Productivity growth in UK industries, 1970-2000: structural change and the role of ICT

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Abstract

This paper uses a new industry-level dataset to quantify the roles of structural change and information and communication technology (ICT) in explaining productivity growth in the United Kingdom, 1970-2000. The dataset is for 34 industries covering the whole economy, of which 31 industries are in the market sector. Using growth accounting, we find that ICT capital accounted for 13% of productivity growth in the market sector in 1970-79 (ie 0.47 percentage points out of 3.62% per annum growth of GDP per hour), 26% in 1979-90, and 28% in 1990-2000. In 1995-2000 the proportion rises to 47%. ICT capital, despite only being a small fraction of the total capital stock, contributed as much to growth as non-ICT capital in 1990-2000 and getting on for twice as much in 1995-2000. Econometric evidence also supports an important role for ICT. Total factor productivity (TFP) growth slowed down in 1995-2000, but we find econometric evidence that a boom in 'complementary investment', ie expenditure on reorganisation that accompanies ICT investment but is not officially measured as investment, could have led to a decline in the conventional measure of TFP growth.

Key words: productivity, TFP, ICT, structural change

JEL classification: O470, O520, D240

Summary

The aim of this paper is to quantify the importance of structural change and of investment in information and communication technology (ICT) in accounting for the growth of productivity in the United Kingdom.

The context is a puzzle about UK productivity in the 1990s. Though in other respects — inflation, unemployment, and job creation — the economy has done well since emerging from the 1990-92 recession, and though productivity growth has been quite rapid, it slowed down after 1995. This was in contrast to the United States which experienced a rise in productivity growth in 1995-2000, widely believed to be associated with the ICT investment boom. Why did nothing comparable happen in the United Kingdom?

The Bank of England industry dataset (BEID)
We use a new industry dataset, containing annual data for 34 industries spanning the whole UK economy (of which 31 industries are in the market sector), running from 1970 to 2000. The dataset satisfies two important principles. First, it is consistent with the national accounts in both nominal and real terms. Second, industry output is measured gross, so that proper account can be taken of the contribution of intermediate input to productivity growth.

Structural change
We considered several different forms of structural change including:

(1) A change in the degree of inter-relatedness of domestic industries, ie a change in the proportion of each industry’s total costs accounted for by buying from other industries. We found that inter-relatedness has risen fairly steadily since 1970 (apart from a dip in the early 1980s). According to growth accounting theory, this means that, even if the growth rates of total factor productivity (TFP) had been constant in individual industries, the aggregate TFP growth rate would still have risen.

(2) A shift in the composition of output towards industries with a high or low *level* of labour productivity, tending either to raise or lower the aggregate labour productivity growth rate. We found however that aggregate labour productivity growth was predominantly due to labour productivity growth in individual industries, not compositional changes.

Productivity growth in the market sector: a growth accounting analysis
Since 1979, input growth (capital deepening plus labour quality growth) has accounted for three quarters of labour productivity growth in the market sector (ie the whole economy excluding the government sector), while capital deepening alone has accounted for more than half. TFP growth accounted for 28% of labour productivity growth in 1979-90 and for 35% in 1990-2000; reallocation effects accounted for the remainder.

Over the three decades, ICT capital services per hour have grown at a remarkable 22.0% per year, while non-ICT services per hour grew at only 3.3% per year. Interestingly, ICT capital services were growing more rapidly in the 1970s than in the 1990s. But their contribution to overall

deepening was lower. This was because in the 1970s the share of ICT capital in income (ie profit attributable to ICT assets as a proportion of GDP) was less than 2%, while by the 1990s it had tripled to more than 5%. The share of ICT capital in income is now about the same as in the United States but ICT capital stocks per capita are still significantly lower in the United Kingdom.

We find that ICT capital accounted for 13% of growth in the market sector in 1970-79 (ie 0.47 percentage points out of 3.62% per annum growth of GDP per hour), 26% in 1979-90, and 28% in 1990-2000. In 1995-2000 the proportion rises to 47%. ICT capital, despite only being a small fraction of the total capital stock, contributed as much to growth as non-ICT capital in 1990-2000 and getting on for twice as much in 1995-2000.

Testing the growth accounting assumptions

The growth accounting analysis makes a number of strong assumptions. So we test these assumptions econometrically by panel regression analysis. We find that the growth rate of labour productivity is more strongly associated with the growth of ICT than with that of non-ICT capital. But the association between productivity and ICT capital gets stronger and more significant statistically as the period over which growth is measured gets longer: over one year the association is low and statistically insignificant, but over five years it is large and highly significant.

