ICT AND PRODUCTIVITY GROWTH IN THE UK

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Summary

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, 56% of capital deepening has been contributed by ICT capital, and 88% since 1994. ICT capital deepening accounts for 23% of the growth of labour productivity over 1989-98 and 39% over 1994-98. 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.

1. Introduction[1]

This paper seeks to measure the contribution of information and communication technology (ICT) to the growth of output and productivity, using a growth accounting approach. Four types of ICT are studied:

- Computers
- Software
- Telecommunications equipment
- 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 here 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, and thus ultimately for the processing power, of chips to double every 18 months to two years.

The motivation for the present study is the striking increase in the growth of US labour productivity that occurred in the second half of the 1990s. This increase was accompanied by an investment boom in ICT equipment. There now seems general agreement that a large part of the increase in output can be accounted for by rapid growth in the stock of ICT equipment (Bassanini *et al.* (2000*);* Bosworth and Triplett (2000); Gordon (2000); Jorgenson and Stiroh (2000); Oliner and Sichel (2000)). 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 (Tevlin and Whelan (2000)). The fall in computer prices has been mainly due to rapid and indeed accelerating

[1] 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 and an anonymous referee, of colleagues in the Bank of England, particularly Ian Bond, Jo Cutler, Jens Larsen and Hasan Bakhshi, and from the detailed comments of ONS officials, in particular Prabhat Vaze. I also thank Bruce Grimm of the BEA for advice on US software estimates and Steve Oliner of the Board of Governors of the Federal Reserve for supplying data on semiconductor prices. Malte Janzarik provided excellent research assistance. None of the above nor the Bank of England should be regarded as necessarily in agreement with the views expressed here.

technical progress in semiconductors (Jorgenson (2000); Jorgenson and Stiroh (2000); Oliner and Sichel (2000)). In the UK by contrast, the second half of the 1990s saw a decline in labour productivity growth. Since ICT products are widely traded internationally, was there a comparable investment boom in the UK? If so, why has it not apparently led to faster labour productivity growth?

The method employed here largely follows that of Jorgenson and Stiroh (2000). The paper which is closest in coverage to the present one is Davies *et al.* (2000). But as will be seen there are some significant differences between their estimates and the ones presented here. This paper takes a wider view than some studies which cover the UK (e.g. Kneller and Young (2000); Schreyer (2000)) 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 include 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 (2000).

The scale of investment in ICT: a US-UK comparison

By way of motivation, we start by comparing the scale of investment in the UK and the US in the three categories of ICT investment and in total. We make the comparison in terms of shares of GDP at current prices. By doing so, we avoid the need to choose deflators to convert output to constant prices or an exchange rate to convert real output in the two countries to a common basis.

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[2] Davies *et al.* (2000) 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. 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 estimate the effect of computers on aggregate input but not aggregate output, i.e. they exclude software and telecommunications equipment.

[3] Computers themselves are of course far from "new". The year 2001 will see 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, page 69 and Table 2.2, page 20).

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

Chart 1

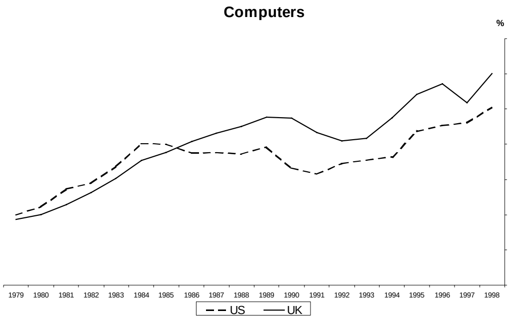


Chart 2

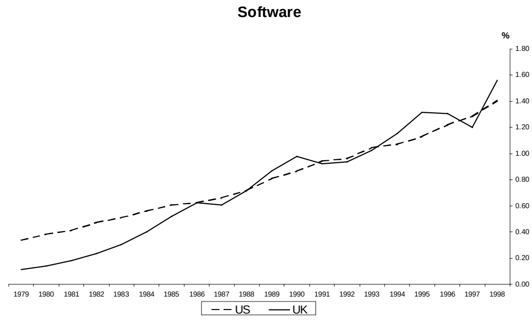


Chart 3

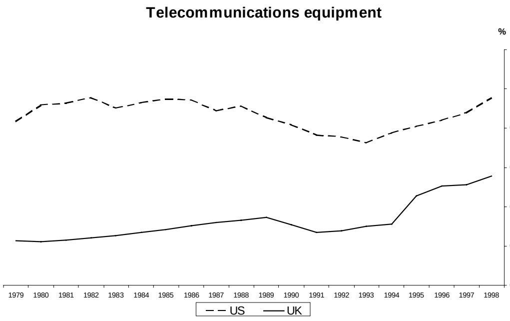
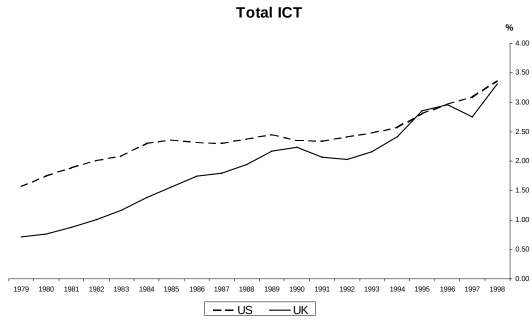


Chart 4



Source US NIPA for the US and own calculations for the UK (see section 4 below).

The UK's total investment in ICT is now rather more than 3% of GDP and is as large as that of the US. 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 we argue below is justified. Second, since US GDP per capita is substantially larger, the result would be less flattering to the UK if investment per capita were being compared.

Plan of the paper

Our strategy is to develop first a baseline estimate of the growth of GDP and of TFP (see section 3). Here we use only official data, in particular we make no adjustments for ICT. ICT is included on both the output and input sides, but its effects are not separately distinguished. Section 4 presents the main results for the baseline estimates. Section 5 discusses the problems raised by the measurement of ICT. Here a number of adjustments to official statistics are made. The two principle ones are first, that we use US price indices, adjusted for exchange rate changes, to deflate ICT outputs and inputs and second, that we triple the official estimate of the nominal level of software investment. Section 6 presents and discusses these new estimates where explicit allowance is made for ICT. Section 7 then asks whether the contribution of ICT will continue to rise in future. Section 8 summarises the findings and suggests some directions for future research.

2. The general framework

The framework employed here is based on Jorgenson and Griliches (1967) and Jorgenson *et al.* (1987); Jorgenson (1990) provides an exposition of the method and a survey of results for the US; Jorgenson and Stiroh (2000) is a recent study employing this method. Broadly the same framework is set out in OECD (2001).[4] For the UK the implementation of the method is necessarily on a much less detailed basis than is possible for the US.

We assume the existence of an aggregate production possibility frontier[5] relating final output of consumption and investment goods to capital and labour inputs. The m consumption goods and n investment goods (F_i) are produced with the aid of the services of l different types of labour (L_j) and of n different types of capital (K_k):

$$G(F_1(t),...,F_{m+n}(t)) = A(t)\cdot f[K_1(t),...,K_n(t);L_1(t),...,L_l(t)] \qquad (1)$$

Here $A(t)$ indexes technology, or the level of total factor productivity (TFP), which is assumed to rise autonomously over time (t). Taking the total logarithmic derivative of equation (1) with respect to time, we obtain

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[4] An alternative framework centring round the concept of "investment-specific technological progress" has been proposed by Greenwood *et al.* (1997) and Hercowitz (1998). The relationship between this framework and growth accounting is discussed in Oulton (2001).

[5] This is a much more general concept than the aggregate production *function* (Hulten 1978). An aggregate production function only exists if the industry-level production functions are identical up to a scaling factor, which is a highly restrictive condition (Jorgenson *et al.* (1987)).

$$\sum_{i=1}^{m+n}\left(\frac{\partial \ln G}{\partial \ln F_i}\right)\cdot \hat{F}_i(t) = \hat{A}(t) + \sum_{k=1}^{n}\left(\frac{\partial \ln f}{\partial \ln K_k}\right)\cdot \hat{K}_k + \sum_{j=1}^{l}\left(\frac{\partial \ln f}{\partial \ln L_j}\right)\cdot \hat{L}_j \qquad (2)$$

where a "hat" (^) denotes a growth rate, e.g. $\hat{A} = d \ln A / dt$. Now add the economic assumptions of perfect competition and constant returns to scale, so that market prices measure marginal costs. Define aggregate output *Y*, aggregate labour *L* and aggregate capital services *K* as Divisia indices of their respective components:

$$\hat{Y}(t) = \sum\nolimits_{i=1}^{m+n} v_i(t)\hat{F}_i(t)$$

$$\hat{L}(t) = \sum\nolimits_{j=1}^{l} w_j^L(t)\hat{L}_j(t) \qquad (3)$$

$$\hat{K}(t) = \sum\nolimits_{k=1}^{n} w_k^K(t)\hat{K}_k(t)$$

Here v_i is the share of the ith type of final output, F_i, in the nominal value of aggregate output (nominal GDP); w_j^L is the proportion of the aggregate wage bill accounted for by the jth type of labour; w_k^K is the share of aggregate profit attributable to the kth type of asset. Each of these sets of shares sums to 1:

$$\sum\nolimits_{i=1}^{m+n} v_i = \sum\nolimits_{j=1}^{l} w_j^L = \sum\nolimits_{k=1}^{n} w_k^K = 1 \qquad (4)$$

Then production theory shows that the elasticities in equation (2) are equal to the corresponding shares in the value of output. Hence we can derive the basic growth accounting relationship in continuous time:

$$\hat{Y}(t) = s_K(t)\hat{K}(t) + (1 - s_K(t))\hat{L}(t) + \hat{A}(t) \qquad (5)$$

where s_K is the share of profits in national income which can also be interpreted as the elasticity of output with respect to capital. Equation (5) expresses the growth of output as a Divisia index of the growth of the inputs plus the residual term, TFP growth.

Equations (3) and (5) use the fact that nominal GDP is the sum of nominal final outputs. An alternative approach is to measure nominal GDP as a sum of value added in the various industries, i.e. to work from the output side rather than from the expenditure side of the national accounts. Since output equals expenditure, the results of the two approaches must in principle be the same. The output approach is more relevant to analysing the contribution of industries rather than that of particular products. It enables us to answer questions like, what has been the contribution of TFP growth in semiconductors to aggregate TFP growth? However, it is much more demanding statistically since it requires detailed input-output tables together with corresponding output and input price indices. We leave this is as a topic for future research.[6]

Adjustment for discrete time

The equations above are in continuous time and use Divisia indices. In empirical work we must use discrete time. The discrete counterpart of a Divisia index is a chain index. More than one type of chain index is possible. Here we employ Törnqvist indices.[7] Experience shows that alternative superlative indices such as the Fisher index produce very similar results. In discrete time equation (5) becomes

$$\Delta \ln Y(t) = \bar{s}_K(t)\Delta \ln K(t) + (1 - \bar{s}_K(t))\Delta \ln L(t) + \Delta \ln A(t) \qquad (6)$$

where the capital share is averaged across adjacent time periods:

$$\bar{s}_K(t) = [s_K(t) + s_K(t-1)]/2$$

The growth rates of the output, capital and labour aggregates now become

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[6] The relationship between these two approaches and different concepts of productivity growth is discussed in Oulton (2000b).

[7] In a Törnqvist index the point-in-time weights of a Divisia index are replaced by the arithmetic average of the weights in the two periods between which growth is being measured; continuous growth rates are replaced by discrete ones. The Törnqvist index is a superlative one and is exact if the underlying function is translog (Diewert 1976).

$$\Delta \ln Y(t) = \sum_i \bar{v}_i(t) \Delta \ln F_i(t)$$

$$\Delta \ln L(t) = \sum_j \bar{w}_j^L(t) \Delta \ln L_j(t) \qquad (7)$$

$$\Delta \ln K(t) = \sum_k \bar{w}_k^K(t) \Delta \ln K_k(t)$$

where the $\bar{v}_i, \bar{w}_l^L$ and $\bar{w}_k^K$ are averages across adjacent periods and are defined analogously to $\bar{s}_K$.

Capital

Amongst the final demands are flows of investment spending on each type of asset. Corresponding to each type of investment, there is an associated stock. The end–of-period stock of the kth type of asset, $Stock_k(t),$ is estimated by cumulating the corresponding investment flow, after allowing for geometric deterioration. In discrete time:

$$Stock_k(t) = I_k(t) + (1-\delta_k) Stock_k(t-1) \qquad (8)$$

where I_k is real gross investment in assets of type k and δ_k is the deterioration rate, assumed constant over time. If deterioration is geometric as here, then the deterioration rate equals the depreciation rate.[8] Note that investment is measured in units of constant quality. In principle, deflating investment in current prices by an appropriate producer price index should achieve just this, since producer price indices aim to adjust for quality change. The only issue is the extent to which they succeed in doing so in practice (see below, section 5).

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[8] The deterioration rate is a "quantity" concept, while the depreciation rate is a "price" concept. The latter is the rate at which an asset's price is changing as it ages. (More precisely, depreciation is the difference between the price of a new asset and the price of a one year old asset, both at time *t*). If the rate of deterioration is constant as assumed here, then the deterioration rate equals the depreciation rate, though this is not true in general. The case for using geometric depreciation is argued by Jorgenson (1996), Hulten and Wyckoff (1996) and Fraumeni (1997). It is now the "default assumption" in the US National Income and Product Accounts. See section 5 below for a discussion of deterioration in the case of computers and software.

Capital services of type *k* during period *t* are assumed to be proportional to the stock available at the beginning of the period:

$$K_k(t) = Stock_k(t-1) \tag{9}$$

where the constant of proportionality is normalised to 1. To construct the capital aggregate, we need to derive the weights, w_k^K. For each asset type, its weight represents the share of total profits attributable to ownership of that asset. In a competitive market, each asset would come with a rental price p_k^K attached to it. The aggregate of all rentals would then equal aggregate nominal profits (Π):

$$\Pi = \sum_k p_k^K K_k \tag{10}$$

The weight to attach to each asset is therefore

$$w_k^K = p_k^K K_k / \Pi \tag{11}$$

The rationale for using rental prices, rather than asset prices, to aggregate different types of asset together is marginal productivity. Under appropriate assumptions, the rental price measures the additional output resulting from an extra unit of capital. Using rental prices rather than asset prices will increase the weight given to machinery, equipment and software relative to buildings since the latter have lower rates of depreciation. Because their cost is lower, their marginal productivity must be lower too in equilibrium. Computers and software have exceptionally high rental prices in relation to their asset prices since not only are their depreciation rates very high but their prices are falling, i.e. unlike buildings they incur capital losses. In other words, they need to be very profitable to cover the high costs of owning them.

The rental price of asset *k*, p_k^K, is not normally observed, but it is related to the asset price, p_k^I, which is observed. Indeed, asset prices must be known in order to calculate investment in constant prices. Rental and asset prices are related by the well-known Hall-Jorgenson formula which in discrete time is:

$$p_k^K(t) = T_k(t)\left\{r(t)\,p_k^I(t-1) + \delta_k\,p_k^I(t) - [\,p_k^I(t) - p_k^I(t-1)]\right\} \qquad (12)$$

Here r is the nominal after-tax rate of return, assumed to be equalised across all asset types, and T_k is the adjustment factor for corporate taxes and subsidies to investment:

$$T_k(t) = \frac{1 - u(t)D_k(t)}{1 - u(t)}$$

where u is the corporate tax rate and D_k is the present value of depreciation allowances per £ spent on asset k.

To implement the method we require data on asset prices and depreciation rates plus tax and subsidy rates. The nominal rate of return is also needed but this can be found by solving equations (10) and (12), given the other data.

The assumption that the rate of return r is equalised across different types of asset is quite strong, particularly in times of rapid change. If producers are over-optimistic, or make insufficient allowance for adjustment costs, then the realised rate on ICT assets will be less than the rate measured by the present method. On the other hand, for a period the realised rate of return might be higher for ICT assets since insufficient time has elapsed for accumulation of such assets to drive the rate of return down to equality with rates obtainable on non-ICT assets. The first possibility means that TFP growth will be understated by the method used in this paper, the second that it will be overstated.

The measurement of capital services makes no explicit allowance for variations in capacity utilisation. But these are not completely ignored since the growth of capital services is weighted by the profit share, which varies procyclically. Berndt and Fuss (1986) show that, in a model with one capital good, varying utilisation of capital is captured by the profit share. But since there are many capital goods, with varying degrees of utilisation, not to mention labour which may be hoarded during recessions, their approach probably does not completely purge the TFP measure of utilisation effects.

Labour productivity and TFP

It is helpful to set out explicitly the relationship between the growth of labour productivity and the growth of TFP. This can be done by subtracting the growth of labour input from both sides of equation (6) to obtain:

$$\Delta \ln[Y(t)/L(t)] = \overline{s}_K(t)\Delta \ln[K(t)/L(t)] + \Delta \ln A(t) \qquad (13)$$

This shows that the growth of labour productivity (the left hand side) can be decomposed into "capital deepening" — the capital share times the growth of capital per unit of labour — plus TFP growth.

A further step would be to decompose both capital deepening and TFP growth at the aggregate level into the contributions coming from different industries. This is a subject for future research.

