17	1.70
1989–98	2.33	0.51	0.49	0.15	1.17
1989–94	3.01	0.40	0.83	0.27	1.51
1994–8	1.47	0.64	0.08	0.00	0.75
High software					
1979–89	2.80	0.42	0.51	0.17	1.70
1989–98	2.41	0.61	0.49	0.15	1.16
1989–94	3.10	0.51	0.82	0.27	1.50
1994–8	1.55	0.74	0.08	0.00	0.73

Notes: Calculated using equation (2). TFP growth is calculated as the residual. Capital deepening is the growth of capital services per hour worked times capital's share. Capital services (except services of dwellings) are from Table 3; hours worked are from O'Mahony (1999), kindly updated by her to 1998.

V. WHY HAS THE ICT EFFECT IN THE UK NOT BEEN AS LARGE AS IN THE USA?

It is well known that US labour productivity growth accelerated in the second half of the 1990s. Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) ascribe virtually all this acceleration to ICT. So why do we not observe anything comparable in the UK? Table 5 attempts to answer this question by setting out the relevant data from the Oliner–Sichel study side-by-side with comparable results for the UK. It shows the acceleration or deceleration which occurred in both countries between the first and second halves of the 1990s. The time periods in the two studies are not identical, but probably close enough for the present purpose.

Labour productivity growth was actually substantially higher in the UK up to 1994/5. This is not too surprising since the UK's productivity level has long been considerably lower:[15] other things equal, we expect countries with a lower productivity level to grow more rapidly. Both countries saw an improvement in the first half of the 1990s. But then in the second half US productivity accelerates while the opposite occurs in the UK. Note, however, that output growth accelerates in both countries, so the difference is in the behaviour of labour input (hours).

On the input side, the contribution of ICT capital is rising in both countries, but is smaller in the UK. In the most recent period, the UK contribution is about 67 per cent of the US one. The main reason why the ICT contribution is lower in the UK is not that ICT inputs are growing more slowly, but rather that their income shares are lower: in the latest period, the aggregate ICT share is 3.6 per cent in the UK compared with 6.3 per cent in the USA (see Oulton, 2001*a*, Table 11).

Part of the UK productivity slowdown can be ascribed to a falling contribution from other capital (a fall of 1.02 p.p.p.a.). There was no parallel to this in the USA, where other capital makes a minor contribution throughout the 1990s. But the most surprising feature of Table 5 is that TFP growth fell in the UK by 0.76 p.p.p.a., while it rose by 0.55 p.p.p.a. in the USA. Up till 1994/5, TFP growth, like labour productivity growth, has been substantially higher in the UK. According to Oliner and Sichel, part of the reason for the rise in US aggregate TFP growth is that TFP growth rose in the computer and semiconductor industries. But they also find that TFP growth accelerated in the rest of the non-farm business sector. A rise in TFP growth in the ICT sector seems likely to have been a world-wide phenomenon, from which the UK should have benefited, too, even if to a lesser extent than the USA. This makes the UK slowdown in aggregate TFP growth even more puzzling.

A possible, though partial, explanation of the UK experience is that the realized rate of return on ICT investment has been lower than that on other assets, contrary to the assumption embodied in our method (see section II). The result would be that we have overestimated the contribution of ICT capital, and in fact of capital in general, through giving too large a weight to the fastest growing part of the capital stock. The corollary would be that we have underestimated TFP growth. This hypothesis by itself does not explain why the rate of return should be lower in the UK.

A second hypothesis is that ICT investment may have incurred large adjustment or learning costs which our method does not allow for (Kiley, 1999). In the US case, these costs were largely incurred prior to 1995, which would help to explain why their productivity performance up to then was disappointing. Since 1995, according to this argument, they have been reaping the rewards. The UK by contrast, which has invested less, is still paying the costs. TFP growth only appears to be low in the UK, because these costs are not accounted for. Alternatively, this hypothesis could explain why the apparent rate of return to ICT investment is low. If this hypothesis is correct, we would expect a revival of measured TFP growth to occur in due course.

A third hypothesis is network externalities. It may be that these depend on a critical mass of users of the new technology being achieved. This critical mass has been reached in the USA, but not as yet in the UK.

[15] According to O'Mahony and de Boer (2002, Table 3), output per hour in 1999 was 30 per cent higher in the USA in the whole economy and 39 per cent higher in the market sector. See O'Mahony (1999) for longer period comparisons.