Complementary investment and capital

It is often argued that successful implementation of an ICT project requires costly reorganisation of the firm around the new technology. By incurring current costs, the firm acquires a capability that helps it to absorb new technology in the future. In other words, the investment in reorganisation creates a stock that yields future benefits. The empirical difficulty is that this type of ‘complementary’ investment is not measured as such in the national accounts.

The effect on the estimation of TFP is quite complex. Omitting the contribution of growth in the stock of complementary *capital* biases the estimate of TFP growth upwards, while omitting the contribution of the growth in complementary *investment* biases it downwards. In a boom investment tends to grow more rapidly than capital, leading to a net downward bias. Simulation shows that the bias can be quite large. We also estimate the bias econometrically on our panel of industries, using ICT capital as a proxy for complementary capital. We find, in accordance with the theory, that ICT capital significantly increases TFP growth, while ICT investment significantly reduces it. So a surge in complementary investment accompanying the surge in ICT investment in the second half of the 1990s may explain some at least of the observed slowdown in TFP growth.

1. Introduction

This paper employs a new industry dataset to build up a picture of output and productivity growth in the market sector of the UK economy. Our aim is to quantify the importance of structural change and of investment in information and communication technology (ICT) in accounting for the growth of productivity in the United Kingdom. Initially we employ growth accounting but we also use econometric methods both to test the growth accounting assumptions and to examine whether additional investment associated with ICT but not measured as such ('complementary investment') is distorting the productivity picture.

Our dataset consists of 34 industries covering the whole economy and extends from 1970 to 2000. Our aggregate estimates are developed in a theoretically consistent way from the industry-level data. Even if one is interested only in the outcome at the aggregate level, it is still useful to look at more disaggregated data. This is because any number of stories can be told to explain a single time series like GDP or GDP per worker. It is often very difficult to reject a particular hypothesis using just aggregate data. Here industry-level data can help.

The context

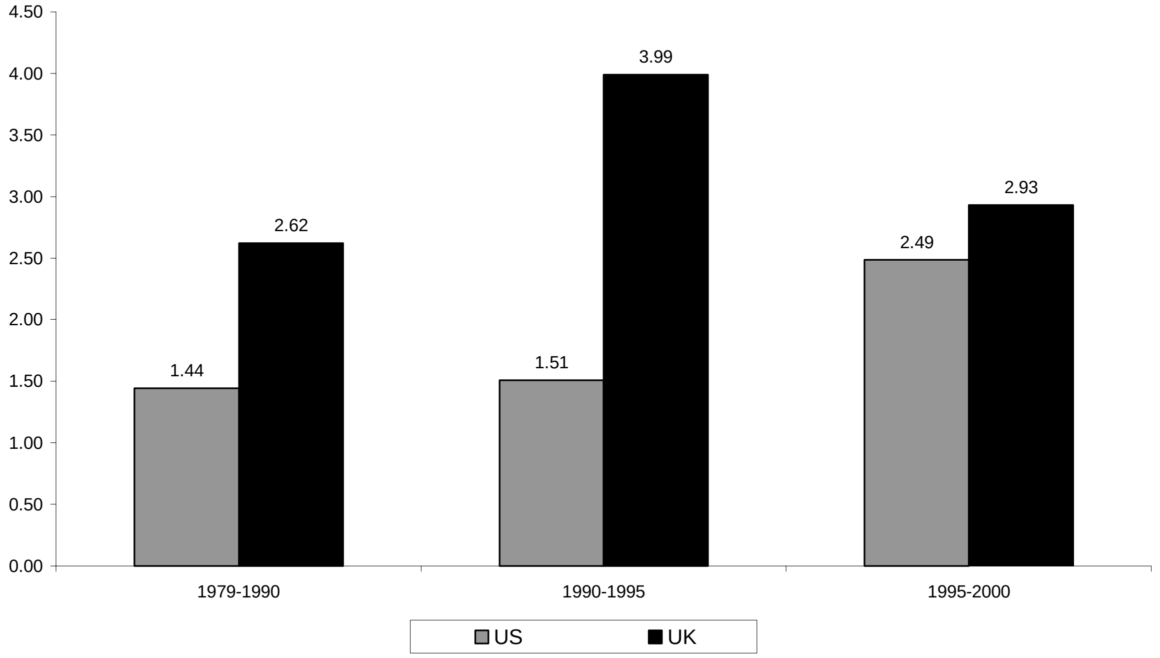
The context is a set of puzzles about UK productivity in the 1990s. First of all, though in other respects — inflation, unemployment, and job creation — the economy has done well since emerging from the 1990-92 recession, the productivity performance deteriorated after 1995. Second, the United States experienced a productivity acceleration in 1995-2000, widely believed to be associated with the ICT investment boom (Oliner and Sichel (2000); Jorgenson and Stiroh (2000a and b), Stiroh (2002a), Gordon (2003)). Why did nothing comparable happen in the United Kingdom?