3. Constructing the baseline estimate[9]

Our goal is to measure each of the elements of equation (6), or equivalently, equation (13). We start by considering a baseline estimate of GDP growth and the corresponding inputs. ICT will be included implicitly in both output and inputs, but not separately identified. In section 5, we consider the changes necessary in order to measure the contribution of ICT explicitly. This will lead us to a discussion of the appropriate deflators to use for ICT products. For the baseline estimate, the period covered is 1950-99. Though our emphasis is on the period since 1979, the earlier period does provide some extra perspective.

Output

Output (GDP) is measured from the expenditure side, making use of the familiar identity that in current prices

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9 See Annex A for more detail.

$$GDP = Consumption + Investment + Exports - Imports.$$

(Government expenditure is potentially included in all these categories). For each component of the right hand side of the identity, we need a series in constant prices and one in current prices; the latter is required for the value shares.

Consumption is split into two components, since only for these two do we have consumption in both current and constant prices:

1. Households and NPISH
2. Total government

Exports and imports form one category each.

The Blue Book allows us to distinguish seven types of fixed investment plus investment in inventories:

1. "New dwellings, excluding land"
2. "Other buildings and structures" [industrial and commercial buildings; infrastructure (e.g. roads, hospitals, schools)]
3. "Transport equipment" [road vehicles, railway rolling stock, ships and aircraft]
4. "Other machinery and equipment and cultivated assets" [plant and machinery]
5. "Intangible fixed assets" [software, mineral oil exploration]
6. "Costs associated with the transfer of ownership of non-produced assets" [transfer costs][10]
7. "Acquisitions less disposals of valuables"
8. "Changes in inventories"

Since the adoption of ESA95 in the 1998 *United Kingdom National Accounts*, software investment has been included in the new category "Intangible fixed assets".

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[10] This item mainly reflects estate agents' fees earned in the course of buying and selling existing dwellings.

Previously, under ESA79, software was treated as intermediate consumption, like business use of electricity or stationery. Expenditure on computers and telecommunications, which has always been treated as investment, is included under “Other machinery and equipment and cultivated assets”.

The last two categories of investment, “Acquisitions less disposals of valuables” and “Changes in inventories”, are small and erratic. Moreover, they are sometimes negative and the Törnqvist index (equation (7)) requires that logs be taken. Hence we distribute expenditure on these two categories equiproportionally across the other components of GDP. Our estimate of output growth is therefore a Törnqvist index with 10 components: two kinds of consumption (private and governmental), 6 kinds of investment, exports and imports.

The use of a chain index is a movement along the road which the ONS intends to follow in a year or two (Brueton 1999). Of course, within each of the components, the weights are fixed, usually for 5 years at a time. This explains why our baseline chain index of output turns out to be very close to the official measure of the growth of GDP at 1995 market prices (see Table A.1).

Capital stocks

For each of the investment series, except “Acquisitions less disposals of valuables”, we have generated a corresponding stock. We have added transfer costs to the dwellings stock. So we finish up with six stocks, one to cover dwellings (including transfer costs) and another five which we later aggregate up to the non-dwellings capital stock, using equation (12). The five other stocks are:

1. Buildings (excluding dwellings)
2. Plant and machinery (including computers and telecommunications equipment)
3. Vehicles
4. Intangibles (including software)
5. Inventories

We have used U.S. depreciation rates taken from Fraumeni (1997). The advantage of these is that they rest on empirical studies of second hand asset prices. In nearly all cases, geometric decay was found to be a good approximation to the decline in asset prices with age (Hulten and Wyckoff (1981a) and (1981b); Oliner (1996)). Unfortunately, no comparable studies exist for the UK.[11] In the non-dwellings stock, each type of capital receives a weight equal to the proportion of total profit which it is calculated to generate.

Labour

We have two measures of labour input: (1) total employment (heads) and (2) total weekly hours worked (hours). The hours series is a proxy for total *annual* hours worked. From 1992 onwards, this is a reasonable approximation (see Annex A). But for the years prior to then, the weekly hours index probably overstates the growth of annual hours, since it takes no account of the increasing length of holidays.

Output shares

To calculate TFP growth we need to weight the growth of the aggregate capital stock by the share of profits before tax in output and the growth of labour input by the share of labour. Profits are now called "Operating surplus, gross" in the Blue Book. Labour income is the income of the self-employed ("Mixed income") plus "Compensation of employees". The sum of these items is output at basic prices.[12]

4 Results: the baseline estimates

Our baseline estimates of output and input growth and of input shares appear in Annex D, Tables D.1-D.3.

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[11] The ONS calculates "gross" capital stocks which assume no depreciation and "net" stocks which assume straight line depreciation. Only the gross stocks are published in constant prices. Both gross and net stocks use the perpetual inventory method as here, but the asset lives assumed are much longer than the US ones. For recent years the ONS net stock estimates are influenced by premature scrapping which is assumed to vary with corporate insolvencies. This adds an element of geometric depreciation since premature scrapping is assumed to affect plant and machinery assets equally, irrespective of their age. The aggregate net capital stock is a wealth measure rather than a measure of the capacity to deliver capital services: different types of asset are aggregated together using asset prices rather than, as in this paper, rental prices.

[12] There might seem to be an inconsistency here since output is measured at market prices. But market prices are what people actually pay, so they are preferable as weights. In any case, it is not possible without considerable difficulty to revalue the components of final output from market to basic prices.

Table 1 shows the growth rates of output (chain-weighted GDP) and of the inputs over a 50 year period. Over 1950-73, both output and the capital stock grew faster than in any of the subsequent periods, showing that the reputation of this period as a "Golden Age" is well-deserved. Labour input (heads) also grew faster except for 1979-89. The poor performance of the 1973-79 period (a complete cycle from peak to peak) is also apparent, though the capital stock grew quite rapidly. The rather disappointing performance of the 1990s is apparent too. Output and employment grew less rapidly than in the preceding 10 year period, 1979-89, though the capital stock grew more rapidly.

The 1950-73 period was also the Golden Age for TFP growth (Tables 2 and 3). TFP growth then slumped in 1973-79 before recovering in the 1980s. Relative to the 1980s, the 1990s have seen a moderate decline, on the basis of both heads and hours. For labour productivity, the picture is a bit harder to read. Comparing the 1990s with the 1980s, labour productivity growth rose on the heads measure but on the hours measure it declined. In both absolute and proportional terms, the contribution of capital deepening to the growth of labour productivity was higher in the 1990s than in the 1980s.

Table 1
Average growth rates of output and inputs, by period, 1950-99

	Output	*Non-dwelling capital stock*	*Dwellings*	*Total capital stock*	*Labour (heads)*	*Labour (hours)*
Period	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1950-73	2.94	4.23	3.51	4.09	0.45	N/A
1973-79	1.54	3.54	3.07	3.43	0.23	N/A
1979-89	2.31	2.62	2.37	2.57	0.72	0.26
1989-99	1.98	3.38	1.72	2.92	0.28	0.05
1950-99	2.44	3.64	2.86	3.46	0.44	N/A

Source Annex D, Table D.1.

Table 2
Labour productivity growth: contributions of capital deepening and TFP, 1950-99, absolute amounts

	Heads			*Hours*		
	Growth of output per worker	*Contrib-ution of growth of capital per worker*	*TFP*	*Growth of output per hour worked*	*Contrib-ution of growth of capital per hour worked*	*TFP*
Period	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1950-73	2.49	0.97	1.52	N/A	N/A	N/A
1973-79	1.31	0.80	0.51	N/A	N/A	N/A
1979-89	1.59	0.52	1.07	2.05	0.64	1.40
1989-99	1.69	0.78	0.91	1.93	0.85	1.08

Source Annex D, Tables D.1-D.3.
Note Calculated using equation (12).

Table 3
Labour productivity growth: contributions of capital deepening and TFP, 1950-99, proportions

	Heads			*Hours*		
	Growth of output per worker	*Contrib-ution of growth of capital per worker*	*TFP*	*Growth of output per hour worked*	*Contrib-ution of growth of capital per hour worked*	*TFP*
Period	*% p.a.*	*%*	*%*	*% p.a.*	*%.*	*%*
1950-73	2.49	38.8	61.2	N/A	N/A	N/A
1973-79	1.31	61.2	38.8	N/A	N/A	N/A
1979-89	1.59	32.9	67.1	2.05	31.4	68.6
1989-99	1.69	46.1	53.9	1.93	43.9	56.1

Source Annex D, Tables D.1-D.3.
Note Calculated using equation (12).

5. Measuring ICT

Our basic strategy for measuring the contribution of ICT is to split output and input into ICT and non-ICT components. On the input side, we first of all estimate investment in current prices for each component, ICT and non-ICT. ICT investment is deflated by the appropriate US price index, adjusted for exchange rate changes. The reasons for using US price indices are set out below. We deflate the non-ICT investment components by the same deflators as used by the ONS, after excluding from them the ICT deflators used by the ONS.[13]

The period covered by our estimates will be 1979-98. Though our investment data go back to 1974, there is an increasing amount of interpolation necessary prior to 1989. Hence we only present results from 1979 onwards. As we sill see, the impact on GDP

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[13] For example, in the case of non-ICT investment in plant and machinery, we first obtain a series in current prices by subtracting our own estimates of investment in computers and telecommunications equipment from the official series for total investment in plant and machinery. To deflate this to constant prices, we start with the implicit deflator for total plant and machinery investment. We then exclude from this deflator the price indices for computers and telecommunications equipment which are implicitly included in it by the ONS. See Annex A for more details.

and the capital stock of making explicit allowance for ICT is small at the beginning of this period. Hence the sometimes rather heroic assumptions necessary to carry the data back prior to 1989 only have a small impact. For the capital stocks, there is the additional consideration that we assume very high rates of depreciation for software and computers. So the influence of the assumed initial stocks of these assets in 1973 on the growth rates from 1979 onwards is negligible.

On the input side, we now have eight types of asset. First, we have the same five types as before, but with computers and telecommunications excluded from plant and machinery ("Other machinery and equipment and cultivated assets") and with software excluded from intangibles ("Intangible fixed assets"). Second, we have three additional capital stocks: computers, software and telecommunications equipment. We use the same depreciation rates as before for the first five stocks. For computers and software, we assume an annual depreciation rate of 31.5% and for telecommunications equipment one of 11%. These rates are taken from Jorgenson and Stiroh (2000).

On the output side, we have the same categories as before (but now with ICT excluded) plus the four ICT categories. To estimate final output of computers, software and telecommunications equipment in current prices, we add to investment exports net of imports, obtained from the input-output balances (see below). To estimate the growth of final output in these categories, these ICT exports and imports are deflated by the same US deflators as are used for investment. For semiconductors, we just have to measure exports and imports. Estimating final output is described in more detail below.

US ICT price indices

Before describing the new estimates, some general points about US indices for ICT products need to be made. It is common to describe the US indices as hedonic ones. The suggestion is then that any substantial difference between the US and other countries arises from the use of hedonic methods.[14]

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[14] The hedonic method is an econometric approach which uses panel data on the prices of different models of a product, together with data on the physical characteristics believed to affect consumer choice, to infer the growth rate of a quality adjusted price.

A number of points can be made here. First, the hedonic technique has a firm basis in economic theory and has been employed in practice in US official statistics for many years (Triplett 1987 and 1990). Its application to US computer prices goes back to Chow (1967) and Cole *et al.* (1986); the latter's work was extended by Oliner (1993) and by Berndt and Griliches (1993).[15]

Second, the traditional approach of national statistical agencies is the matched models approach, under which a set of physically identical products, sold on commercially identical terms, is tracked over time. The US computer price index is often described as a hedonic index. But this is rather misleading. In fact, the index uses the normal matched model approach. Hedonic methods are employed only when an old model drops out and it is necessary to link a new model into the index: see Sinclair and Catron (1990) for an account of the US methodology.

Third, the rapid rate of fall of US price indices for ICT products is not due entirely to the use of hedonic techniques. Indices based purely on the matched models approach can also show rapid rates of decline. For example, a price index for semi-conductors constructed at the Fed and used by Oliner and Sichel (2000) was falling at more than 40% p.a. between 1996-99. This index was entirely based on matched models and made no use of hedonic methods at all. Aizcorbe *et al.* (2000) (see also Landefeld and Grimm 2000), using a large database of computer prices gathered by a market research firm, have shown that a matched models price index for computers can fall just as rapidly as the official index. But the models included have to be a representative sample and the data have to be sampled at relatively high frequency (quarterly in their study). It is also desirable that data on quantities as well as prices are available so that a superlative price index can be constructed. It is possible therefore that some of the difference between the US computer price index US and those of other statistical agencies may be due to the fact that these conditions are not always satisfied.

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[15] Nor are such studies confined to the US. In a pioneering study of UK computer prices using hedonic methods, Stoneman found that over the period 1955-1970, with quality held constant, his preferred price index fell at about 10% p.a. (Stoneman, 1976, chapter 3, Table 3.2, series (e)).

Fourth, the UK retail price index for computers (which is published as part of the Harmonised Index of Consumer Prices) is also not hedonic, but has been falling at about the same rate as its US counterpart and much more rapidly than the UK PPI. This provides an additional reason for suspecting a problem with the latter.

Fifth, in work commissioned by the ONS, Stoneman, Bosworth, Leech and McAusland constructed a hedonic index for UK computer prices for the years 1987 to 1992; their results are reported in Stoneman and Toivanen (1997, Table A3). They found that their index fell at 19.1% p.a. over this period; by contrast the official PPI for computers (ONS code PQEK) fell at only 7.2% p.a.

Next, there are three criticisms that are often made of the application of US indices to the UK or other foreign countries:

- US producers possess monopoly power so that prices charged in the US are not representative of prices charged in the UK.
- Adjusting for the exchange rate assumes that ICT products are priced in dollars with instantaneous passthrough into sterling, which may not be true.
- The US price indices are averages over different products, e.g. in computers they are averages over the prices of PCs, notebooks, servers, etc. The mix of products may differ between countries.

In response to the first point, the *level* of prices may differ between countries because of market discrimination by suppliers who possess some monopoly power, but here we are concerned with *changes* in prices. Even if the degree of monopoly power alters, the effect of this on the growth rate of UK prices is likely to be swamped by the huge falls observed in US prices. Also, casual empiricism suggests that, if anything, the UK market for ICT has become more competitive in recent years relative to the US. If so, UK prices will have fallen more rapidly than assumed, thus accentuating the effects studied here.

The second and third points are valid in principle. How important they are in practice requires direct research on prices to resolve. Even so, it is not clear that such research would necessarily support a higher growth rate of UK prices than assumed here.

We now describe how ICT investment and ICT prices are measured in the two countries and how our estimates differ from those of the ONS.

Investment in computers

Our current price series for investment in computers are consistent with those of the ONS. Our series are derived from the input-output balances (and for years prior to 1989, from the 1974, 1979 and 1984 input-output tables). These are for the somewhat larger category of “office machinery and computers”. We exclude the low tech items included in the larger category by using information from the regular sales inquiries (now published in *Product Sales and Trade*).[16]

To deflate the nominal series, we employ the Bureau of Economic Analysis’s price index for computers (adjusted for the dollar-pound exchange rate), which as just discussed uses hedonic techniques to correct for quality change. This price index is the one employed in the US National Income and Product Accounts.[17]

In the UK there is a producer price index (PPI) for computers (ONS code PQEK). However the ONS estimates investment in constant prices on an industry, not a product basis. This means that the PPI for computers is not used to deflate investment in computers directly. Rather, this PPI is included in the industry-level deflators which are used to deflate the whole of an industry’s investment in plant and machinery. Table B.1 of Annex B compares this PPI with the corresponding US price index.

Software investment in current prices

Software investment has three components:

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[16] The input-output tables for 1979, 1984, 1989 and 1990 used the 1980 SIC while the 1974 tables used the 1968 SIC. But the 1974 tables turned out to be helpful in another way since they are the only ones to date which separate the computer industry from the rest of office machinery.

- prepackaged software, e.g. an office suite sold separately from the computer on which it is to be run
- custom software, written (usually) by a software company specifically for sale to another company and
- own account software, written in-house for a company's own use

There is a fourth category, bundled software, e.g. the operating system and other programs which are typically sold together with a PC. This category is included under investment in computers.

Software investment was first incorporated into GDP in the 1998 Blue Book, following the adoption of ESA95. Previously, all spending on software was treated as intermediate consumption (like business purchases of stationery). The procedure was first to estimate a benchmark figure for 1995, based on an 1991 survey of sales of computer service companies, and then to carry this figure forward and backwards using the growth of indicator series. For the earlier years, the growth of total billings by the computer services industry was used. Years after 1995 used the growth of the wage bill of full time programmers, computer engineers and managers in the computer services industry (Rizki 1995).

The growth rate of software investment in current national prices has been very similar in the US and the UK. But there is a very large discrepancy in the levels. In the US, software investment as a proportion of computer investment (both in current prices) began steadily climbing in 1984 and levelled off after 1991. During the 1990s it averaged 140% of computer investment. In the UK by contrast, software investment averaged only 39% of computer investment in the 1990s. Since people buy computers to run software, it seems very unlikely that there should be such a large discrepancy between the UK and the US.

There is also a striking discrepancy in the proportion of the sales of the computer services industry which are classified as investment in the two countries. In the

[17] This price index is now maintained by the Bureau of Labor Statistics, following the original research by the BEA.