Table 5
Productivity Acceleration/Deceleration in the Second Half of the 1990s: The USA and UK Compared (percentage points per annum)

	USA 1995–9 over 1990–5	UK 1994–8 over 1989–94
Growth of output per hour	+1.04	–1.54
Growth of output	+2.07	+1.73
Contributions from		
ICT capital	+0.45	+0.24
Other capital	+0.03	–1.02
TFP plus labour-force quality	+0.55	–0.76
Memorandum items		
ICT income share (% of GDP)	+1.00	+1.48
Growth rates of inputs (% p.a.)		
Computers	+18.40	+9.78
Software	+0.30	–5.20
Telecommunications equipment	+3.60	+4.86

Notes: US figures relate to the non-farm, non-housing business sector, UK figures to the whole economy (low software variant, since this matches better with the US data). For the UK, other capital includes dwellings. Income shares are profits attributable to each asset as a proportion of GDP. The source for the USA gives the contribution of labour quality separately from that of TFP, while this is amalgamated with TFP growth in the UK case. Hence, for purposes of comparison I amalgamate labour-force quality with TFP for the USA; for the UK 'TFP plus labour-force quality' corresponds to what was called just TFP in Table 4.
Sources: USA: Oliner and Sichel (2000, Tables 1 and 2). UK: Oulton (2001*a*).

Finally, a more mundane explanation for the UK slowdown is special conditions in manufacturing, in particular the strong pound, particularly in the period 1995–8. The official figures for labour productivity growth certainly suggest that the slowdown was much more pronounced there than in the rest of the economy.

None of these hypotheses explains why the UK lags behind the USA in the application of ICT. Gust and Marquez (2002) suggest that regulatory barriers, particularly employment protection legislation and other burdens on business, have hindered the adoption of ICT in the OECD outside of North America. However, on their measures of the barriers the UK ranks very close to the USA. Another possibility is that competitive pressures have been lower in the UK, which lowers the incentive to cut costs through ICT or any other kind of investment (Nickell, 1996).

VI. HOW LARGE WILL ICT'S CONTRIBUTION BE IN THE FUTURE?

Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) both argue that the acceleration in US productivity growth has been driven by an acceleration in technical progress in the semiconductor industry, which Oliner and Sichel, at least, treat as an acceleration of TFP in that sector. If rapid technical progress continues in semiconductors, then the relative price of computers and telecommunications equipment will continue to fall, thus encouraging continuing rapid accumulation of ICT capital. This suggests that to assess the future contribution of ICT we need to forecast technical progress in this crucial sector: will Moore's Law continue to hold?

There is another more economic aspect. As stated above, the contribution to output growth of any sector is its share in GDP (in current prices) multiplied by the growth rate of its final output. If the output share is 3 per cent and the volume growth is 20 per cent p.a., then the contribution to GDP growth is 0.6 p.p.p.a., which is substantial. But suppose that prices are falling at 30 per cent p.a., in other words demand is inelastic. Then the share in GDP is falling, too, and in the next period will be less than 3 per cent (in fact, about 2.7 per cent). So even if prices continue to fall at 30 per cent and volumes to rise at 20 per cent, the contribution to GDP growth will steadily diminish and will in fact approach zero.

A similar point applies on the input side. Here the contribution of ICT capital to the growth of aggregate input is the share in GDP of profits attributable to ICT capital, multiplied by the growth rate of ICT capital. However rapidly the stock of ICT capital is rising, the contribution of ICT capital to aggregate input will go to zero if the ICT share of profits is going to zero. This is because the share measures the elasticity of output with respect to the input. A falling share would indicate that the marginal product is declining more rapidly than the stock is rising, so additions to the stock would eventually have a vanishingly small effect on output.

It seems quite plausible that, initially, as prices fall there should be a phase where the share of expenditure rises, i.e. demand is elastic. But eventually, as prices continue to fall, demand will become inelastic, so the share will decline. Indeed, this is just the pattern implied by the textbook linear demand curve. So the fact that the ICT share in GDP has been rising does not necessarily imply that it will continue to do so.

However, up to now the software industry has been successful in inventing new uses for computers. In fact, one could argue that developments in the software, computer, and semiconductor industries mutually reinforce each other. New types of software, such as those involving graphics, make greater demands on hardware, thus increasing the demand for more sophisticated machines. And the availability of more sophisticated machines makes it worthwhile to develop software which can make use of the increased power now on offer.