Chart 1.1 compares growth in labour productivity (output per hour) in the United States and the United Kingdom since 1979. For the United States we use the standard measure of labour productivity in the nonfarm business sector, from the U.S. Bureau of Labor Statistics. For the United Kingdom we use our own measure derived from the Bank of England Industry Dataset (BEID), described below in Section 3. The UK measure is for what we call the market sector, ie the whole economy excluding the public sector (public administration and defence, education, and health and social work) and the services of the housing stock. The coverage of the two measures is similar. The UK performance looks better on these figures than on the official, headline productivity measure (output per worker in the whole economy) for three main reasons: first, because of the exclusion of the public sector where productivity growth is low (at least as currently measured); second, because we have made a number of adjustments (detailed below in Section 3) to the official series to improve the measurement of ICT; and third, because we use hours worked, not number of workers, to measure labour input. All three factors bring the UK figures closer methodologically to the US ones.

Two facts are immediately striking in Chart 1.1. First, productivity grew more rapidly in the United Kingdom in both the 1980s and the 1990s. Second, while productivity growth in the United States rose by about 1% per annum in the second half of the 1990s, it fell by a similar amount in the United Kingdom, even though still remaining higher than in the United States. The fact that growth was faster in the United Kingdom (though apparently little known) is not necessarily surprising. The US productivity level is substantially higher (by about 39% according to O'Mahony and de Boer (2002) in 1999), so the scope for catch-up was considerable. But the UK productivity slowdown contrasts strikingly with the US improvement over 1995-2000. As we shall see, the United Kingdom also experienced a boom in ICT investment in this period and our paper seeks to make a contribution to understanding this puzzle.

Chart 1.1

Growth of output per hour, % pa
(US: nonfarm business sector UK: market sector)



Sources: United States: Bureau of Labor Statistics (downloaded from www.bls.gov)
United Kingdom: Bank of England Industry Dataset (see below, Section 3)

Plan of the paper

Section 2 sets out our growth accounting framework. It shows how the familiar aggregate concepts of TFP growth and capital deepening can be built up consistently from corresponding concepts at the industry level. It also discusses how reallocation of inputs and shifts in industrial structure affect aggregate productivity. Section 3 describes how we constructed our 34 industry dataset (Annex A does this in much more depth).(1) This dataset is for 1970-2000 and covers the whole economy. Our industry data were designed to be consistent with the national accounts, prior to several adjustments that we made mainly relating to the measurement of ICT output and investment. So in Section 4 we compare our estimates at the aggregate level with the national accounts. Section 5 then quantifies the effect of the various types of structural change that we identified in Section 2. Next Section 6 presents a growth accounting analysis of the market sector, ie the whole economy except for the government sector (defined as public administration and

(1) Annex A, along with Annexes B-D which deal with some of the theoretical issues in more depth, are available on the Bank of England website at www.bankofengland.co.uk/workingpapers/wp259techannex.pdf.

defence, health, and education) and also excluding the services of the housing stock. Here we quantify the contribution of ICT capital to the growth of labour productivity. In this section, we take it that the assumptions that lie behind growth accounting are true (to a sufficient degree of approximation). In the next section, Section 7, we test these assumptions econometrically, using our panel of 34 industries. Section 8 introduces a simple model to show the effect of unmeasured investment on TFP growth. We argue that, accompanying ICT investment, there is likely to be a significant amount of expenditure by firms on re-training and organisational change. This should be considered as a form of investment, which we call complementary investment. This investment leads to the accumulation of a stock of complementary capital. Since complementary investment is not measured as such, but is instead erroneously classified as intermediate consumption, the conventional measure of TFP growth is biased. We show that in a boom the absolute size of the bias is likely to increase, depressing the conventional measure below its true level. We test this idea econometrically on our panel of industries. Finally, Section 9 presents our conclusions.

2. Theoretical framework

Our framework is based on the growth accounting methodology developed and applied over many years by Domar, Hulten, Griliches, Jorgenson and others (see eg Domar (1961), Jorgenson and Griliches (1967), Jorgenson *et al* (1987), Jorgenson and Stiroh (2000a), and Hulten (2001)). This approach has now been codified in two OECD manuals (OECD (2001a) and (2001b)). Annex B[(2)] sets out the approach formally. Here we give an informal treatment.