BEA's 1996 input-output table, we find that 60% of total sales of products of industry 73A, "Computer and data processing services, including own account software", was classified as final sales (mostly investment). The 1996 figure was based on the 1992 economic census which asked firms in this industry to distinguish between receipts from prepackaged software, from custom software and receipts from other activities, the first two of these being investment.[18] In the UK in the same year, investment accounted for only 17.5% of total sales of the corresponding product group (input-output group 107, "Computer and related activity").

The UK also appears to be out of line with other European countries. Lequiller (2001) has compared France with the US. He finds that the ratio of software investment to IT equipment investment was about the same in the two countries in 1998 (his page 25 and chart 6). He also finds that the ratio of software investment to intermediate consumption of IT services is substantially lower in France than in the US (page 26-27). This ratio is exceptionally high in the US, but equally his chart 7 shows that it is exceptionally low in the UK. In fact, the UK ratio is substantially lower than in France, the Netherlands, Italy and Germany.

Part of the difference in software levels may be due to a different treatment of own account software in the US. This now constitutes about a third of all US software investment and is estimated from the wage bill (grossed up for other costs) of computer programmers employed throughout the economy (Parker and Grimm 2000). Own account software is likely to be important in the UK too. In 1995 only 27% of software engineers and computer programmers were employed in the computer services industry (see Annex B). Presumably, an important function of the other 73% was to write software.

For these reasons, Annex C re-examines the whole issue. It employs US methods to estimate own account software. The result is that 1995 software investment is estimated to be about 4.1 times the official figure. Alternative, rougher multipliers are suggested by the two discrepancies noted above. A multiplier of 3.6 is arrived at by

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18 When the results of the 1997 economic census are fully incorporated, there will likely be increasingly large upward revisions to the software investment figures post 1992 (information from Bruce Grimm of the BEA).

dividing the US ratio of computer investment to software investment, averaged over 1990-98 (=1.40), by the corresponding UK ratio (=0.39). A factor of 3.4 is suggested by the comparison of the UK and US input-output tables. In order to err on the conservative side, we choose a multiplier of 3. The growth rate of nominal UK investment is of course left unchanged by this adjustment.

Misclassification of software spending

If what is really software investment has been misclassified as intermediate consumption, this has implications for the rest of the national accounts. First, the level of GDP in current prices is too low by the misclassified amount. Second, income must equal expenditure so profits have to be raised by the same amount. That is, profits are higher and firms are choosing to spend the additional amount on software investment.

There is another possibility. Instead of being previously classified as intermediate consumption, the missing software investment might have been counted as some other form of investment. In this case, there would be no effect on the level of nominal GDP or profits. This could arise for example if companies are correctly recording their investment, including in software, but the total is then being incorrectly allocated across products.

The main sources for aggregate investment are the annual and quarterly capital expenditure surveys which now specifically ask for software investment to be included though such spending cannot be separately identified.[19] A conscientious respondent to these surveys would probably follow his company's accounting treatment of software. If software spending is classified as current spending, then the whole of it can be written off against corporation tax in the current tax year. If it is classified as investment, then it can only be written off over the asset's lifetime. So

[19] There is another survey which does ask detailed questions about the asset composition of investment. This has been done only at irregular intervals in the past though now it is to be more regular. The sample size is much smaller than in the quarterly and annual surveys.

there is an obvious incentive to classify software spending as current.[20] Two points about the tax treatment of software may be relevant here:

- Inland Revenue rules allow software spending which is deemed to have a life of up to two years to be classified as current. By the rules of national income accounting, any spending with a life of more than one year should be classified as investment.
- If software is purchased by an annual licence fee, rather than outright, it is classified by the Revenue as current expenditure.[21]

It is not possible at the moment to resolve this issue, though more detailed information may become available in future from the surveys.[22]

Software price indices

In the US, each of the three types of software has a different price index (Parker and Grimm 2000). In the case of prepackaged software, an index using hedonic techniques exists. For own account software, there is no hedonic index and the growth of the price index for this component is linked to the growth of wages of computer programmers. This means that the price index is assuming zero productivity growth amongst programmers. For the remaining component, custom software, the BLS uses a weighted average of the prepackaged (25%) and own account (75%) indices. Nominal investment in each type of software is deflated by its own price index and then summed to get real software investment. The overall price index is derived as an implicit deflator: total nominal divided by total real investment.

The packaged software index falls steeply throughout our period, though not as rapidly as the computer price index. Expenditure on prepackaged software is a rising proportion of the total. Consequently, the official US software price index shows a

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[20] However, quoted companies have an additional, opposite incentive since they may wish to maximise earnings per share. The more spending that can be classified as capital, the higher are earnings per share.

[21] I am grateful to Ruth Steedman of Arthur Andersen for advice on the tax treatment of software, though she is not responsible for my conclusions.

[22] Estimates of the effect on GDP growth are presented in Oulton (2000a), assuming either that 100% of the missing software was misclassified as intermediate consumption or that 100% was misclassified as other types of investment.

hump-shaped pattern over our period. The assumption of zero productivity growth amongst computer programmers employed to write own account software is extremely implausible. This assumption heavily influences the path of the custom software price index too. We have no direct evidence but it seems more likely that the productivity of those writing own account or custom software has risen at about the same rate as of those writing prepackaged software.

Accordingly, we employ two alternative price indices for software: “low” and “high”. The low variant is the official US price index for software (again adjusted for the dollar-pound exchange rate), while the high variant is the US prepackaged software price index. That is, for the high variant we assume it is appropriate to deflate all of software investment by the price index for one component of software.

There is no PPI for software in the UK. Expenditure on software is deflated (at the industry level) by the same deflator as is used for all investment in machinery, equipment and software. Table B.1 of Annex B compares this deflator with the official US price index.

Telecommunications equipment

Our nominal series is consistent with the ONS estimates and is derived again from the input-output balances. It is deflated by the BEA’s price index for telecommunications equipment (adjusted for the exchange rate). The latter has been criticised by some US researchers (e.g. Jorgenson and Stiroh 2000) as likely to understate quality improvement and so overstate price growth. The reason is that it only uses hedonic techniques for some of its components (e.g. electronic switches), but not for others (e.g. fibre optic cables) where there have been huge quality improvements in recent years.

The corresponding UK PPI (ONS code PQGT) is included by the ONS in the industry-level deflators for machinery, equipment and software. Table B.1 of Annex B compares this deflator with the corresponding US price index.

ICT capital stocks and depreciation

Estimates of the stocks of computers, software and telecommunications equipment are generated from equation (8). As mentioned above, the depreciation rates for computers and software are 31.5% p.a. These rates are high and certainly influence the results substantially, by increasing the weight of these fast-growing assets in the aggregate capital stock. So some discussion seems necessary.

Expositions of the neo-classical approach to capital measurement (e.g. Hulten and Wyckoff 1996) often seem to imply that capital deteriorates physically. Since this is plainly not the case for computers and software (at least not to a significant extent), how can we justify such high rates of depreciation? Though there is no physical deterioration, computers have a very short life in the business sector and software is frequently upgraded.[23] The theoretical point here is that physical deterioration is only one possibility. Anything which causes the *profitability* of capital equipment to decline will do just as well. Two possible causes of declining profitability have been identified:

1. If capital is used in fixed proportions with labour (a putty-clay world), rising wages will cause older equipment to be discarded even if it is physically unchanged. As equipment ages, its profitability declines and it is discarded when profitability reaches zero. Ex post fixed proportions seem quite realistic for computers, where the rule is one worker, one PC. Suppose to the contrary that computer capital were malleable ex post. Then if the optimal proportion were one worker, one PC with the latest machine, it would be one worker, two older PCs, if older ones have half the power of newer ones, and so on. This is contrary to observation. Oulton (1995) shows that, in a putty-clay world, growth accounting can still be consistently done with a capital stock where assets are weighted by their profitability. Depreciation will not be geometric (since assets have a finite life) but geometric depreciation could still be a good approximation.
2. As capital ages, it may require higher and higher maintenance expenditure. This is particularly the case for computers and software, provided we understand

[23] Unlike in the case of cars, which also have a short life in the business sector, the market for second hand PCs does not appear to be very extensive. The market for second hand software seems to be even more limited.

maintenance in an extended sense to include maintenance of interoperability with newer machines and software. Whelan (2000) has analysed the optimal retirement decision in such a world (although he assumes malleable capital). He finds that depreciation is not geometric in his model, but the contribution of computer capital is even larger than if computers are assumed to depreciate geometrically.

Converting investment to final output

For the output side of the growth accounting equation (6), investment in ICT needs to be converted to final output of ICT. We obtain ICT exports and imports of computers, software and telecommunications equipment from the input-output balances for the years 1992-98. These ICT exports and imports are deflated by the same US deflators as are used for investment. In the absence of better information, the non-ICT exports and imports are deflated by the ONS implicit deflators for total exports and imports. Prior to 1992, exports and imports are assumed to stand in the same ratio to investment as they did in 1992. See Annex B for these ratios.[24]

Semiconductors

We identify semiconductors as "Electronic valves and tubes and other electronic components" (sub-class 32.1 of SIC92), which is row 73 of the IO balances; these are unfortunately only available from 1992 to 1998. We deflate both exports and imports by an unpublished price index for semiconductors developed at the Fed and used by Oliner and Sichel (2000).[25] Between 1992 and 1998 this price index, derived entirely from a matched models approach, fell at 39% pa. The volume of exports is consequently estimated to have grown at a remarkable 49.7% pa and that of imports at 49.3% pa over the same period. The trade balance was negative in 5 out of the 7 years.

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[24] In the case of software, we only gross up the official level, not the new, corrected level. That is, to obtain our estimate of final output of software, we first gross up the official level of software investment by the final output/investment ratio. Then we add to this twice the official level of software investment.

[25] I am grateful to Steve Oliner of the Board of Governors of the Federal Reserve for kindly supplying this index.

6. *The contribution of ICT*

Our ICT estimates cannot be carried back as far as our baseline ones, and the investment series stop at the moment with 1998, so in this section results are presented for the period 1979-98. Tables containing the underlying data for the results to be discussed below will be found in Annex D, Tables D.4–D.11.

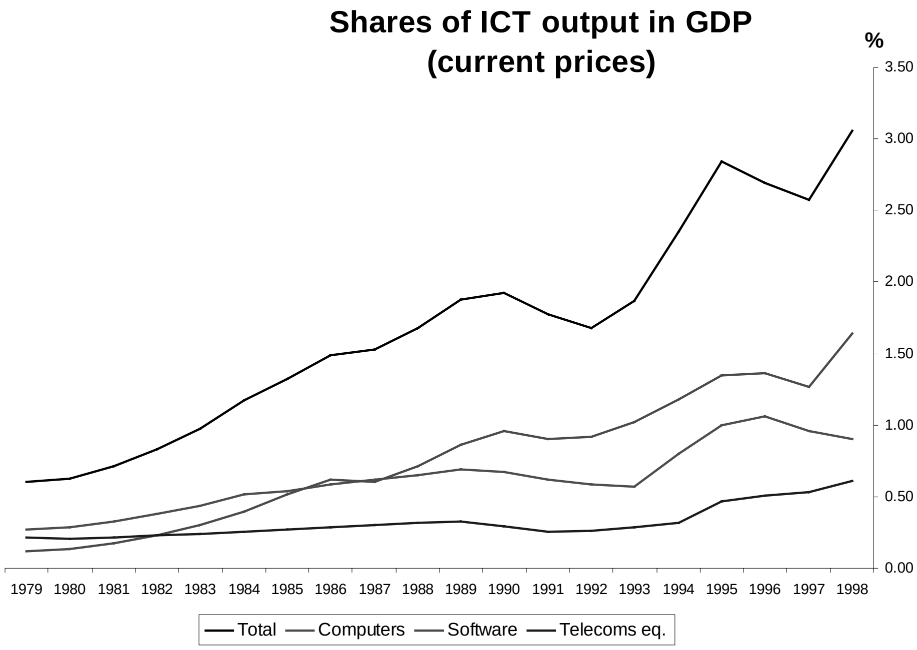
The ICT adjustment to GDP growth

The share of ICT output in GDP in current prices was 0.6% in 1979 but has risen fairly steadily since then and by 1998 had reached 3.1% of GDP. 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% 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 chart. It was in fact very small, averaging –0.1% over 1992-98.[26]

Chart 7 shows the dramatic contrast between the growth rates of ICT output and of everything else, labelled non-ICT output (currently, 97% of GDP). ICT output has grown much more rapidly and its growth has been far more volatile. It was severely affected by both the 1980-81 and the 1991-92 recessions. Chart 7 also shows that ICT was growing just as rapidly in the 1980s as in the 1990s.

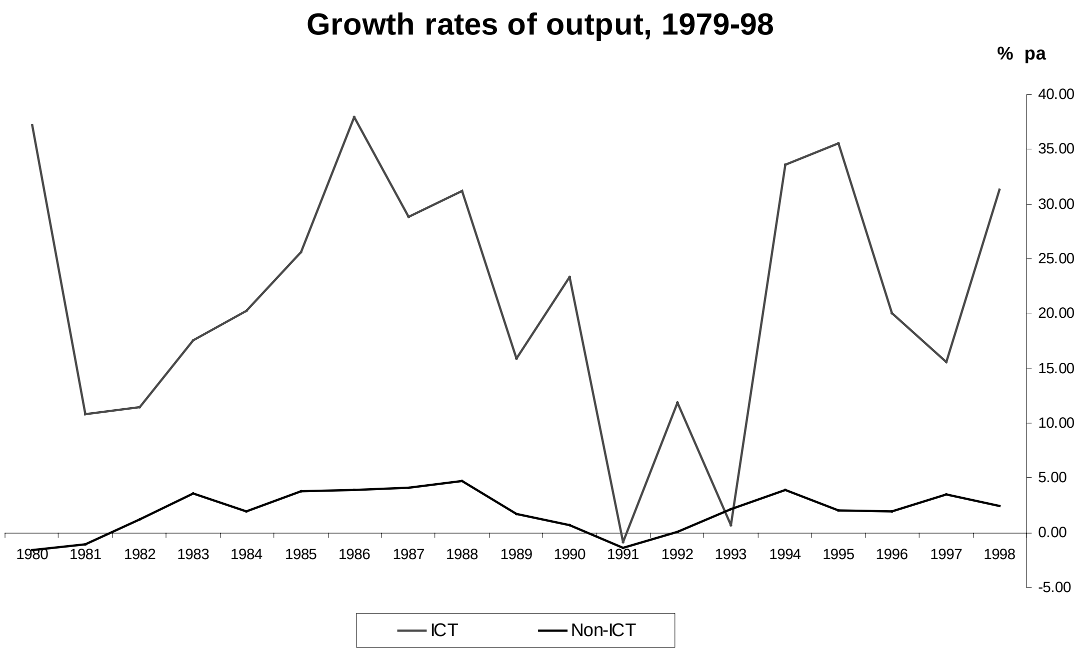
[26] In computers, consumption accounted for between 11 and 19% of final output over 1992-98. In telecommunications equipment this proportion ranged from 2-7%. In computer services it was zero, as a result of the definition of this industry. See Appendix B, Table B.3.

Chart 6



Source Annex D, Table D.4.
Note Semiconductors included in total from 1992 onwards but not shown separately.

Chart 7



Source Annex D, Table D.6.

The effect of incorporating such a rapidly growing component as ICT in a chain-weighted estimate of GDP growth is substantial, even though its weight is still quite small even in 1998. Table 4 shows four different estimates of GDP growth. The first two columns show the two estimates which make explicit allowance for ICT. Recall that the low and high software variants differ just by the price index used to deflate software (see above, section 4). The third column is our baseline estimate. This is chain-linked but makes no explicit allowance for ICT; in effect it accepts the ONS treatment of ICT, including the use of UK deflators. The last column shows one of the official estimates, GDP growth at 1995 market prices. This is not annually chain-linked but the weights are periodically adjusted, nowadays at five year intervals.

Table 4
Alternative measures of GDP growth, by period

	GDP (chain-linked, ***low*** *software variant)*	*GDP (chain-linked,* ***high*** *software variant)*	*GDP (chain-linked, no ICT adjustment)*	*GDP (at 1995 market prices [ABMI])*
Period	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1979-89	2.47	2.52	2.31	2.37
1989-98	2.12	2.21	1.93	1.91
1989-94	1.35	1.44	1.17	1.17
1994-98	3.09	3.16	2.89	2.83

Source Annex D, Table D.5.

Annual chain-linking alone has a fairly small effect; it raises GDP growth in the last five years by only 0.06 p.p. p.a. The ICT adjustment has a substantial and growing effect. The differences between the two adjusted series and the official one are as follows:

Table 5
Effect of ICT adjustment

	Low software variant	*High software variant*
Period	*p.p. p.a.*	*p.p. p.a.*
1979-89	+0.10	+0.15
1989-98	+0.21	+0.30
1989-94	+0.18	+0.27
1994-98	+0.26	+0.33

Source Table 4.

The contributions of computers and software are roughly equal, while that of telecommunications is small. A substantial part of the effect is due to the software levels adjustment (see Oulton (2000a) for more detail on this).[27]

The ICT contribution to aggregate output

A 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 6 for the high software variant; results are similar for the low one. Recall that the contribution of ICT to GDP growth is the share of final output of ICT in GDP multiplied by the growth rate of ICT output. Table 6 shows that despite its small share in GDP, ICT accounted for 13% of output growth in 1979-89 and 21% in 1989-99. In absolute terms, the ICT contribution is clearly on a rising trend. Over 1994-98, 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 (see chart 7) — but rather to the steadily rising share ICT share (chart 6).