Furthermore, from the point of view of the UK, any potential fall in the income share of ICT seems likely to be some way in the future: as we have just seen, the share is still only about two-thirds of the US level. Figures 5 and 6 show the output and income shares rising fairly steadily over the last 20 years. In fact we know that the shares of computers and software have been rising for five decades since they were zero prior to 1951 (when the first commercial computer was introduced into service). All this suggests that the contribution of ICT to growth in the UK, on both the output and the input sides, is likely to go on rising, once current difficulties have been overcome.[16]

VII. CONCLUSIONS

On the basis of the new estimates of ICT output and investment presented here, there has been a substantial and growing understatement of GDP growth. From 1994 to 1998, accepting the new estimates would add between 0.25 and 0.33 p.p.p.a. to the growth rate, depending on which deflator is used for software. If we decline to make the 'times 3' adjustment to the level of software investment that I have argued for in section III, then the understatement of GDP growth is reduced to 0.13–0.16 p.p.p.a. (see Table 1).

The share of ICT output in GDP has been rising fairly steadily, but still only reached 3 per cent by 1998. Despite this, the growth of ICT output has contributed about a fifth of GDP growth from 1989 to 1998.

On the input side, since 1979 about half of the growth of capital services has been accounted for by the growth of ICT capital. Since 1989, 55 per cent of capital deepening (the growth of aggregate capital services per hour worked times capital's share) has been contributed by ICT capital. From 1994 to 1998, ICT capital accounted for a remarkable 90 per cent of capital deepening.

The proportion of labour productivity growth that can be accounted for by the growth of ICT capital per unit of labour is rising. ICT capital deepening

[16] A similar view is expressed by Baily (2001) and by DeLong and Summers (2001) about the US economy.

accounted for 25 per cent of the growth of output per hour in 1989–98 and 48 per cent in 1994–8.

Despite the ICT adjustments, there is still a slowdown in the growth rate of labour productivity after 1994. Part of the slowdown can be ascribed to a fall in the contribution of non-ICT capital, but part is due to a slowdown in TFP growth, the reasons for which are at the moment mysterious. By contrast, the US labour productivity acceleration has been accompanied by rising TFP growth (in both the ICT and non-ICT sectors of the economy).

The picture for the UK bears some similarities to the US experience. There has been no sudden emergence of a 'New Economy'. ICT has always been there, but its impact has been growing steadily and has only recently become a dominant force. ICT has made its impact through investment and capital accumulation, and not through TFP. But, by contrast with the USA, there has been no upsurge of TFP growth, but rather a slowdown.[17] A number of possible hypotheses were suggested in the previous section to explain this divergence. But within the scope of the present paper the issue cannot be resolved. Nevertheless, there is reason for optimism about the future. Since the ICT income share in the UK, though rising, is still only two-thirds that in the USA, we may expect the contribution of ICT capital to economic growth to continue to increase, once current difficulties are overcome.

The estimates presented here only go up to the end of 1998. Does anything that has happened since affect the conclusions? In 1999 and 2000, real computer investment continued to grow rapidly, by 19.1 per cent and 17 per cent, respectively. Real software investment stagnated, despite the millennium bug: growth was 0.8 per cent in 1999 and –2.4 per cent in 2000.[18] The growth of labour productivity (GDP per hour worked) remained low in 1999, but rebounded sharply in 2000 to a level substantially above its average level over the previous 20 years. However, since then it has declined again below trend. Judging by past experience, this is not too surprising given the slowdown in GDP growth that started in 2001 (though US productivity growth has held up much better during its more pronounced slowdown). Much of the decline in UK output and productivity growth can be attributed to the very large absolute fall in the output of the 'electrical and optical' sector (which corresponds roughly to what is called ICT here, though excluding software). This fall is associated with the world-wide decline in ICT spending and will no doubt be reversed in time. All in all, however, there is as yet no evidence in the aggregate data of a speed-up in UK productivity growth.

The present paper has taken an aggregate approach. But in order to understand better the role of ICT, and perhaps to explain the divergence between US and UK performance, it is necessary to break down the aggregate estimates of capital deepening and TFP by sector. We know that investment in ICT is highly skewed towards some of the services industries, such as finance and business services. Understanding how investment in these sectors generates productivity growth at the whole economy level is an important task for future research.

[17] The failure so far of ICT investment to produce a productivity improvement is not confined to the UK, but is true of the rest of the European Union as well (see the papers by Daveri and by Bassanini and Scarpetta in this issue). Daveri finds that the other countries invested less in ICT than did the UK in the 1990s. Bassanini and Scarpetta report a similar finding for computers. They also find that the UK does poorly on software, but we have argued that the UK figures may be understated.

[18] Current price investment figures are taken from the 2002 Supply and Use Tables and are deflated as before by US price indices, adjusted for exchange-rate changes.

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