The aggregate framework

The starting point is the familiar aggregate growth accounting equation:

Growth of GDP = Capital's share *times* growth of capital input + Labour's share *times* growth of labour input *plus* Aggregate TFP growth. **(1)**

Here GDP growth is a chain (Törnqvist) index of the growth of real value added in each of the industries; the weights are shares of each industry in aggregate nominal value added (nominal GDP). Similarly, the growth of capital is a chain index of the growth rates of the services (not stocks) of the various types of asset. And the growth of labour is a chain index of the various types of labour services (differentiated by age, gender and skill). Given the output, capital and labour aggregates, aggregate TFP growth can be estimated as the residual in **(1)**. This equation can be rearranged in per hour worked terms as:

Growth of GDP per hour worked = [Capital's share *times* growth of capital input per hour worked]
plus [Labour's share *times* growth of labour input per hour worked]
plus Aggregate TFP growth.

(2) Available on the Bank of England website at www.bankofengland.co.uk/workingpapers/wp259techannex.pdf.

Now define capital deepening as capital's share times the growth of capital input per hour worked and the labour quality contribution as the growth of labour input (human capital) per hour worked weighted by labour's share. Then we can rewrite the last equation as:

Growth of average labour productivity (ALP) = Capital deepening
plus Labour quality contribution *plus* Aggregate TFP growth. **(2)**

Note the symmetric treatment of capital and labour. The growth of aggregate capital (labour) services is constructed as a weighted average of the growth rates of each type of capital (labour) service; the weights are the shares of each type in aggregate profit (wage bill). In the case of labour, the unit of service is hours worked. So the growth of labour input is the weighted growth rate of hours worked. The growth of labour quality is defined as the growth of labour input minus the unweighted growth of hours worked, ie the growth rate of a simple sum of hours worked. In the case of capital, the flow of each type of services is assumed to be proportional to the corresponding stock: by convention, one 1995 pound's worth of an asset yields a service flow of one 1995 pound per annum.

Building up from the industry level

The next step is to build up the aggregate relationship of equation **(2)** from corresponding relationships at the industry level. Let us start with the production function for industry *i*:

$$Y_i = f^i(K_i, L_i, M_i, t). \qquad \textbf{(3)}$$

Here Y is *gross* output, K is capital services, L is labour services, M is intermediate input (an aggregate of purchases from all the industries), and t (time) indexes efficiency (TFP). This equation can be used to derive the growth of real value added: see Annex D.[(3)] It can also be used to derive the growth of industry-level TFP:

Growth of TFP in industry *i* = Growth of gross output of industry *i*
minus share-weighted growth of inputs of *K*, *L* and *M* into *i*. **(4)**

The crucial link between the industry TFP rates and the aggregate TFP growth rate is provided by the concept of *Domar aggregation* (Domar (1961)):

Aggregate TFP growth rate = Domar-weighted sum of industry TFP growth rates **(5)**

where the *Domar weight* for industry *i* is:

Nominal gross output of industry *i* ÷ Nominal GDP

and the aggregate TFP growth rate is defined by equation **(1)**. Note that the Domar weights sum to more than 1. Equation **(5)** can be shown to hold exactly if any given input (eg university-educated female employees aged 30-34) is paid the same wage in all industries. If this is not the case, then

(3) Available on the Bank of England website at www.bankofengland.co.uk/workingpapers/wp259techannex.pdf.

the equation for aggregate TFP growth also contains terms reflecting the reallocation of capital and labour towards or away from higher value uses (Jorgenson *et al* (1987)).

The more general result is that equation **(1)** defines the Solow residual:

Solow residual = Growth of output per hour *minus* Physical and human capital deepening.

The relationship between the Solow residual and TFP growth is then:

Solow residual = Aggregate TFP growth *plus* Reallocation **(6)**

where TFP growth is calculated by **(5)** and reallocation is calculated as the residual. The reallocation term is positive if inputs are moving from low to high return industries.

A similar decomposition can also be derived for the aggregate capital deepening term in equation **(2)**; see Annex B again:(4)

Aggregate capital deepening = Domar-weighted sum of industry-level capital deepening *plus* Reallocation effect. **(7)**

Capital deepening in industry *i* is defined analogously to the aggregate definition. It is the share of capital in industry *i times* the growth rate of capital per hour worked in *i*. Note that the same Domar weights appear in the decomposition for TFP growth and in the one for capital deepening. The reallocation effect is positive if hours worked are growing more rapidly in industries with a high *level* of capital intensity. It would be zero *either* if capital intensity were the same in all industries *or* if hours worked were growing at the same rate in all industries.