Because of the phenomenal rate at which their prices are falling, semiconductors have the potential to make a major contribution to output growth. In fact, from 1994 to

[27] Davies *et al.* (2000) report much higher figures. They estimate that adopting US price indices raises the growth rate of business sector GDP by 0.53 p.p. p.a. over 1996-99; this despite the fact that they do not make the “times 3” adjustment to software investment.

1998, exports of semiconductors grew at an extraordinary 41.8% 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% p.a., which reduced GDP growth by 0.49 p.p. p.a. So the net effect of semiconductors was to reduce GDP growth by 0.11 p.p. p.a.

Table 6
Contributions of ICT and non-ICT output to GDP growth: annual averages (high software variant)

	Non-ICT		*ICT*		*Growth of GDP*
	Contrib-ution	*Prop-ortion of GDP growth*	*Contrib-ution*	*Prop-ortion of GDP growth*	
Period	*p.p. p.a.*	*%*	*p.p. p.a.*	*%*	*% 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
1994-98	2.59	81.8	0.57	18.2	3.16

Source Annex D, Table D.6.
Note See Table D.6 for the low software variant.

The ICT contribution to aggregate input

The contribution of ICT capital to the growth rate of the aggregate capital stock is the share of aggregate profits attributable to ICT capital multiplied by the growth rate of ICT capital. Chart 8 shows the ICT profit share. In 1998 it was 15%. It has tripled since 1979. Since the overall profit share has not changed very much, chart 8 also tracks the share of profits due to ICT in GDP; this share now stands at about 3%, very similar to the output share in GDP. Chart 9 shows the growth rates of ICT and non-ICT capital services. ICT growth is much higher and considerably more volatile. Chart 10 shows the effect of incorporating these adjustments into the aggregate capital stock. The ICT-adjusted estimates have a similar profile but lie uniformly above the baseline estimate. The adjustment clearly has a substantial effect on the aggregate growth rate. As Table 7 shows, ICT capital (high software variant) was growing at 21.49% p.a. over 1989-98 while non-ICT capital grew at only 2.34% p.a. The result was that, compared to the baseline estimate of 3.13 % p.a., the high software variant of aggregate capital services grew at the substantially faster rate of 4.76% over the same period.[28]

Table 7
Growth of capital services: ICT, non-ICT and total

	Non-ICT	*ICT (low software)*	*ICT (high software)*	*Aggregate capital services (low software)*	*Aggregate capital services (high software)*	*Aggregate capital services (baseline)*
Period	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% 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
1994-98	2.01	19.11	22.01	4.65	5.08	3.14

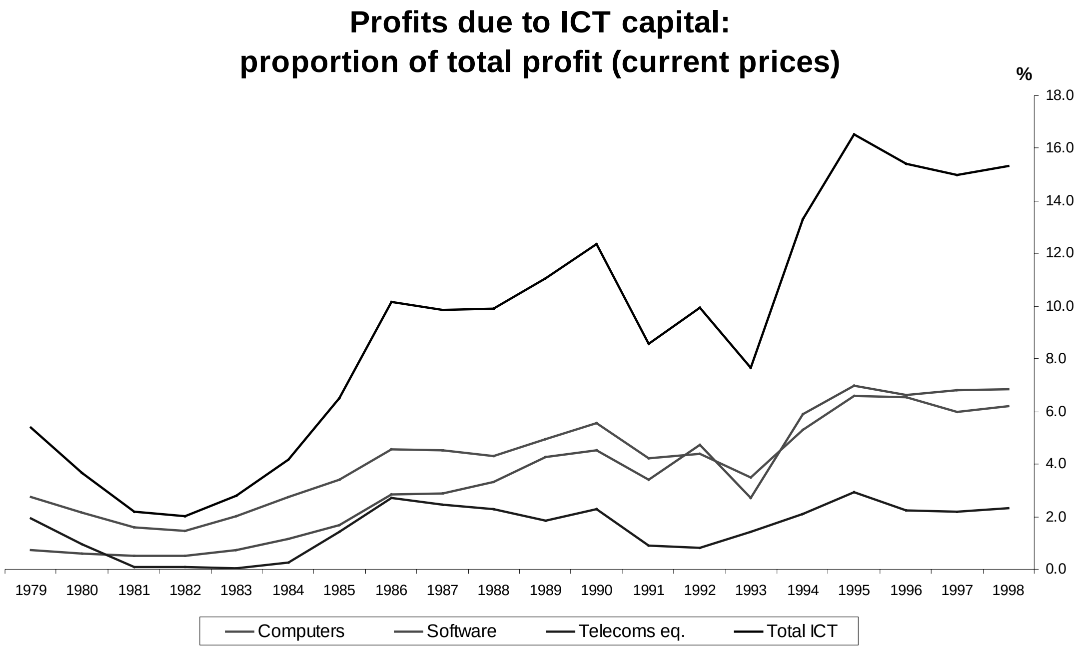
Source Annex D, Table D.7.
Note Dwellings excluded from all these series.

It is also interesting to compare the effect of weighting by rental prices, which is theoretically preferred, to weighting by asset prices. The two series in chart 11 use identical data but different weights. As expected, the series using rental price weights grows more rapidly and the effect is very substantial: for example, it adds over 4 p.p. p.a. in 1999. We noted above that the share of ICT capital in aggregate profits had

[28] Kneller and Young (2000) estimate the contribution of computers only to the growth of aggregate input as 0.10-0.13 p.p. p.a. over 1991-95 and 0.25-0.27 p.p. p.a. over 1996-97. Their figure derives from multiplying the share of profits generated by computers in GDP by the growth rate of the computer stock. This estimate is roughly consistent with Table 7 and results below in Tables 9 and 10.

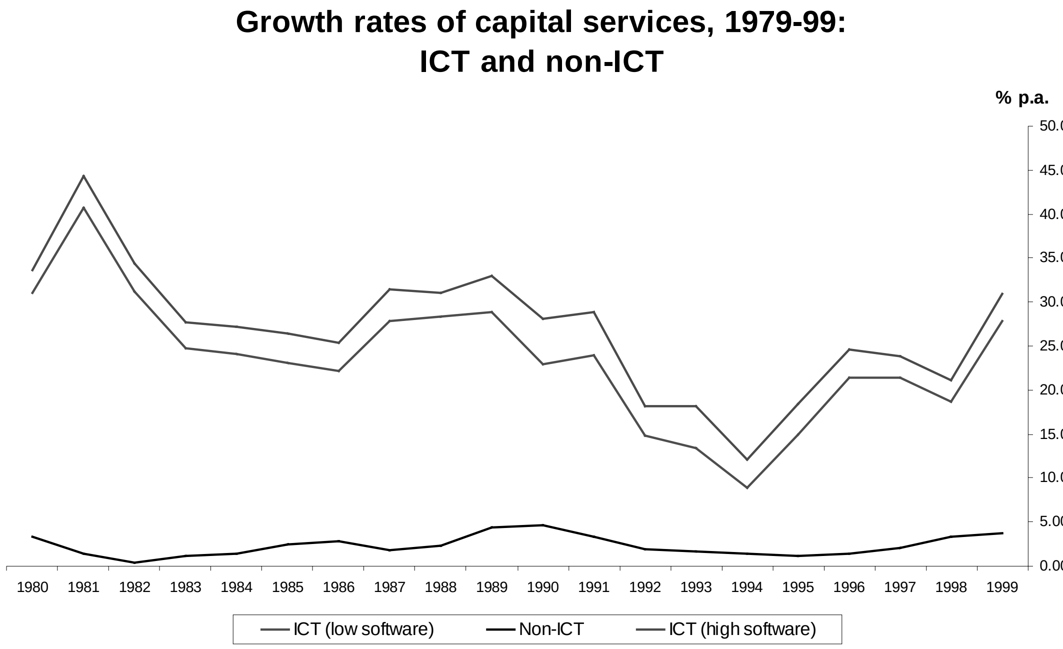
reached 15% by 1998. By contrast, the share of ICT capital in the nominal value of the aggregate (non-dwellings) capital stock was only 5% in that year.

Chart 8



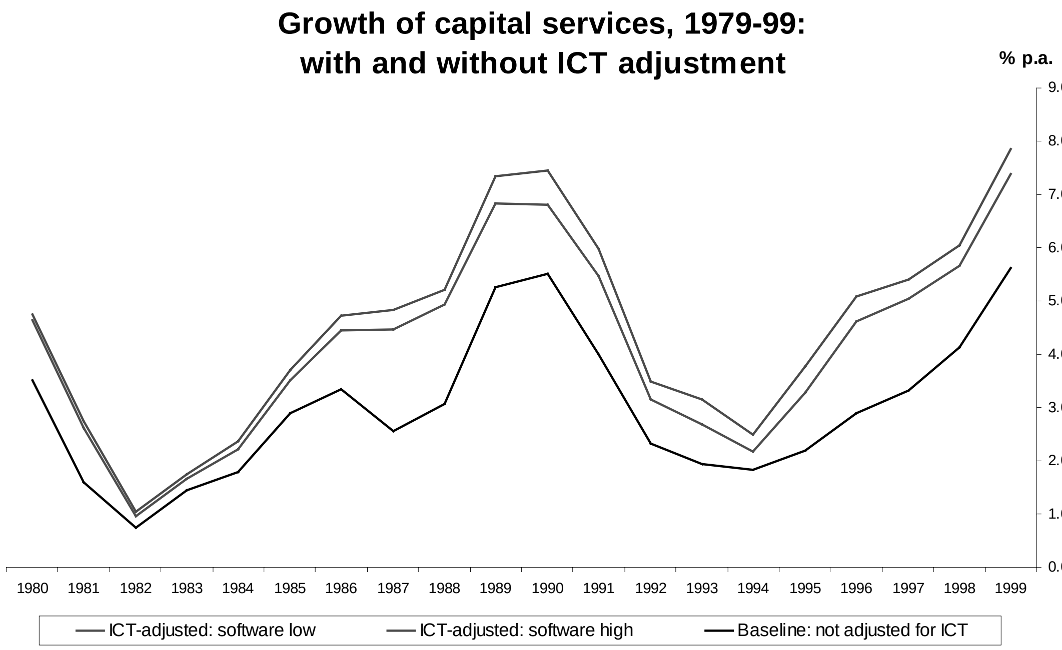
Source Annex D, Table D.8.

Chart 9



Source Annex D, Table D.9.

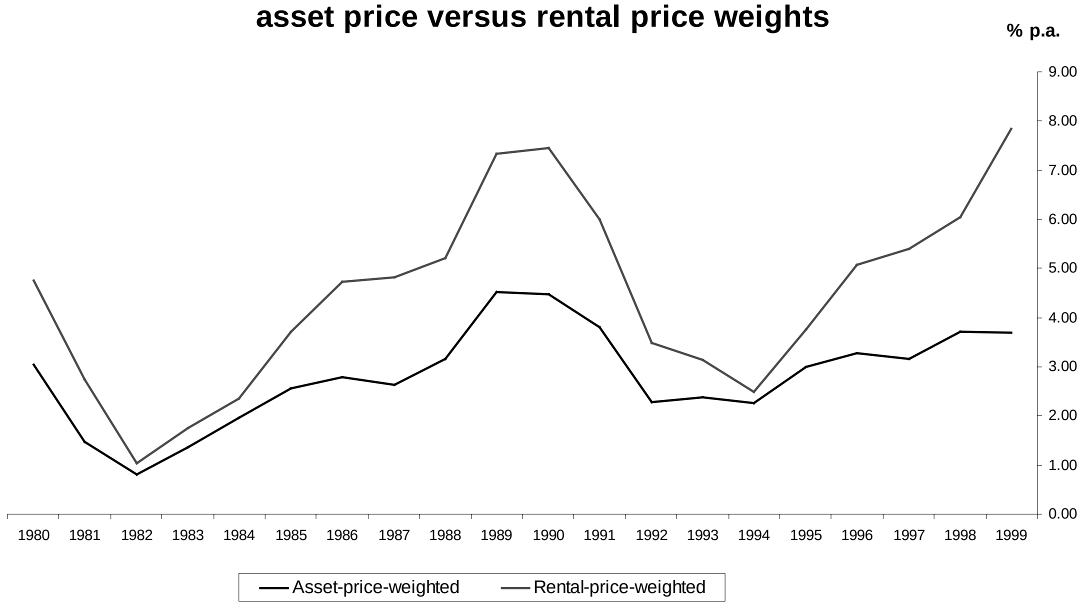
Chart 10



Source Annex D, Table D.9.

Chart 11

Growth rate of capital services, 1979-99: asset price versus rental price weights



Source Annex D, Table D.9.

ICT and TFP growth

The ICT adjustments change the growth rates of output and of the capital stock. Therefore they also change the growth rate of TFP. As we have seen, the output and capital stock effects are both positive but it turns out that they are of fairly similar size. Hence the impact on TFP growth relative to our baseline estimate, though negative, is also fairly small (Table 8). On the high software variant and on an hours basis, the ICT adjustment reduces TFP growth by 0.08 p.p. p.a. over 1989-98 relative to the baseline estimate. As chart 12 shows, the profile of these two estimates is very similar.

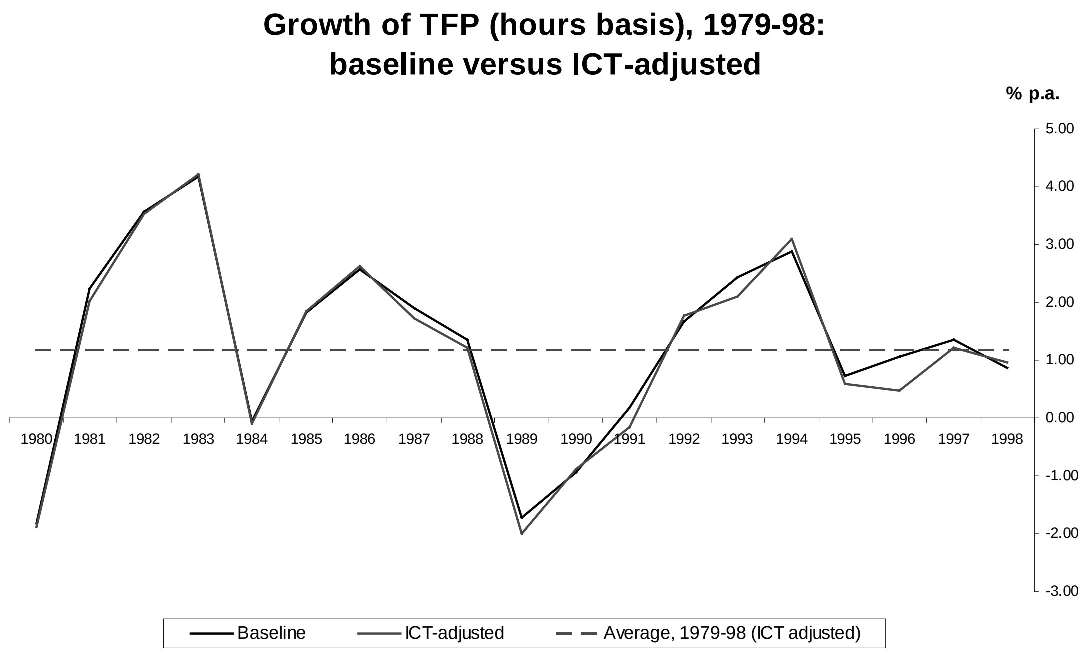
We can also note that the new estimate of TFP growth has been below its 1979-98 average from 1995 onwards.

Table 8
Growth of TFP: comparison of estimates

	Heads		*Hours*	
	Baseline	*High software*	*Baseline*	*High software*
Period	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1979-89	1.07	0.99	1.40	1.32
1989-98	0.99	0.91	1.13	1.05
1989-94	0.91	0.89	1.24	1.22
1994-98	1.09	0.93	1.00	0.83

Source Annex D, Table D.11.

Chart 12



Source Annex D, Table D.11.

Labour productivity growth: the contributions of ICT and non-ICT capital and of TFP

We are now in a position to assess the contribution of ICT to capital deepening and so to see how much of the growth of labour productivity growth it can account for, based on equation (12). Table 9 shows the absolute amounts contributed by capital deepening and TFP to the growth of labour productivity on an hours basis. Table 10 shows these expressed as proportions of labour productivity growth. Because the picture for the low and high software variants is very similar, we concentrate on the latter. The results are also similar for labour productivity on a heads basis.

It is a remarkable fact that since as early as 1979 ICT has contributed the majority of capital deepening: 51% in 1979-89[29] and 56% in 1989-98. It is true that its contribution slipped back in 1989-94, which includes the recession years, to only 40%. But in the latest period, 1994-98, it contributed no less than 88% of the total. Overall, the contribution of capital deepening (excluding dwellings) to labour productivity growth has been rising. It accounted for 34% of productivity growth in 1979-89 and 44% in 1989-98.[30] Within overall capital deepening, the part contributed by ICT has risen; it accounted for 16% of labour productivity growth in 1979-89, 23% in 1989-98 and no less than 39% in 1994-98.

Does the ICT adjustment alter the received picture of a slowdown in labour productivity growth from 1995 onwards? The answer is no. Chart 13 shows that over these last four years labour productivity has been growing at below its average rate since 1979 (as has TFP: recall chart 12).