There is no reallocation effect for TFP in the absence of input price distortions, but capital deepening can be affected by reallocation even in the absence of any distortions. It might be asked why this is so. The answer is that, under the competitive assumptions made here, and in the absence of input price distortions, the *level* of TFP is the same in all industries (Baumol and Wolff (1984); Oulton (2001a)). This is because, were TFP (measured in current prices) to be higher in one industry than in another, it would imply higher profits in that industry; resources would then flow to that industry, thus driving down its output price and eliminating the TFP gap. Hence in equilibrium there is no gain to TFP in reallocating resources. But there is no reason why the labour productivity level should be the same in all industries. Some industries are inherently more (human or physical) capital intensive than others, so reallocation effects do arise from capital deepening.

These decompositions cover the input side. We can also do a decomposition for the output side: see Annex C.(5) This divides aggregate ALP growth into a part due to ALP growth in individual industries and a part due to shifts in employment towards or away from industries with a high *level* of labour productivity. Since industry outputs are in different units, the comparison of levels must be in value terms, at a point in time. The decomposition is:

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(4) This decomposition of capital deepening seems to be a new result.
(5) Available on the Bank of England website at www.bankofengland.co.uk/workingpapers/wp259techannex.pdf.

Growth of aggregate ALP = Value-added-weighted sum of industry ALP growth rates *plus* Reallocation effect. **(8)**

Here the weights are shares in nominal value added (nominal GDP) and sum to 1. The reallocation effect would be zero either if the nominal level of labour productivity were the same in all industries or if labour input were growing at the same rate in all industries.

3. The Bank of England industry dataset (BEID)

We use a new industry dataset developed at the Bank of England, containing annual data for 34 industries spanning the whole UK economy, running from 1970 to 2000. For each industry, we have gross output, value added, and inputs of capital services, labour services, and intermediate goods and services, in both nominal and real terms. A full account of our methods and sources is in Annex A.(6) The list of industries is shown in Table 3.1.

The starting point was a dataset on nominal gross output, value added, and domestic and imported intermediate input, and associated price indices, for 49 industries. This was prepared for us to our specification by a private sector economic consultancy, Cambridge Econometrics (CE). To this we added our own estimates of labour and capital input, finishing up with a dataset of 34 industries. The reduction from 49 to 34 industries was mainly necessitated by our desire to measure ICT capital services separately.

We constructed our own dataset since nothing comparable is currently available from official sources. The raw materials for our dataset are of course the series collected by the Office for National Statistics (ONS) and used by them to construct the national accounts. But these series are not put together in the form required for productivity analysis. For example, no official measures of ICT capital stocks or services have so far been produced. On the labour side, total hours worked are published only at the aggregate level, not by industry. On the output side, only real value added is published by industry, not real gross output. And there are no official measures of real intermediate input.(7)

An important principle behind the construction of the dataset is that it should be as far as possible consistent with the national accounts, both in nominal and real terms. The reason is that, unless the industry data when aggregated up match the aggregate data, no hypothesis which happens to fit the industry data will carry much conviction as an explanation of the behaviour of the whole economy. Since the national accounts are continually revised, the dataset can only be consistent with the accounts at a specific point in time. In the present case, this means consistent with the 2002 *Blue Book*, the latest available when our work began. For the period 1992-2000, nominal consistency is relatively easy to achieve since for this period we have the Input-Output Supply and Use Tables and these data are themselves consistent with the 2002 *Blue Book*. The Supply and Use Tables (SUTs)

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(6) Available on the Bank of England website at www.bankofengland.co.uk/workingpapers/wp259techannex.pdf. The analyses reported in Groth *et al* (2004) also employ this dataset.

(7) See Oulton (2004) for more on how the national accounts could better serve needs of productivity analysis.

give gross output, value added, profits, the wage bill and intermediate purchases (domestic plus imports), all in nominal terms, for 123 industries and products. So we can ensure that, for our original 49 industries, these series match those of the SUTs. Prior to 1992, detailed nominal consistency is harder to achieve, though we can ensure that it holds for broad sectors.

Real consistency means that, when we aggregate our industry estimates of real output up to the aggregate level, the growth rate of the aggregate should equal that of the official estimate of GDP. In fact, we make a number of adjustments to our output estimates (described below) so that neither real nor nominal consistency holds for the series we eventually employ to estimate TFP growth. But real consistency does hold for the output series prior to these adjustments. Actually, we do find a small difference between the growth of our aggregate and the official estimate of GDP growth, which arises from our figure of GDP growth being derived at a higher level of aggregation than that of the ONS. Hence we make a common adjustment to the growth of each of our industries to eliminate this discrepancy.