The contribution of TFP has been shrinking in both proportional and absolute terms, comparing the 1980s with the 1990s. How do these results compare with the conventional view of the importance of TFP? The latter is obtained by expressing TFP growth as a proportion of output growth. For the OECD countries since the first oil shock, and even for the East Asian "tigers", the result is generally a small number (Oulton 1997). In Tables 9 and 10, however, we are dividing TFP growth by the growth of output per hour. This will necessarily produce a larger number if labour input growth is positive, as was the case form 1994-98 though not from 1989-94. In

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[29] That is, 100*[0.40/(0.40+0.39)].

[30] The capital deepening estimates are somewhat different from those in Davies *et al.* (2000) who use apparently similar methods. They estimate the contribution of capital deepening as rising from 0.37 p.p. p.a. over 1990-95 to 0.84 p.p. p.a. over 1996-99. These may be compared with Table 9's figures of 0.39 p.p. p.a. and 0.62 p.p. p.a. for roughly similar periods. The difference may be due partly to the fact that their figures refer to the business sector, not the whole economy as here, and partly to their use of PPPs to convert US prices to sterling terms, rather than exchange rates. Note though that their

addition, Hulten (1979) has argued that part of what is accounted capital accumulation is really induced by TFP growth and so should be ascribed to the latter. He would prefer to measure the contribution of TFP by TFP growth divided by the share of labour, expressed as a ratio to the growth of output per hour. His argument assumes an exogenous (Solow) growth model where the balanced growth path is one along which both output per hour and capital per hour grow at the TFP growth rate divided by the labour share. Adopting Hulten's approach would raise the contribution of TFP to labour productivity growth in the 1990s from 47.2% (high software) to 68.3%.

Also apparent from chart 13 is how closely the growth rates of TFP and of output per hour move together. To what extent this is due to failure to measure correctly varying degrees of factor utilisation, or to inadequacies of the labour input measure, remains a subject for future research.

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estimate of the contributions from software are much smaller than ours since they do not make the "times 3" adjustment.

Table 9
Contributions of capital deepening and TFP to growth of output per hour, 1979-98, by period: absolute amounts

		Capital deepening			
	Growth of output per hour	*ICT*	*Non-ICT*	*Dwellings*	*TFP*
Period	*% p.a.*	*p.p. p.a.*	*p.p. p.a.*	*p.p. p.a.*	*p.p. p.a.*
Low software					
1979-89	2.20	0.35	0.39	0.13	1.32
1989-98	2.13	0.49	0.45	0.14	1.06
1989-94	2.57	0.39	0.72	0.24	1.23
1994-98	1.58	0.62	0.10	0.01	0.85
High software					
1979-89	2.25	0.40	0.39	0.13	1.32
1989-98	2.22	0.59	0.45	0.14	1.05
1989-94	2.66	0.49	0.72	0.24	1.22
1994-98	1.66	0.72	0.10	0.01	0.83

Source Annex D, Table D.10.
Note High software variant. Calculated in accordance with equation (12).

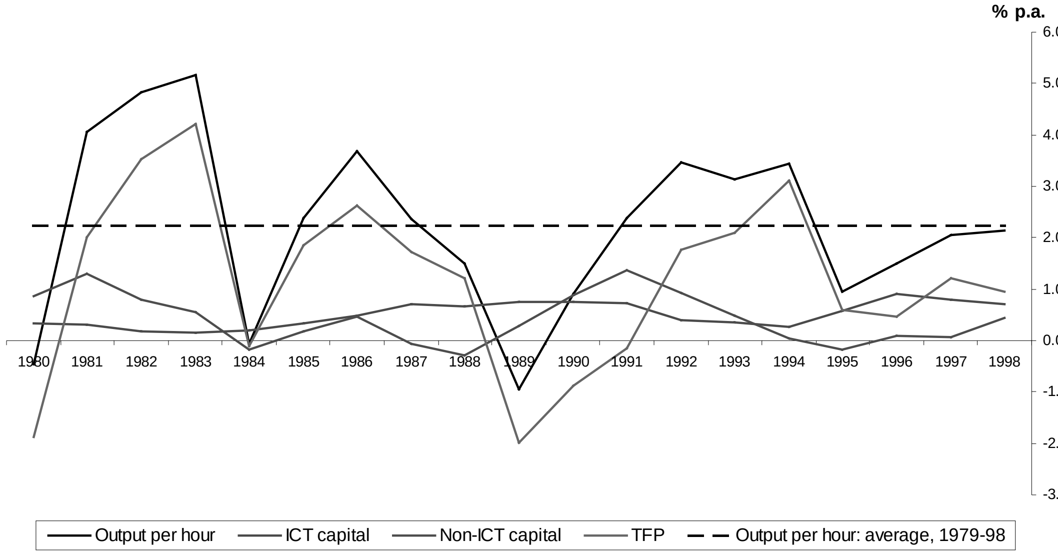
Table 10
Contributions of capital deepening and TFP to growth of output per hour, 1979-98, by period: proportions

		Capital deepening			
	Growth of output per hour	*ICT*	*Non-ICT*	*Dwellings*	*TFP*
Period	*% p.a.*	*%*	*%*	*%*	*%*
Low software					
1979-89	2.20	16.1	17.7	6.0	60.2
1989-98	2.13	23.0	20.9	6.4	49.7
1989-94	2.57	15.0	28.1	9.2	47.6
1994-98	1.58	39.4	6.3	0.5	53.8
High software					
1979-89	2.25	18.0	17.3	5.8	58.9
1989-98	2.22	26.6	20.1	6.1	47.2
1989-94	2.66	18.2	27.1	8.9	45.7
1994-98	1.66	43.4	6.0	0.5	50.1

Source Annex D, Table D.10.
Note High software variant. Calculated in accordance with equation (12).

Chart 13

Labour productivity growth (hours): contributions of ICT, non-ICT and TFP



Source Annex D, Table D.10.

Why has the ICT effect in the UK not been as large as in the US?

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 don't we observe anything comparable in the UK? Table 11 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. Table 12, derived from 11, focuses on the acceleration or deceleration which occurred in both countries between the first and second halves of the 1990s. In this comparison, we use the low software variant for the UK since Oliner and Sichel employ the official BEA deflator for software. The time periods in the two studies are not identical but probably close enough for the present purpose.

The first thing to note is that labour productivity growth was actually substantially higher in the UK up to 1994/95. This is not too surprising since the UK's productivity level has always been considerably lower (O'Mahony 1999). Both countries saw an improvement in the first half of the 1990s. But then 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 65% of the US one. The lower half of table 11 shows that the 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% in the UK compared with 6.3% in the US. The second half of the 1990s saw an acceleration of the growth of computer and telecommunications capital in both countries, though software capital decelerated in the UK (table 12).

Part of the UK productivity slowdown can be ascribed to a falling contribution from other capital (a fall of 0.85 p.p. p.a.). There was no parallel to this in the US, where other capital makes a minor contribution throughout the 1990s. But the most surprising feature of Tables 11 and 12 is that TFP growth fell in the UK by 0.38 p.p. p.a. while it rose by 0.57 p.p. p.a. in the US.[31] Up till 1994/95, 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. The sales to GDP ratio rose too in both industries thus giving a double boost to aggregate TFP growth. But they also find that TFP growth accelerated in the rest of the non-farm business sector (Oliner and Sichel (2000), Tables 4 and 5). 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 US. This makes the UK slowdown in aggregate TFP growth even more mysterious.

A possible explanation is that the realised rate of return on ICT investment has been lower than that on other assets, contrary to the assumption embodied in our method (see section 2). The result would be that we have overestimated the contribution of

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[31] We are not quite comparing like with like here since our UK TFP estimate includes the effects of changes in labour quality. The latter is estimated separately by Oliner and Sichel and shows a small deceleration in the second half of the 1990s, from 0.44 to 0.31 p.p. p.a. For comparative purposes we aggregate TFP and labour quality growth for the US.

ICT capital, and in fact of capital in general, through giving too large a weight to the fastest growing part of the capital stock. This would mean that we have underestimated TFP growth. Note that the contrary is frequently argued: the contribution of ICT is larger than allowed for by growth accounting (it is claimed) since network externalities generated by ICT investment are (wrongly) swept up in TFP. Alternatively, ICT investment may have occurred large adjustment costs which our method does not allow for (Kiley 1999), in which case we would expect a revival of measured TFP growth to occur in due course.

Table 11
Productivity and the contribution of ICT: a US-UK comparison

	US			*UK*		
	1974-90	*1990-95*	*1995-99*	*1979-89*	*1989-94*	*1994-98*
Growth of output per hour (% p.a.)	1.37	1.53	2.57	2.20	2.57	1.58
Growth of output (% p.a.)	3.06	2.75	4.82	2.47	1.35	3.09
Contributions from (p.p. p.a.):						
ICT capital	0.44	0.51	0.96	0.35	0.39	0.62
Other capital	0.37	0.11	0.14	0.52	0.96	0.11
TFP plus labour quality	0.55	0.92	1.47	1.32	1.23	0.85
Memorandum items						
Income shares (% of GDP):						
ICT	3.3	5.3	6.3	1.4	2.2	3.6
of which:						
Computers	1.0	1.4	1.8	0.7	1.0	1.4
Software	0.8	2.0	2.5	0.4	0.9	1.6
Telecommunications eq.	1.5	1.9	2.0	0.3	0.3	0.6
Growth rates of inputs (% p.a.)						
Computers	31.3	17.5	35.9	34.4	18.6	28.4
Software	13.2	13.1	13.0	25.2	17.8	12.6
Telecommunications eq.	7.7	3.6	7.2	11.1	8.7	13.5

Note US figures relate to the non-farm business sector, UK ones to the whole economy (low software variant). For the UK, other capital includes dwellings. Income shares are profits attributable to each asset as a proportion of GDP.
Source US: Oliner and Sichel (2000), Tables 1 and 2. UK: Tables 4 and 9 and Annex D, Tables D.2, D.7, D.8 and D.10.

Table 12
Productivity acceleration/deceleration in the second half of the 1990s: the US and UK compared

	US	*UK*
	1995-99 over 1990-95	*1994-98 over 1989-94*
Growth of output per hour (% p.a.)	+1.04	-0.99
Growth of output (% p.a.)	+2.07	+1.74
Contributions from (p.p. p.a.):		
ICT capital	+0.45	+0.23
Other capital	+0.03	-0.85
TFP plus labour quality	+0.55	-0.38
Memorandum items		
ICT income share (% of GDP)	+1.00	+1.40
Growth rates of inputs (% p.a.)		
Computers	+18.40	+9.80
Software	+0.30	-5.20
Telecommunications eq.	+3.60	+4.80

Source Table 11.

7. 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. 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% and the volume growth is 20% 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% pa. Then the share in GDP is falling too and in the next period will be less than 3% (in fact, about 2.7%). So even if prices continue to fall at 30% and volumes to rise at 20%, 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 (provided the growth rate is bounded from above), the contribution of ICT capital to aggregate input will go to zero if the ICT share of profits is going to zero. Assuming constancy of the other elements, the share will decline if the asset price is falling more rapidly than the quantity is rising.

It seems quite a plausible pattern for some (though not necessarily all products) 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.

More technically, the crucial concept is the elasticity of substitution between ICT capital and other inputs. It is this which determines whether the share of output generated by ICT capital (the ICT share of total cost) is rising or falling and hence whether, for a given growth rate of ICT capital, the contribution to aggregate input is rising or falling. On the input side, the crucial share is (using the notation of section 2):

$$\frac{p_{ICT}^{K} K_{ICT}}{pY} \qquad (14)$$

where p is the price of output (GDP deflator). On the output side, the crucial share is

$$\frac{p_{ICT}^{I} I_{ICT}}{pY} = \left(\frac{p_{ICT}^{I}}{p_{ICT}^{K}}\right)\left(\frac{I_{ICT}}{K_{ICT}}\right)\left(\frac{p_{ICT}^{K} K_{ICT}}{pY}\right) \tag{15}$$

(Recall that p_{ICT}^{K} is the rental price and p_{ICT}^{I} is the asset price of ICT capital). Equation (15) shows that, in a steady state, these two shares will stand in constant ratio to each other. Whether they rise or fall will be determined by the elasticity of substitution.[32]

This elasticity has apparently been greater than one up to now. In theory there is no reason to expect it to be constant. However, with the cost functions generally used in empirical work, there is some danger that a possible future fall to a value below one will be ruled out by assumption. With a Cobb-Douglas cost function, the own price elasticity of an input is of course equal to one. With a translog cost function, demand is either elastic at all prices or inelastic at all prices (because the share of an input in total cost is linear in the log of prices). Both these cost functions are consistent with economic theory. It seems hard to find a cost function which is (a) consistent with economic theory and (b) allows demand to be elastic at high prices and inelastic as sufficiently low ones. Still, this should not prevent consideration of just such a hypothesis.[33]

This argument shows that the impact of ICT on growth and productivity could decline even if TFP growth in semiconductors continues to be rapid. But in addition, there may be knock on effects in the semiconductor industry. In reality, the falling prices of semiconductors may be driven by R&D in that industry (i.e. by a form of investment) and not by TFP growth. So if consumers are less willing to pay for greater speed and larger memory, R&D budgets will be cut back and the rate of innovation will fall. Alternatively, the research may be being done in government-financed university laboratories, whose results are distributed free to the semiconductor industry, so that it shows up as TFP there. But with falling consumer interest, a redirection of

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[32] If we hold the prices of all other inputs constant, we can aggregate them into a single input, say *X*. Then the elasticity of substitution is defined as $-d\ln(K_{ICT}/X)/d\ln(p_{ICT}^{K}/p_{X})$.

[33] Marshall (1920, chapter IV) suggested in the case of consumer demand that demand would be elastic at high prices and inelastic at low ones. He also argued that demand would be elastic for products with multiple uses. His example was water but the same point might apply to computers.

government research funding might be expected eventually. So either way the rate of progress could slow down, even in the absence of any physical limits to the continued holding of Moore's Law.

So far it has been argued that the elasticity of substitution between ICT and other inputs is the crucial factor. An alternative force which could maintain or continue to raise the share of ICT in total cost is technical progress which is biased towards ICT. In less economic language, the nub of the matter may be whether new uses will be found for ICT. If computers and the associated software and networks just continue to perform the same functions as they do today, then it seems likely that demand for them will become less elastic. The ability to send an email more rapidly or to do a find and replace operation in a document more speedily would not command much of a price premium.

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 (Table 11), the share is still only about two thirds of the US level.

8. Conclusions

The main conclusions are:

- 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 0.27 and 0.33 p.p. p.a. to the growth rate.

- The share of ICT output in GDP has been rising fairly steadily but still only reached 3% 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 the greater part of the growth of the capital stock has been accounted for by the growth of ICT capital. Since 1989, 56% of capital deepening (the growth of aggregate capital services per hour worked) has been contributed by ICT capital. From 1994 to 1998, ICT capital accounted for a remarkable 88% 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 accounted for 23% of the growth of output per hour in 1989-98 and 39% in 1994-98.
- 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 which emerges 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.[34] ICT has made its impact through investment and capital accumulation, and not through TFP, contrary to the picture presented in Brookes and Wahhaj (2001). But by contrast with the US, there has been no upsurge of TFP growth, but rather a slowdown. Since the ICT share in GDP in the UK, though rising, is still only two thirds that in the US, we may expect the contribution of ICT capital to economic growth to continue to increase.

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[34] This is consistent with some of the micro evidence, e.g. the study by Abernathy *et al.* (1999) of "lean retailing" and the US clothing industry. For example, bar codes were adopted in the 1970s mainly because they increased the productivity of workers at supermarket checkouts. But they later proved to be an indispensable tool of information management (for ordering, tracking progress of deliveries, and inventory management), in conjunction with subsequent investment in ICT.

Important topics for future research remain. In order to understand better the slowdown in TFP growth it is necessary to:

- improve the measure of labour input, by adjusting hours worked for skills and experience
- 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 creates productivity growth at the whole economy level is an important task.

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ANNEX A

SOURCES AND METHODS FOR THE BASELINE ESTIMATES

This Annex describes the sources and methods used to construct our baseline estimates, i.e. those which make no special allowance for ICT. The actual results, which are annual and cover the period 1950-99, appear in Annex D. There, Table D.1 shows the growth rates of output and inputs, Table D.2 shows the contributions of capital and labour and of TFP to output growth, and Table D.3 shows the input shares.

Output

The baseline Törnqvist index of output growth was constructed from the following components of final expenditure.

Final expenditure category	*ONS codes (current prices, 1995 prices)*
Consumption	
1. Households and NPISH	NSSG, ABPF+ABNO
2. Central and local government	NMBJ+NMMT, NSZK+NSZL
Investment	
3. New dwellings, excluding land	DFDK, DFDV
4. Other buildings and structures	DLWS, EQDP
5. Transport equipment	DLWZ, DLWJ
6. Other machinery and equipment and cultivated assets	DLXI, DLWM
7. Intangible fixed assets	DLXP, EQDT
8. Costs associated with the transfer of ownership of non-produced assets	DFBH, DFDW
9. Changes in inventories	ABMP, ABMQ
10. Acquisition less disposals of valuables	NPJO, NPJP
Foreign sector	
11. Exports	KTMW, KTMZ
12. Imports	KTMX, KTNB

Collectively, these 12 categories of final expenditure sum in current prices to “GDP at market prices” [YBHA], apart from the statistical discrepancy [GIXM].