A second important principle behind the dataset is that industry output should be measured gross, so that proper account can be taken of the contribution of intermediate input. An input-output approach was therefore necessary, so something needs to be said about the availability of input-output tables in the United Kingdom. For the period 1992-2000 we have the 2002 edition of the SUTs. These are fully consistent with the 2002 national accounts and use the 1992 Standard Industrial Classification (SIC). However, they give only total purchases by each industry, not the breakdown into domestic and imported purchases. For 1989-91, we have earlier versions of the SUTs. These are not fully consistent with the national accounts and they use the 1980 SIC. Prior to 1991 there are no annual SUTs. But we do have full input-output tables for selected years. These give the breakdown into domestic and imported purchases but within our period they are only available for 1968, 1974, 1979, 1984, 1990 and 1995. Furthermore, the SIC according to which industries are defined and the conceptual basis of the tables has changed in significant ways over time.

These earlier input-output tables were converted to a common SIC and price concept. This was possible since they all break down the economy into considerably more than 49 industries. They were also made consistent with the 2002 national accounts. Intervening years were then interpolated using national accounts totals as controls.(8)

For 1992-2000, nominal gross output and intermediate purchases come from the 2002 Supply and Use Tables. These tables do not split purchases into domestic and intermediate. This split and similar data for earlier years were constructed for us on a consistent basis by Cambridge Econometrics, for 49 industries. They also supplied us with price indices for domestic output and imports at the same level of aggregation. For each industry, the growth of real intermediate input is then derived as a weighted average of the growth of purchases from all of the other industries and

(8) This part of the work was performed by Cambridge Econometrics.

from imports, each deflated by the appropriate price index. Our series for real value added at the industry level derive from the national accounts.[9]

Capital services cover four types of non-ICT capital and three types of ICT capital. The non-ICT assets are structures, plant and machinery (equipment), vehicles, and intangibles. The three ICT assets are computers, software and communication equipment. The real capital input index is a rental-price weighted average of the growth rates of these asset stocks; see Oulton and Srinivasan (2003) for a full account of the methodology, which is based on Jorgenson (1989).

Labour services are measured as quality-adjusted hours worked and are built up in a number of steps. First, we estimate total usual hours, for each industry, as the number of employees (from the Annual Business Inquiry (ABI) and its predecessors) plus self-employed (from the Labour Force Survey (LFS)) times usual hours per week (from the New Earnings Survey (NES)). Second, we apply two aggregate adjustments. The first is to constrain the growth of total hours to conform to the official index of aggregate hours worked (ONS code: YBUS). This introduces an element of cyclical variability into our hours worked index, though at the same rate in all industries. The second aggregate adjustment is to apply a correction for changes in labour quality, mainly due to rising levels of educational attainment. The quality adjustment is borrowed from the whole economy measure developed by Bell, Burriel-Llombart and Jones (2005). Their index of labour input is a Törnqvist one that allows for changes in the composition of the labour force by age, gender and qualifications.[10] The growth of labour quality is then measured as the growth of aggregate labour input minus the growth of aggregate hours worked.

Turning to the adjustments we have made to the national accounts, the most important relate to the treatment of ICT. Because we want to be able to compare our results with those for the United States, we need to use the same methodology to derive ICT capital services in both countries. We therefore assume that computers, software and communications equipment depreciate geometrically at rates similar to those used in studies of the United States (eg Jorgenson and Stiroh (2000a)), which are in turn based on those used by the Bureau of Economic Analysis (BEA) in the US National Income and Product Accounts. We also employ US price indices, converted to sterling terms, to deflate current price investment in computers and software. US ICT prices generally fall faster than UK ones, so this means that our ICT capital and investment measures will grow more rapidly. The UK is also an ICT producer, so we have made corresponding adjustments to the growth rates of output of the ICT industries.

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(9) In practice the ONS proxies real value added by real gross output. As explained in Annex D, this means that the expenditure and output measures of the real growth rate of GDP are no longer equal even in principle (of course they would differ in practice because of errors and omissions). For equality to hold in principle, inputs and outputs of each industry have to be deflated separately ('double deflation'). The ONS overcomes this difficulty by adjusting growth in the private services industries so that the output measure conforms to the expenditure one; the latter is believed to be the more reliable. As an alternative to using the national accounts series, we experimented with deriving our own estimates of double-deflated value added. But we found that such series, when aggregated across industries, failed to match the growth rate of GDP at all closely (see Annex A).