A complication is that while the nominal series for each type of investment goes back to 1948, the corresponding real series only goes back to 1965 in the cases of

"Transport equipment", "Other machinery and equipment and cultivated assets" and "Intangible fixed assets" and only to 1989 in the case of "Other buildings and structures". For "Other buildings and structures" over the period 1965-88, we have used the growth in the constant price series DLWT, which is the same as EQDP except that it includes transfer costs. For the years 1948-64, we have constructed our own implicit deflators for buildings and for plant and machinery from detailed, industry-level investment data provided by the ONS. These investment series are the ones employed in the ONS's capital stock model.[35]. These implicit deflators were spliced on to the later series in 1965. We have used our plant and machinery deflator to deflate investment in intangibles over 1948-64.

The last two categories of investment, "Acquisitions less disposals of valuables" and "Changes in inventories", are small and erratic. Moreover, they are sometimes negative and the Törnqvist index requires that logs be taken. Hence we distribute expenditure on these two categories equiproportionally across the other categories. Our estimate of output growth is therefore a Törnqvist index with 10 components: two kinds of consumption (private and governmental), 6 kinds of investment, exports and imports.

The table below compares the growth rate of our index with three official measures: GDP at market prices, at basic prices and at factor cost. The growth rates are all very similar when averaged over economic cycles, though there can be larger differences for individual years.

[35] These detailed series are not fully consistent with the Blue Book investment series for years after 1947, partly because they are a somewhat earlier vintage of data and partly because reclassification to a common (SIC80) basis causes some inconsistencies. These difficulties do not affect their use to generate starting stocks.

Table A.1
GDP growth: four concepts compared, by period, 1950-99

	GDP at 1995 market prices [ABMI]	*GDP at 1995 basic prices [ABMM]*	*GDP at 1995 factor cost [YBHH]*	*GDP at 1995 market prices (10 component Törnqvist)*
Period	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1950-73	2.96	2.95	2.86	2.94
1973-79	1.46	1.26	1.40	1.54
1979-89	2.37	2.36	2.35	2.31
1989-99	1.93	2.01	2.02	1.98
1950-99	2.44	2.43	2.40	2.44

Capital stocks

We have used U.S. depreciation rates taken from Fraumeni (1997). These are for a more detailed asset breakdown than the one to be found in the Blue Book so we have chosen the most closely corresponding rates. The rates were as follows:

Table A.2
Depreciation rates

Asset	*Depreciation rate (annual)*
New dwellings, excluding land	0.012
Other buildings and structures	0.025
Transport equipment	0.250
Other machinery and equipment and cultivated assets	0.130
Intangible fixed assets	0.330
Costs associated with the transfer of ownership of non-produced assets	0.012
Changes in inventories	0.000[36]

[36] The assumption of a zero depreciation rate for inventories is taken from Jorgenson and Stiroh (2000).

There is another category of investment, "Acquisitions less disposals of valuables" [NPJO, NPJP] which is zero prior to 1986 and small thereafter. As mentioned above, this is included in our estimate of GDP growth. But it is not counted as an asset within the capital aggregate since we have no basis for estimating a starting stock.

For the fixed assets, the stock of each asset was accumulated using the Blue Book investment series from 1948 onwards (see above), employing equation (3). We therefore needed an initial stock for each asset in 1947. For "Other buildings and structures", "Other machinery and equipment and cultivated assets" and "Transport equipment", a starting stock was generated using the same detailed, industry-level data supplied by the ONS. In generating these starting stocks, the same depreciation rates were employed as were used from 1948 onwards. For dwellings, this procedure produced an initial stock substantially higher than the official estimate of the net stock of dwellings, probably because it ignored war damage. Hence for dwellings the 1947 starting stock was based on the official estimate of the net stock of dwellings [CIWZ].[37]

For "Costs associated with the transfer of ownership of non-produced assets", a starting stock was obtained by multiplying the ratio of transfer costs to investment in dwellings, averaged over 1948-50, by the dwellings stock in 1947.

For inventories, the Quarterly National Accounts gave the stock of inventories in 1995 prices at the end of 1998. The stock in each year in constant prices was then estimated by adding or subtracting the change in inventories in constant prices. The value of the stock of inventories in current prices was then generated by revaluing the constant price stock using the price index for manufacturing [PLLU] from 1963 onwards and, prior to then, the implicit deflator for GDP.

The asset price of each asset type is derived as an implicit deflator: the current price investment series divided by the constant price investment series.

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[37] More precisely, the official estimate of the net stock of dwellings in current prices in 1948 was revalued to 1995 prices using the implicit deflator for dwellings investment. The 1947 stock was then derived using equation (3).

The tax/subsidy factors T_k were kindly supplied by HM Treasury. At the moment, these are the same for all asset types, except inventories for which D_k is zero, hence in this case $T_k(t) = 1/(1-u(t))$.

Rental prices

To calculate the rental prices and hence the weights for each asset type in the capital aggregate, we consider inventories and fixed assets except for dwellings and use these to solve for the nominal rate of return (r) and hence for the rental prices p_k^K and weights w_k^K. Hence the profit total is aggregate profits ("Operating surplus, gross" [ABNF]) less what should be attributed to ownership of dwellings.

Dwellings are excluded from these calculations because of the unusual treatment of housing in the national accounts. Housing expenditure takes two forms: the actual rents paid by tenants, "Actual rentals for housing" [ADFT], and the imputed rents of owner-occupiers, "Imputed rentals for housing" [ADFU]), to use the ESA95 terms. Housing consumption is the sum of these two items. If there is expenditure, there has to be some "industry" which supplies the product. In the case of imputed rentals, households are considered to operate unincorporated businesses to which these rentals are notionally paid.[38] No labour input is associated with the supply of this service. Hence the whole of these notional payments form part of the operating surplus of the household sector (and not of mixed income). We have assumed that the actual rents paid by tenants increase the operating surplus of the other sectors by an equivalent amount. This is an overestimate since there is a labour element involved in managing rented accommodation. But the error is probably small since around two thirds of housing consumption is imputed.

Under ESA79, the two components of housing consumption were known as "Other rents" [CDDG] and "Imputed rents of owner-occupied dwellings" [CDDF] respectively. Data under the new codes do not go back before 1986. The old codes have been continued and have identical values with the new ones where they overlap. Hence we use the old codes which however do not go back before 1963. For 1948-

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[38] *National Accounts Concepts, Sources, and Methods,* paragraph 10.199-10.200.

62, we estimate housing consumption by applying the ratio of housing consumption to the official estimate of the net stock of dwellings in current prices [CIWZ], averaged over the years 1963-65, to the net stock in the earlier period.

In summary, the profit total which appears in equation (5), Π, is measured as “Operating surplus, gross” [ABNF] less housing consumption [CDDF+CDDG].

Labour

Two measures of labour input are employed. The first measure is just a headcount. We use the growth of workforce jobs [DYDA] up to 1979 and of LFS total employment [MGRZ] from 1979 onwards. LFS employment, which does not exist prior to 1979, is considered the more accurate headcount measure; it has grown more rapidly than workforce jobs since 1979. Both workforce jobs and LFS employment include the self-employed.

The second measure is an experimental measure of total weekly hours constructed by Craig Lindsay of the ONS. [This measure has been provided for research purposes only and should not be published without permission]. Total weekly hours are average weekly hours multiplied by total employed. Such a measure is already published from 1992 onwards [JBUS] and Lindsay’s series extends this back to 1974. In principle, hours are better than heads. But what we want is annual hours, not weekly hours. The two measures will show the same trend if average weekly hours cover not only those actually at work in the week in question but also those who are employed but off work for some reason, e.g. because they are on holiday, sick or on maternity leave. The present LFS-based series of total weekly hours is an average of the hours worked of all those employed whether they actually were at work or not. That is, it includes a substantial number with zero hours of work. The point is that the number of days off for holidays and other reasons has risen substantially over the last 20 years. So a measure of the growth of hours based on those actually at work will overestimate labour input. Hence Lindsay’s measure of the growth of weekly hours probably overstates the growth of annual hours for the years prior to 1992.

In later work, we hope to improve the labour input measure by breaking it down by age, sex and qualifications.

The profit share

Total profit is now called “Operating surplus, gross” [ABNF] in the Blue Book. Returns to labour are made up of “Mixed income” [HAXH], i.e. the income of the self-employed, and “Compensation of employees” [HAEA]. The profit share is calculated as the first of these items as a proportion of the sum of all three items.[39] Some of “Mixed income” should probably be classed as a return to capital: part of what a self-employed window cleaner receives is the return on the capital invested in his van and ladders. But “Mixed income” as a proportion of what is defined here as the return to labour was 8.2% in 1998, which is about the same as the proportion which the self-employed form of the labour force. This suggests that the return to capital element in “Mixed income” is small and so that we are justified in ignoring it.

As described above, the profit share is split up into two parts, one which applies to dwellings (housing consumption as a proportion of total income) and the other which applies to the remainder of the capital stock.

In this treatment, all profits are assumed to be generated by produced assets. This seems to leave no role for non-produced assets such as land and sub-soil assets. These assets can generate what are called “rents” under ESA95 (not to be confused with “rentals” which are payments for the services of produced assets). Rents are a form of property income and do not form part of output (Office for National Statistics (1998), paragraph 5.31-5.33). An alternative treatment to the one here would be to subtract aggregate rents from the aggregate operating surplus and treat these as the return on an asset, “land”, whose quantity was constant. This would make little difference in practice since rents totalled only £0.7 billion in 1999 (most accruing to the government) and so are only a small fraction of total profits.

[39] These three items plus “Taxes on production and imports” [NZGX] less “Subsidies” [AAXJ] plus “Statistical discrepancy” [GIXQ] equal “GDP at market prices” [YBHA]; all these items are in current prices.

Labour productivity

The growth of labour productivity is measured either as the growth of GDP per worker (heads basis) or as the growth of GDP per hour worked (hours basis). The two measures of labour input are discussed above.

Results

See tables D.1-D.3 of Annex D for the estimates.

ANNEX B
SOURCES AND METHODS FOR ICT

B.1 Investment and final output of ICT and non-ICT: current prices

Computers

Investment in "Office machinery and computers" (IO group 69, SIC92 sub-class 30) is from the input-output balances, 1989-98, table 6; these were carried back to earlier years using the 1974, 1979, 1989 and 1990 input-output tables. Missing years were interpolated. Investment in non-computer office machinery was stripped out by using ratios derived from *Product Sales and Trade.* Investment was converted to final output basis using ratios derived from input-output balances, tables 2 and 3, for 1992-1998 (see below).

Software

Investment in "Computer and related activity" (IO group 107, SIC92 sub-class 72) is from the input-output balances 1989-98, Table 6. For reasons explained in the text (section 4) and more fully in Annex C below, this figure is multiplied by 3. Adjustment to a final output basis was made to the original investment series (i.e. prior to multiplication by 3) using ratios derived from the input-output balances, 1992-98, Tables 2 and 3. That is, to obtain our estimate of final output of software, we first gross up the official level of software investment by the final output/investment ratio. Then we add to this twice the official level of software investment. The series was carried back using the growth rate of total billings of computer services industry, from DTI inquiry (Business Monitor SDQ 9, *Computer services: fourth quarter 1979* and CSO Bulletin, *Distributive and Services Trades (1991)*. Missing years were interpolated.

Telecommunications equipment

Investment in "Television and radio transmitters and line for telephony and line telegraphy " (IO group 74, SIC92 subclass 32.2) is from the input-output balances, 1989-98, table 6; the series was carried back to earlier years using the 1974, 1979, 1989 and 1990 input-output tables. Missing years were interpolated. Investment was converted to final output using ratios derived from the input-output balances, tables 2 and 3, for 1992-1998.

Non-ICT

Non-ICT investment, exports and imports were derived by subtracting the ICT categories from the same totals as employed in the baseline estimates.

B.2 Investment and final output: constant prices

ICT investment, exports and imports were deflated using US price indices, adjusted for exchange rate changes: see below. Non-ICT investment in plant and machinery and in intangibles were deflated using the UK implicit deflators for these categories, adjusted to exclude the UK ICT deflators. That is, for plant and machinery we constructed a price index which excluded the UK PPIs for computers and telecommunications equipment; for intangibles, we constructed a deflator which excluded the UK software deflator. Non-ICT exports and imports in current prices were deflated by the implicit deflators for exports and imports respectively.

US price indices (BEA)

US price indices, converted to sterling terms using an annual average of the $/£ exchange rate, are with one exception from the US National Income and Product Accounts (downloaded from BEA website). The “low” software variant is the official price index for software; the “high” variant is the prepackaged software component of the overall software index (from Parker and Grimm 2000).

UK price indices (ONS)

(1) computer price: PPI, product code 3302, identifier PQEK.

(2) software price: implicit deflator for investment in “Other machinery and equipment and cultivated assets” [series DLXI ÷ DLWM].

(3) telecommunications equipment price: PPI, product code 3220, identifier PQGT.

B.3 Results

The growth rates of the UK and US price indices are in Table B.1. Table B.2 shows the levels of the US price indices, adjusted for exchange rate changes, together with ICT investment in current prices.

B.4 Converting investment to final output

The accounting identity linking final output and investment is, in current prices:

Final output = Consumption + Investment + Exports – Imports

The input-output balances allow us to quantify the elements of this identity. The three relevant categories distinguished in the balances are office machinery and computers (row 69), computer services (row 107), and telecommunications equipment (row 74). Computers made up around 94% of the “Office machinery and computers” category in 1998. I have argued that, within the computer services category, software investment is understated by official figures but here no adjustment is made.

Table B.3 shows exports, imports, and investment as a proportion of final output for the three ICT categories. It turns out that consumption of software and telecommunications equipment is small or zero, while consumption of office machinery and computers as a proportion of final output has varied from 11% to 19% over 1992-98. In the latter category, there was substantial two way trade, with both exports and imports greatly in excess of final output. The trade balance was negative in every year, so investment has tended to exceed final output. Nevertheless, the picture of the UK as being substantially dependent on imports in this area does not seem to be borne out by the facts. In the other two categories, the net trade balance was positive in most years and was rising. So investment was a declining proportion of final output.

Table B.1
Growth rates of ICT prices, 1979-98: ONS and BEA compared (% p.a.)

	ONS			*BEA*			
	Computers	*Software*	*Telecomm-unications equipment.*	*Computers*	*Software (low)*	*Software (high)*	*Telecomm-unications equipment*
1980	-18.91	10.22	8.08	-34.03	-3.58	-23.39	-2.62
1981	0.69	8.12	3.11	1.01	19.70	6.29	21.65
1982	-2.69	6.76	7.60	3.57	19.23	8.04	20.02
1983	-6.18	4.64	1.28	-3.88	15.35	3.71	16.62
1984	-4.31	3.18	-0.34	-8.60	13.13	0.35	16.19
1985	-2.18	4.48	-15.87	-13.29	2.88	-6.64	4.86
1986	-5.76	1.75	-57.48	-27.20	-13.85	-25.98	-11.53
1987	-3.63	5.30	4.04	-27.13	-10.58	-17.22	-10.76
1988	-4.47	-0.80	2.24	-15.60	-7.10	-19.92	-8.12
1989	-3.06	3.63	1.83	1.42	5.91	-9.98	8.43
1990	3.51	2.85	-6.93	-18.38	-10.04	-22.39	-8.63
1991	-13.52	2.44	2.59	-9.71	1.60	-3.98	1.38
1992	-21.84	1.63	-0.28	-15.52	-5.82	-22.00	-0.58
1993	-14.28	5.36	-1.53	0.32	16.51	11.39	15.10
1994	-4.88	2.58	-0.87	-14.65	-4.32	-10.95	-4.07
1995	-14.84	1.26	-2.96	-20.99	-2.64	-8.42	-6.92
1996	-6.83	0.19	0.60	-26.17	-0.82	-4.77	-1.45
1997	-14.24	-4.01	-0.30	-30.26	-7.37	-13.45	-5.86
1998	-20.18	-5.78	-1.10	-31.24	-3.14	-9.70	-2.80

Average growth rates (% p.a.)

1979-89	-5.05	4.73	-4.55	-12.37	4.11	-8.47	5.47
1989-98	-11.90	0.72	-1.20	-18.51	-1.78	-9.36	-1.54
1989-94	-10.20	2.97	-1.41	-11.59	-0.41	-9.58	0.64
1994-98	-14.02	-2.09	-0.94	-27.16	-3.49	-9.08	-4.26

Note Growth rates are measured logarithmically: growth of P is $100*\ln[(P(t)/P(t\text{-}1)]$. US price indices are adjusted for exchange rate changes.

Table B.2
ICT deflators and investment in current prices

	Price indices (1995=100)				*Investment (£ million, current prices)*		
	Computers	*Software (low)*	*Software (high)*	*Telecomm-unications equipment*	*Computers*	*Software*	*Telecomm-unications equipment*
1974	1858.1	54.0	662.5	46.4	388.0	68.2	134.0
1975	1780.9	59.2	655.1	52.8	441.3	86.7	170.7
1976	1829.6	74.4	725.8	68.4	501.9	117.0	217.3
1977	1646.1	79.0	691.0	68.7	570.8	140.7	276.7
1978	1012.5	72.7	505.5	65.2	649.2	175.9	352.3
1979	758.8	69.5	410.0	60.1	738.4	228.1	448.5
1980	539.9	67.1	324.4	58.5	927.1	323.2	512.8
1981	545.4	81.7	345.5	72.6	1164.1	457.8	586.4
1982	565.2	99.0	374.4	88.7	1461.6	648.5	670.4
1983	543.7	115.4	388.6	104.8	1835.2	918.6	766.6
1984	498.9	131.6	390.0	123.2	2304.3	1301.3	876.5
1985	436.8	135.4	364.9	129.3	2680.2	1843.4	1010.0
1986	332.8	117.9	281.4	115.2	3117.3	2382.4	1163.9
1987	253.7	106.1	236.9	103.5	3625.7	2549.4	1341.2
1988	217.1	98.8	194.1	95.4	4217.1	3344.9	1545.6
1989	220.2	104.8	175.7	103.8	4904.9	4467.0	1781.0
1990	183.2	94.8	140.4	95.2	5266.2	5433.0	1719.0
1991	166.3	96.3	135.0	96.5	5069.9	5403.0	1585.0
1992	142.4	90.9	108.3	96.0	4987.8	5679.0	1690.0
1993	142.8	107.2	121.4	111.6	5347.0	6543.0	1917.0
1994	123.4	102.7	108.8	107.2	6446.0	7815.0	2106.0
1995	100.0	100.0	100.0	100.0	7725.1	9381.0	3254.0
1996	77.0	99.2	95.3	98.6	8636.3	9885.0	3828.0
1997	56.9	92.1	83.3	93.0	8344.5	9681.0	4122.0
1998	41.6	89.3	75.6	90.4	10236.2	13266.0	4739.0

Note The price indices are US ones, adjusted for exchange rate changes. Software investment incorporates the “times 3” adjustment.

Table B.3
Exports, imports, investment, and consumption: ratios to final output, 1992-98 (%)

	Office machinery and computers				*Computer services*				*Telecommunications equipment*			
	Exports	*Imports*	*Con-sumption*	*Investment*	*Exports*	*Imports*	*Con-sumption*	*Investment*	*Exports*	*Imports*	*Con-sumption*	*Investment*
1992	127.9	159.8	18.1	113.8	43.9	46.9	0.0	102.9	60.5	78.0	6.6	111.0
1993	161.2	197.9	18.6	118.2	45.8	43.8	0.0	98.0	72.2	85.9	5.9	107.8
1994	136.4	152.2	14.2	101.6	47.4	40.1	0.0	92.7	94.3	91.9	4.6	93.0
1995	131.8	139.1	11.5	95.7	44.6	36.6	0.0	92.0	91.0	82.9	2.8	89.1
1996	123.6	129.8	10.7	95.5	42.2	29.2	0.0	87.0	102.1	101.7	2.6	96.9
1997	138.9	145.5	12.3	94.3	46.2	31.9	0.0	85.7	105.0	93.8	2.6	86.2
1998	132.7	160.5	14.4	113.3	39.4	24.6	0.0	85.2	100.1	77.2	2.3	74.8

Source Input-output balances, 1992-98. The rows employed are 69, 74, and 107.
Note The computer services figures are not adjusted, i.e. the official figures are used. Final output is consumption plus investment plus exports minus imports.

ANNEX C
ESTIMATING SOFTWARE INVESTMENT IN CURRENT PRICES

C.1 Introduction

In the text, two reasons were suggested for suspecting that UK software investment in current prices might be understated:

- US software investment averaged about 140% of computer investment in the 1990s (both in current prices). In the UK by contrast, software investment averaged only 39% of computer investment in the 1990s.
- In the US in 1996, 60% of the sales of the computer services industry were classified as final sales, mostly to domestic firms for investment. In the UK in the same year, only 18% of sales of this industry were classified as investment.

Since people buy computers to run software, it seems very unlikely that there should be such a large discrepancy between the UK and the US. Both countries are trying to implement the same national accounts methodology for software (SNA93 or ESA95). Even so, there may be differences in implementation.

These discrepancies do not of course prove that the UK figures are wrong, but they do give rise to concern. This annex looks in more detail at how the US and UK estimates were constructed.

C.2 The US estimates

The US procedures are set out in Parker and Grimm (2000) and have been further clarified by emails from Bruce Grimm of the Bureau of Economic Analysis. The US current price estimates of pre-packaged and custom software, which currently account for two-thirds of software investment, are benchmarked to the 1992 input-output table. That table's estimates are based on the 1992 economic censuses that required survey respondents to separately report pre-packaged and custom software receipts, and to distinguish them from other receipts. The estimates of own account software are based on the wage bill of computer programmers employed outside the computer services industry, grossed up for overhead costs. Adjustments are made for the proportion of programmers whose software is bundled into products, and therefore already counted as investment, and for the proportion of such people's time which is devoted to non-investment activities. The BEA considers that their own account software investment estimates are conservative.

The not-yet-completed input-output table based on the 1997 economic census will lead to revisions in post-1992 estimates; preliminary calculations from the census data suggest that there will be increasingly large upward revisions in pre-packaged software.

C.3 The UK estimates

The official figures for software investment in current prices are based on a benchmark figure for 1995, which is carried forward and backwards by indicator series (Rizki 1995). The 1995 benchmark figure, which was £3.127 billion, was derived from a sample survey of firms in the computer services industry (Activity Heading 8394 of the old 1980 SIC). The survey was last carried out in 1991 and its results are reported in Central Statistical Office (1992). The sample covered 40% of the industry by turnover. The 1991 figure obtained from this survey was projected forward to obtain the 1995 benchmark. The results of this survey for 1991, which are not grossed up, are reproduced in Table C.1.

Investment in software can initially be equated to total billings to domestic clients for the categories of “Custom software”, “Semi-custom software”, “Software products”, and “Software/programs incl those sold independently of or in conjunction with hardware sales by hardware manufacturers”. The figures in these categories reported by the firms in the sample came to £1.594 billion in 1991 (total billings less billings to foreign clients — the latter totalled £0.193). To this should be added an adjustment for estimated imports in the same categories. The ratio of exports to imports of computer services was 1.22 in 1995 (source: 1995 input-output balances). This suggests imports of about £0.158 billion. Adding these, we reach a figure of £1.752 billion. Grossing up to reflect the fact that the survey only covers 40% of turnover, we obtain a figure £4.381 billion for software investment in 1991. The official figures show that investment grew by a factor of 1.736 between 1995 and 1991. Applying this ratio, we obtain a figure of £7.606 billion for 1995.

This is already nearly two and a half times the official benchmark figure of £3.127 billion. Even so, it could be too low since I have assigned zero investment to the categories “Software support/maintenance”, “Independent consulting”, “Other professional services”, “Database services” and “Value added services”.

More important, my figure makes no allowance for own account software. The great majority of programmers and software engineers are employed outside the computer services industry. In 1995 this proportion was 73%: see Table C.2. In the US the BEA estimates that about half of such people are engaged in developing software which is bundled with other products and therefore already counted as investment. Also, they estimate (conservatively, in their view) that only 50% of the time of programmers and software engineers outside the computer services industry is devoted to activities which constitute software investment. Applying both these adjustments to the UK, we can estimate that own account software is a multiple of $0.5 \times 0.5 \times 73 \div 27 = 0.68$ of other software, yielding a 1995 total of £12.778 billion or 4.1 times the official figure.

An alternative estimate is provided by the proportion that own account software investment forms of the total. In the US, this proportion was estimated to be a third of the total in 1998, down from 44% in 1990 and 40% in 1995. Assuming a 40% ratio applied to the UK too in 1995, we would obtain a total for all software investment of £12.677 billion, again 4.1 times the official figure.

It has been suggested that some software investment could be included under the output of “Printing and publishing” rather than of “Computer services”. According to the 1995 input-output supply and use tables, only £218 million of the gross output of £28,884 million of this industry (row 34 of the tables) was classified as investment, or 0.8%. In 1998, only £281 million out of £34,478 million was so classified (0.8% again). If any of this is software, or if any of what is classified as intermediate expenditure on this industry's output is really software investment, then any such investment would be additional to the total estimated here.

C.4 Conclusion

These estimates are obviously subject to a large margin of error. Further work would be required to see whether the adjustments which the BEA makes to software employment are appropriate to the UK. Nevertheless, on the basis of the calculations above, it appears that UK software investment has been substantially understated. The factor of three adjustment used in the text can fairly be described as conservative.

Table C.1
Sales of the computer services industry in 1991

	Total billings to clients (including foreign clients) for work done	**Billings to foreign clients**
	£ thousands	***£ thousands***
	1991	***1991***
Section A: Bureau services		
Database services	193,446	58,909
Value added network services	147,888	5,500
Other services	478,157	28,629
Total section A	819,491	93,038
Section B: Software		
Custom software	765,700	79,520
Semi-custom software	48,135	
Software products	563,819	113,446
Software support/maintenance	267,408	31,404
Total section B	1,645,062	224,370
Section C: Hardware		
Hardware	339,886	8,466
Hardware maintenance	115,996	
Total section C	455,882	8,466
Section D: Other professional services		
Independent consulting	460,547	40,872
Education and Training	91,651	4,716
Other professional services including unclassified billings (a)	327,807	20,279
Total section D	880,005	65,867
Total billings	3,800,440	391,741
Software/programs incl those sold independently of or in conjunction with hardware sales by hardware manufacturers	409,627	0

Source Central Statistical Office (1992).

Table C.2
Software personnel employed in computer services and in the whole economy

(a) sample numbers: full time adults, males and females, 1% sample

	Software engineers (SOC 214)		*Computer analysts (SOC 320)*		*Total software personnel (SOC 214 + SOC 320)*	
	Class 72	*Whole economy*	*Class 72*	*Whole economy*	*Class 72*	*Whole economy*
1991	95	224	138	684	233	908
1992	109	334	184	1204	293	1538
1993	128	349	182	1159	310	1508
1994	133	377	175	1162	308	1539
1995	169	402	237	1120	406	1522
1996	209	438	274	1130	483	1568
1997	216	445	329	1233	545	1678
1998	284	542	398	1366	682	1908
1999	332	619	468	1475	800	2094

(b) Proportions of all software personnel who are employed in Class 72, %

	Software engineers	*Computer analysts*	*Total computer personnel*
	(SOC 214)	*(SOC 320)*	*(SOC 214 + SOC 320)*
1991	42.4	20.2	25.7
1992	32.6	15.3	19.1
1993	36.7	15.7	20.6
1994	35.3	15.1	20.0
1995	42.0	21.2	26.7
1996	47.7	24.2	30.8
1997	48.5	26.7	32.5
1998	52.4	29.1	35.7
1999	53.6	31.7	38.2

Source *New Earnings Survey* (special tabulation).
Note Employees are those whose pay was not affected by absence. Class 72 of SIC92 is "Computer and related activities".

ANNEX D
UNDERLYING DATA

LIST OF TABLES

Table D.1
Growth rates of output and inputs, 1950-99: baseline estimates

	Output (GDP at market prices)	*Non-dwelling capital stock*	*Dwellings (inc. transfer costs)*	*Total capital stock*	*Labour (heads)*	*Labour (hours)*
	% p.a.	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1951	0.53	2.82	2.34	2.71	1.48	—
1952	2.24	4.40	2.27	3.95	-0.06	—
1953	4.37	2.08	2.77	2.22	0.48	—
1954	4.04	2.91	3.67	3.06	1.40	—
1955	2.97	3.41	3.73	3.48	1.08	—
1956	1.50	4.38	3.35	4.18	0.89	—
1957	1.98	4.31	3.12	4.08	0.12	—
1958	0.68	4.73	2.91	4.38	-1.09	—
1959	3.81	4.14	2.73	3.89	0.51	—
1960	4.03	4.46	3.13	4.23	1.80	—
1961	3.41	5.60	3.38	5.20	1.15	—
1962	1.21	5.08	3.48	4.78	0.75	—
1963	4.04	3.44	3.50	3.45	0.14	—
1964	4.84	3.60	3.45	3.58	1.19	—
1965	2.36	5.66	4.21	5.42	1.04	—
1966	2.20	5.24	4.18	5.05	0.64	—
1967	2.79	4.63	4.07	4.52	-1.37	—
1968	4.07	4.98	4.46	4.88	-0.55	—
1969	1.25	5.18	4.64	5.08	0.13	—
1970	2.63	4.53	4.19	4.46	-0.36	—
1971	2.79	4.93	3.61	4.66	-1.30	—
1972	2.72	3.82	3.82	3.82	-0.07	—
1973	7.17	2.91	3.83	3.10	2.31	—
1974	-0.70	6.08	3.55	5.50	0.31	—
1975	0.10	4.04	3.04	3.78	-0.34	—
1976	3.33	2.50	3.11	2.65	-0.81	-1.58
1977	1.12	2.77	3.10	2.84	0.10	0.22
1978	3.36	2.82	2.83	2.82	0.62	1.04
1979	2.02	3.04	2.81	3.00	1.52	1.55
1980	-1.56	3.52	2.76	3.36	-0.10	-0.89
1981	-0.97	1.60	2.38	1.78	-2.39	-5.00
1982	1.28	0.75	1.83	1.01	-1.68	-3.53
1983	3.63	1.46	1.98	1.58	-1.09	-1.42

1984	2.06	1.78	2.29	1.89	2.21	2.21
1985	3.85	2.90	2.38	2.79	1.47	1.69
1986	4.01	3.33	2.17	3.08	0.59	0.73
1987	4.15	2.55	2.37	2.51	1.50	2.15
1988	4.82	3.07	2.56	2.96	3.60	3.68
1989	1.82	5.26	2.98	4.77	3.12	3.02
1990	0.71	5.50	2.60	4.83	0.90	0.34
1991	-1.52	4.00	2.03	3.49	-2.03	-3.74
1992	0.09	2.32	1.51	2.09	-2.38	-3.01
1993	2.31	1.94	1.46	1.80	-1.17	-0.90
1994	4.25	1.84	1.61	1.77	0.83	1.19
1995	2.78	2.18	1.68	2.04	1.23	2.06
1996	2.52	2.90	1.51	2.51	1.19	0.96
1997	3.49	3.33	1.57	2.84	1.89	1.82
1998	2.76	4.14	1.64	3.44	1.16	1.17
1999	2.39	5.62	1.62	4.43	1.22	0.63

Source See Annex A.

Table D.2
Shares of inputs in the value of output, current prices, 1950-99

	Non-dwellings capital	*Dwellings*	*Labour*
1950	0.191	0.059	0.750
1951	0.195	0.057	0.747
1952	0.216	0.053	0.731
1953	0.220	0.053	0.726
1954	0.220	0.055	0.726
1955	0.215	0.053	0.732
1956	0.208	0.051	0.741
1957	0.208	0.049	0.742
1958	0.213	0.048	0.738
1959	0.219	0.048	0.732
1960	0.228	0.047	0.725
1961	0.213	0.048	0.739
1962	0.208	0.049	0.743
1963	0.225	0.044	0.731
1964	0.225	0.045	0.730
1965	0.225	0.046	0.728
1966	0.214	0.048	0.738
1967	0.216	0.050	0.734
1968	0.217	0.051	0.732
1969	0.218	0.052	0.729
1970	0.206	0.054	0.740
1971	0.215	0.054	0.731
1972	0.215	0.055	0.731
1973	0.212	0.055	0.733
1974	0.176	0.060	0.764
1975	0.167	0.057	0.776
1976	0.184	0.058	0.758
1977	0.222	0.056	0.722
1978	0.226	0.056	0.718
1979	0.218	0.057	0.725
1980	0.207	0.057	0.736
1981	0.202	0.064	0.734
1982	0.217	0.067	0.716
1983	0.234	0.067	0.699
1984	0.234	0.065	0.701
1985	0.245	0.064	0.691

1986	0.230	0.065	0.705
1987	0.238	0.064	0.698
1988	0.239	0.064	0.698
1989	0.234	0.065	0.701
1990	0.216	0.070	0.714
1991	0.203	0.078	0.719
1992	0.196	0.085	0.718
1993	0.210	0.087	0.703
1994	0.221	0.088	0.691
1995	0.224	0.090	0.686
1996	0.234	0.088	0.678
1997	0.233	0.088	0.679
1998	0.225	0.089	0.686
1999	0.209	0.095	0.697

Source See Annex A.
Note The shares sum to 1.