(10) It would clearly be desirable to measure the deviation of actual hours from usual hours at the industry level, but the only source for this would be the LFS. Unfortunately, the breakdown of employment by industry derived from the LFS is quite different from the breakdown yielded by the employer-based survey (the ABI) and the latter is considered the more reliable in this respect. A similar difficulty arises if one attempts to use the LFS to derive indices of quality adjustment at the industry level.

In addition, we have made a large adjustment to the official nominal level of software investment, multiplying it by a factor of three, for reasons discussed in Oulton (2001b, Appendix C) and (2002); see also Ahmad *et al* (2003). (This entails making a corresponding adjustment to each industry's profit and value added.) Compared with the United States, official software investment is very low relative to computer investment; also, a much lower proportion of the sales of the computer services industry is classified as investment. The 'times three' adjustment can be justified as putting the two countries on the same footing methodologically; we would also claim that the adjustment brings us closer to the truth.

Since productivity is our focus, we have excluded housing services from GDP. In the national accounts housing services (the rents paid by tenants and the imputed rent of owner-occupiers) constitute an industry without any associated employment.

Finally, we have given the banking sector a larger weight by excluding the (negative) 'adjustment for financial services'. This moves part of the way towards the treatment recommended in ESA95: see Annex A for more detail. If banking output grows more rapidly than the rest of GDP, our treatment raises the growth of GDP relative to the official estimate.

The next step is to compare our estimates at the aggregate level with the official ones, first in order to verify that we have (prior to the various adjustments) achieved consistency with the national accounts, and second to show the effect of the adjustments.

Table 3.1
The 34 industries used in the empirical analysis

	Industry	*SIC92*	*Share of value added in GDP (per cent)*	
			1970	*2000*
1	Agriculture	01,02,05	2.85	1.08
2	Oil and gas	11,12	0.07	2.78
3	Coal & other mining	10,13,14	1.04	0.30
4	Manufactured fuel	23	0.56	0.33
5	Chemicals & pharmaceuticals	24	2.06	1.90
6	Non-metallic mineral products	26	1.33	0.63
7	Basic metals & metal goods	27,28	3.65	1.99
8	Mechanical engineering	29	7.79	1.51
9	Electrical engineering & electronics	30,31,32,33	2.52	2.68
10	Vehicles	34,35	3.89	1.91
11	Food, drink & tobacco	15,16	3.07	2.51
12	Textiles, clothing & leather	17,18,19	3.64	0.81
13	Paper, printing and publishing	21,22	1.89	2.53
14	Other manufacturing	20,25,36,37	2.31	2.01
15	Electricity supply	40.1	2.07	1.15
16	Gas supply	40.2,40.3	0.63	0.43
17	Water supply	41	0.20	0.35
18	Construction	45	6.02	5.38
19	Wholesale, vehicle sales & repairs	50,51	7.80	7.04
20	Retailing	52	4.03	5.53
21	Hotels & catering	55	2.12	3.45
22	Rail transport	60.1	0.17	0.32
23	Road transport	60.2,60.3	2.67	2.13
24	Water transport	61	0.04	0.20
25	Air transport	62	0.36	0.67
26	Other transport services	63	1.97	1.97
27	Communications	64	2.37	3.20
28	Finance	65, 66	5.78	4.99
29	Business Services[a]	67, 70,71,72,73,74	5.76	17.00
30	Public administration and defence	75	6.26	5.01
31	Education	80	4.18	6.06
32	Health and social work	85	3.31	6.91
33	Waste treatment	90	2.38	0.62
34	Miscellaneous services	91-99	5.20	4.63
	WHOLE ECONOMY[a]		100.00	100.00

Note: SIC92 is the 1992 version of the UK's Standard Industrial Classification. It is identical to the European NACE system. Details on SIC92 industry codes can be found at http://www.statistics.gov.uk/methods_quality/sic/contents.asp. Value added adjusted as described in Section 3. Industries 1-29, 33 and 34 constitute the market sector.

a. Excluding housing services.