Table D.3
Contributions to the growth of output, 1950-99: baseline estimates

	Contribution of capital	*Contribution of labour (heads)*	*Total input contribution*	*TFP (heads)*
	% p.a.	*% p.a*	*% p.a*	*% p.a*
1951	0.68	1.11	1.79	-1.26
1952	1.03	-0.04	0.99	1.25
1953	0.60	0.35	0.95	3.41
1954	0.84	1.02	1.86	2.18
1955	0.94	0.78	1.73	1.25
1956	1.10	0.65	1.75	-0.25
1957	1.05	0.09	1.14	0.84
1958	1.14	-0.80	0.34	0.34
1959	1.03	0.37	1.40	2.41
1960	1.15	1.31	2.46	1.57
1961	1.40	0.84	2.24	1.17
1962	1.24	0.56	1.80	-0.59
1963	0.91	0.10	1.01	3.03
1964	0.96	0.87	1.83	3.00
1965	1.47	0.75	2.22	0.14
1966	1.35	0.47	1.81	0.38
1967	1.19	-1.01	0.19	2.60
1968	1.30	-0.40	0.90	3.17
1969	1.37	0.10	1.46	-0.21
1970	1.18	-0.26	0.92	1.71
1971	1.23	-0.96	0.28	2.51
1972	1.03	-0.05	0.98	1.74
1973	0.83	1.69	2.53	4.65
1974	1.38	0.23	1.62	-2.32
1975	0.87	-0.26	0.61	-0.51
1976	0.62	-0.62	-0.01	3.34
1977	0.74	0.08	0.81	0.31
1978	0.79	0.45	1.24	2.13
1979	0.83	1.10	1.93	0.09
1980	0.91	-0.07	0.83	-2.39
1981	0.47	-1.75	-1.28	0.32
1982	0.28	-1.22	-0.94	2.22
1983	0.46	-0.77	-0.31	3.94
1984	0.57	1.55	2.12	-0.05
1985	0.85	1.02	1.87	1.98

1986	0.93	0.41	1.34	2.67
1987	0.75	1.05	1.80	2.35
1988	0.89	2.51	3.41	1.42
1989	1.43	2.18	3.61	-1.80
1990	1.41	0.64	2.05	-1.34
1991	0.99	-1.45	-0.47	-1.05
1992	0.59	-1.71	-1.12	1.21
1993	0.52	-0.83	-0.31	2.62
1994	0.54	0.58	1.11	3.14
1995	0.64	0.85	1.48	1.30
1996	0.80	0.81	1.61	0.91
1997	0.91	1.28	2.20	1.29
1998	1.09	0.79	1.88	0.88
1999	1.37	0.84	2.21	0.18

Source Tables D.1 and D.2
Note The contribution of an input is its growth rate multiplied by its output share.

Table D.4
Shares of ICT final output in GDP, current prices, 1979-98

	Computers	*Software*	*Telecomm-unications equipment*	*Semi-conductors*	*Total ICT*
	%	*%*	*%*	*%*	*%*
1975	0.29	0.08	0.15	N/A	0.52
1976	0.29	0.09	0.16	N/A	0.54
1977	0.28	0.10	0.18	N/A	0.56
1978	0.28	0.10	0.20	N/A	0.58
1979	0.27	0.12	0.22	N/A	0.60
1980	0.29	0.14	0.21	N/A	0.63
1981	0.32	0.18	0.22	N/A	0.72
1982	0.38	0.23	0.23	N/A	0.83
1983	0.44	0.30	0.24	N/A	0.98
1984	0.51	0.40	0.26	N/A	1.17
1985	0.54	0.51	0.27	N/A	1.32
1986	0.59	0.62	0.29	N/A	1.49
1987	0.62	0.60	0.30	N/A	1.52
1988	0.65	0.71	0.31	N/A	1.68
1989	0.69	0.86	0.33	N/A	1.88
1990	0.67	0.96	0.29	N/A	1.92
1991	0.62	0.90	0.25	N/A	1.77
1992	0.58	0.92	0.26	-0.083	1.68
1993	0.57	1.02	0.29	-0.011	1.87
1994	0.80	1.18	0.31	0.058	2.35
1995	1.00	1.35	0.47	0.025	2.84
1996	1.06	1.36	0.50	-0.239	2.69
1997	0.96	1.27	0.53	-0.185	2.57
1998	0.90	1.64	0.61	-0.099	3.06

Source See Annexes A-C.
Note Total excludes semiconductors prior to 1992.

Table D.5
Alternative measures of GDP growth

	*GDP (chain-linked, **low** software variant)*	*GDP (chain-linked, **high** software variant)*	*GDP (chain-linked, no ICT adjustment)*	*GDP (at 1995 market prices [ABMI])*
	% p.a.	*% p.a.*	*% p.a.*	*% p.a.*
1980	-1.37	-1.34	-1.56	-2.20
1981	-0.97	-0.94	-0.97	-1.28
1982	1.28	1.31	1.28	1.78
1983	3.71	3.74	3.63	3.68
1984	2.10	2.15	2.06	2.42
1985	4.03	4.07	3.85	3.71
1986	4.37	4.44	4.01	4.12
1987	4.48	4.52	4.15	4.33
1988	5.11	5.19	4.82	5.04
1989	1.94	2.06	1.82	2.09
1990	1.13	1.24	0.71	0.66
1991	-1.41	-1.36	-1.52	-1.48
1992	0.31	0.46	0.09	0.07
1993	2.19	2.24	2.31	2.30
1994	4.54	4.62	4.25	4.29
1995	2.93	3.01	2.78	2.75
1996	2.40	2.45	2.52	2.52
1997	3.79	3.87	3.49	3.45
1998	3.22	3.32	2.76	2.61
1999	N/A	N/A	2.39	2.09

Source See Annexes A-C.

Table D.6
Contributions of ICT and non-ICT output to GDP growth, 1975-98

	Low software variant			*High software variant*		
	Non-ICT	*ICT*	*Growth of GDP*	*Non-ICT*	*ICT*	*Growth of GDP*
	p.p. p.a.	*p.p. p.a.*	*% p.a.*	*p.p. p.a.*	*p.p. p.a.*	*% p.a.*
1975	0.17	0.07	0.24	0.17	0.08	0.25
1976	3.37	0.04	3.42	3.37	0.05	3.43
1977	1.12	0.12	1.25	1.12	0.13	1.26
1978	3.37	0.26	3.63	3.37	0.28	3.65
1979	1.99	0.22	2.21	1.99	0.23	2.23
1980	-1.60	0.23	-1.37	-1.60	0.25	-1.34
1981	-1.04	0.07	-0.97	-1.04	0.09	-0.94
1982	1.20	0.09	1.28	1.20	0.11	1.31
1983	3.55	0.16	3.71	3.55	0.19	3.74
1984	1.88	0.22	2.10	1.88	0.26	2.15
1985	3.71	0.32	4.03	3.71	0.36	4.07
1986	3.84	0.53	4.37	3.84	0.60	4.44
1987	4.05	0.44	4.48	4.05	0.48	4.52
1988	4.61	0.50	5.11	4.61	0.58	5.19
1989	1.65	0.28	1.94	1.65	0.41	2.06
1990	0.69	0.44	1.13	0.69	0.56	1.24
1991	-1.40	-0.02	-1.41	-1.40	0.04	-1.36
1992	0.11	0.20	0.31	0.11	0.35	0.46
1993	2.21	-0.02	2.19	2.21	0.03	2.24
1994	3.78	0.77	4.54	3.78	0.84	4.62
1995	2.18	0.75	2.93	2.18	0.82	3.01
1996	2.31	0.09	2.40	2.31	0.14	2.45
1997	3.45	0.34	3.79	3.45	0.42	3.87
1998	2.41	0.81	3.22	2.41	0.91	3.32

Source See Annexes A-C.

Table D.7
Growth rates of capital services, 1979-99, % p.a.

	NON-ICT					*ICT*			
	Plant and machinery	*Intangible fixed assets*	*Buildings*	*Vehicles*	*Inventories*	*Computers*	*Software (low)*	*Software (high)*	*Telecomm-unications equipment*
1980	3.67	-3.54	2.28	4.42	3.93	39.87	24.11	41.93	19.13
1981	2.89	1.68	1.95	-1.12	-3.98	49.37	30.97	51.21	18.32
1982	1.09	5.58	1.74	-6.22	-3.94	34.24	23.40	38.47	12.09
1983	0.88	11.36	2.08	-4.33	-1.62	26.79	19.90	32.41	8.42
1984	1.28	8.34	2.07	-2.69	1.72	26.72	19.72	31.75	6.40
1985	2.21	11.59	2.36	1.88	1.35	28.95	20.59	33.13	4.94
1986	3.63	5.83	2.26	2.73	1.01	28.68	25.77	37.45	5.62
1987	3.13	-7.12	2.33	-0.63	1.21	35.54	32.47	45.20	9.09
1988	3.29	-9.78	2.86	1.93	1.64	39.08	25.12	33.79	12.26
1989	5.18	-2.96	3.41	4.22	4.90	34.67	29.49	40.81	14.48
1990	6.46	-7.18	3.53	5.02	2.51	24.40	26.37	39.78	12.54
1991	4.53	0.89	3.85	1.09	-1.66	24.90	27.92	40.96	10.98
1992	2.11	6.90	3.51	-5.19	-4.41	16.50	14.55	22.25	7.16
1993	1.31	-3.67	3.45	-5.00	-1.67	15.41	13.04	24.42	7.13
1994	0.51	-10.46	3.16	-0.79	0.31	11.88	7.18	14.96	5.55
1995	0.49	-16.78	3.07	2.46	4.05	20.85	12.84	20.84	6.84
1996	2.17	-17.87	2.70	-0.14	3.64	29.36	16.13	23.48	15.67
1997	3.22	-13.09	2.43	1.51	1.44	33.33	12.05	17.52	16.16
1998	4.62	-5.61	2.59	3.73	2.89	30.07	9.44	14.95	15.46
1999	6.19	-35.14	2.67	6.64	3.15	41.30	19.70	26.56	15.77

Source See Annexes A-C.
Note The growth rate of the capital services of an asset in year t is the growth rate of the stock of that asset from t-2 to t-1: see equation (9).

Table D.8
Shares of each asset in total profits accruing to the non-dwelling capital stock, 1979-98 (high software variant)

	NON-ICT					*ICT*		
	Plant and machinery	*Intangibles*	*Buildings*	*Vehicles*	*Inventories*	*Computers*	*Software*	*Telecommunications equipment*
	%	*%*	*%*	*%*	*%*	*%*	*%*	*%*
1979	56.3	2.5	11.2	17.7	6.9	2.8	0.7	1.9
1980	46.2	2.2	25.7	15.8	6.3	2.1	0.6	0.9
1981	37.5	2.0	38.2	14.3	5.9	1.6	0.5	0.1
1982	22.9	1.6	59.1	9.0	5.4	1.5	0.5	0.1
1983	27.1	2.0	52.6	9.8	5.7	2.0	0.7	0.1
1984	32.1	2.4	46.0	9.4	5.9	2.8	1.1	0.2
1985	32.7	2.8	42.2	9.6	6.1	3.4	1.7	1.4
1986	37.8	3.2	32.4	10.2	6.3	4.6	2.9	2.7
1987	31.9	3.2	39.2	9.7	6.2	4.5	2.9	2.4
1988	45.2	3.1	23.8	11.6	6.4	4.3	3.3	2.3
1989	54.4	3.7	8.6	15.3	6.9	5.0	4.3	1.9
1990	33.0	2.5	36.0	10.3	5.9	5.6	4.5	2.3
1991	21.3	2.3	53.7	8.7	5.5	4.2	3.4	0.9
1992	16.6	2.3	57.3	8.5	5.4	4.4	4.7	0.8
1993	18.9	2.8	55.5	9.5	5.6	3.5	2.7	1.4
1994	30.3	3.1	38.3	9.0	6.0	5.3	5.9	2.1
1995	42.2	3.3	20.3	11.3	6.3	6.6	7.0	2.9
1996	37.7	2.9	27.2	10.5	6.3	6.5	6.6	2.2
1997	32.7	2.1	34.8	9.5	6.0	6.0	6.8	2.2
1998	38.0	2.2	29.6	8.7	6.2	6.2	6.8	2.3

Source See Annexes A-C.
Note Shares calculated from equations (10) and (12). Results for the low software variant are similar. The share of profits from any asset in GDP can be computed from this table and from Table D.2, column 1 (“Non-dwellings capital”).

Table D.9
Growth rates of capital services: ICT and non-ICT assets, 1979-99

	Non-ICT capital (low software)	*ICT capital (low software)*	*Non-ICT capital (high software)*	*ICT capital (high software)*	*Total capital (low software)*	*Total capital (high software)*	*Total Capital (no ICT adjustments)*
	% p.a.	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*	*% p.a.*
1980	3.62	12.66	3.62	13.73	4.63	4.75	3.52
1981	1.60	13.07	1.60	14.42	2.63	2.76	1.60
1982	0.36	8.24	0.36	9.36	0.97	1.06	0.75
1983	1.18	7.28	1.18	8.39	1.67	1.76	1.46
1984	1.57	8.82	1.57	10.18	2.23	2.37	1.78
1985	2.62	10.75	2.62	12.40	3.53	3.73	2.90
1986	3.08	12.68	3.08	14.55	4.47	4.74	3.33
1987	2.05	17.12	2.05	19.35	4.51	4.87	2.55
1988	2.59	17.26	2.59	18.96	4.96	5.24	3.07
1989	4.73	17.45	4.74	20.17	6.88	7.38	5.26
1990	5.12	14.74	5.12	18.15	6.84	7.48	5.50
1991	3.56	15.48	3.56	18.69	5.49	6.01	4.00
1992	2.14	9.19	2.13	11.44	3.15	3.50	2.32
1993	1.81	8.10	1.81	11.20	2.69	3.15	1.94
1994	1.48	5.71	1.48	7.77	2.17	2.51	1.84
1995	1.31	10.63	1.31	13.05	3.29	3.79	2.18
1996	1.50	15.41	1.50	17.66	4.63	5.10	2.90
1997	2.29	15.23	2.29	16.98	5.06	5.42	3.33
1998	3.63	13.29	3.63	15.05	5.68	6.06	4.14
1999	3.99	19.83	3.99	22.01	7.39	7.87	5.62

Source See Annexes A-C.
Note The growth rate of the capital services of an asset in year *t* is the growth rate of the stock of that asset from *t*-2 to *t*-1: see equation (9). Both the total capital series use rental price weights.

Table D.10
Contributions of capital deepening and of TFP to growth of output per hour, 1979-98

	Low software					*High software*				
		Capital deepening					*Capital deepening*			
	Growth of output per hour	*ICT*	*Non-ICT*	*Dwellings*	*TFP*	*Growth of output per hour*	*ICT*	*Non-ICT*	*Dwellings*	*TFP*
	% p.a.	*p.p. p.a.*	*p.p. p.a.*	*p.p. p.a.*	*p.p. p.a.*	*% p.a.*	*p.p. p.a.*	*p.p. p.a.*	*p.p. p.a.*	*p.p. p.a.*
1980	-0.50	0.31	0.87	0.21	-1.88	-0.47	0.34	0.87	0.21	-1.88
1981	4.03	0.27	1.29	0.45	2.02	4.05	0.30	1.29	0.45	2.02
1982	4.81	0.15	0.79	0.35	3.52	4.84	0.17	0.79	0.35	3.53
1983	5.13	0.14	0.56	0.23	4.21	5.16	0.16	0.56	0.23	4.22
1984	-0.11	0.17	-0.17	0.01	-0.12	-0.07	0.20	-0.17	0.01	-0.11
1985	2.34	0.27	0.17	0.04	1.85	2.38	0.32	0.17	0.04	1.85
1986	3.62	0.42	0.46	0.09	2.64	3.68	0.49	0.46	0.09	2.65
1987	2.33	0.60	-0.06	0.01	1.77	2.37	0.69	-0.06	0.01	1.73
1988	1.42	0.58	-0.28	-0.07	1.20	1.50	0.64	-0.28	-0.07	1.21
1989	-1.08	0.62	0.28	0.00	-1.98	-0.96	0.74	0.28	0.00	-1.98
1990	0.79	0.58	0.87	0.15	-0.82	0.90	0.73	0.87	0.15	-0.85
1991	2.32	0.61	1.32	0.42	-0.04	2.37	0.72	1.32	0.42	-0.10
1992	3.32	0.32	0.91	0.37	1.73	3.47	0.39	0.91	0.37	1.80
1993	3.09	0.24	0.48	0.20	2.16	3.14	0.34	0.48	0.20	2.12
1994	3.35	0.18	0.04	0.04	3.11	3.43	0.25	0.04	0.04	3.11
1995	0.87	0.43	-0.16	-0.03	0.63	0.95	0.54	-0.16	-0.03	0.60
1996	1.43	0.76	0.08	0.05	0.55	1.49	0.86	0.08	0.05	0.50
1997	1.97	0.70	0.06	-0.02	1.24	2.06	0.78	0.06	-0.02	1.24
1998	2.05	0.60	0.42	0.04	0.98	2.15	0.69	0.42	0.04	0.99

Source See Annexes A-C.

Table D.11
Growth rates of TFP, 1979-99: comparison of concepts

	Heads		*Hours*	
	Baseline	*High software*	*Baseline*	*High software*
	% p.a.	*% p.a.*	*% p.a.*	*% p.a.*
1980	-2.39	-2.46	-1.81	-1.88
1981	0.32	0.10	2.23	2.02
1982	2.22	2.18	3.57	3.53
1983	3.94	3.98	4.17	4.22
1984	-0.05	-0.11	-0.05	-0.11
1985	1.98	2.00	1.83	1.85
1986	2.67	2.75	2.57	2.65
1987	2.35	2.19	1.89	1.73
1988	1.42	1.27	1.36	1.21
1989	-1.80	-2.05	-1.72	-1.98
1990	-1.34	-1.24	-0.95	-0.85
1991	-1.05	-1.32	0.17	-0.10
1992	1.21	1.34	1.67	1.80
1993	2.62	2.31	2.43	2.12
1994	3.14	3.36	2.89	3.11
1995	1.30	1.17	0.73	0.60
1996	0.91	0.34	1.07	0.50
1997	1.29	1.19	1.34	1.24
1998	0.88	1.00	0.87	0.99
1999	0.18	N/A	0.59	N/A

Source See Annexes A-C.