4. Comparing the BEID with the national accounts

We first check how much difference our adjustments make to the growth rate of aggregate output. The left-hand panel of Table 4.1 compares the official measure of GDP growth, with and without housing services, with the measure derivable from the BEID. Our measure is estimated as an annually chain-linked average of the growth rates of real value added in our 34 industries. Recall that, prior to the adjustments listed above, the growth rates of the official and BEID measures were constrained to be equal.(11) We consider first the effect of excluding housing services. Chart 4.1 compares the official measure of the growth of GDP at basic prices [ONS code ABMM], which includes housing services, with the same measure after housing services have been excluded (by us). The exclusion of housing clearly makes very little difference. Chart 4.2 compares the official measure (after housing has been excluded by us) with our own (BEID) measure of GDP growth (which also excludes housing services). There is a clear tendency for the BEID measure to exceed the 'official' one, though the time path of the two measures is similar. Over the whole 30-year span, the BEID measure exceeds the 'official' one by 0.32 percentage points per year. For the most recent years the divergence is due to the ICT adjustments, for earlier years the treatment of the banking sector is mainly responsible.

Chart 4.3 makes the same comparison for a productivity measure (see also the right-hand panel of Table 4.1). The only difference from Chart 4.2 is in the numerator; the denominator of both measures is total hours worked [ONS code YBUS]. Finally, within the BEID, we consider the effect of removing the government sector (industries 30, 31 and 32). Chart 4.4 compares growth of labour productivity (output per hour worked) in the whole economy with growth in the market sector (defined as the whole economy less the government sector). Labour productivity has grown more rapidly in the market sector. Over the whole 30-year span, the difference was 0.42 percentage points per year; in the 1990s the difference was 0.52 per percentage points per year (see Table 4.1). There are well known difficulties in measuring the volume of government output, so lower productivity growth in the government sector should not necessarily be taken at face value.(12) This illustrates in fact one of the uses of the BEID: it enables us to strip out any sector that may be distorting the aggregate picture or indeed build up estimates for sectors of the economy from the bottom up. Finally, note that whichever output concept we employ, the growth of output accelerated and that of productivity decelerated in the second half of the 1990s (see Table 4.1, last line).

(11) That is, prior to adjustments, the growth rate of the BEID measure of GDP was constrained to equal that of official GDP at 1995 basic prices [ABMM] as at the time of the 2002 *Blue Book*.

(12) In 1998 the ONS started to implement the recommendations of ESA95 for measuring government output. This entails measuring real output by a cost-weighted average of a set of physical indicators. Currently, some 70% of government output is covered by this new methodology. But the new methodology has only been applied to data from 1986 onwards. Prior to then, the figures reflect the older methodology under which output was measured by input (primarily labour).

Table 4.1
Output and labour productivity, various concepts: average annual growth rates, % per annum

	Output				*Labour productivity*		
	ONS GDP at basic prices [ABMM]	ONS GDP at basic prices, exc. housing	BEID[a] GDP, whole economy		ONS GDP at basic prices, exc. housing, per hour	BEID[a] GDP per hour, whole economy	BEID[a] GDP per hour, market sector
Period	(1)	(2)	(3)		(4)	(5)	(6)
1970-2000	2.24	2.29	2.61		2.45	2.78	3.20
1970-1979	2.16	2.15	2.54		2.98	3.38	3.62
1979-1990	2.22	2.29	2.70		1.75	2.15	2.62
1990-2000	2.34	2.40	2.58		2.76	2.94	3.46
1990-1995	1.83	1.86	1.88		3.41	3.44	3.99
1995-2000	2.84	2.93	3.28		2.10	2.45	2.93
Change	*+1.01*	*+1.07*	*+1.40*		*-1.31*	*-0.99*	*-1.05*

a. Bank of England Industry Dataset.
Notes: Columns (4), (5) and (6): Hours worked for the whole economy are total weekly hours from the *Labour Force Survey* [ONS code YBUS] for 1993-2000; data for earlier years come from an internal Bank of England estimate. Market sector hours worked are our own estimate and are consistent with the whole-economy figures: see Annex A.

Chart 4.1

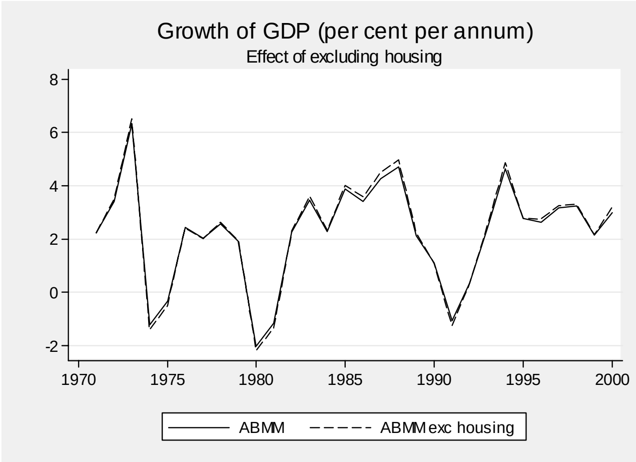


Chart 4.2

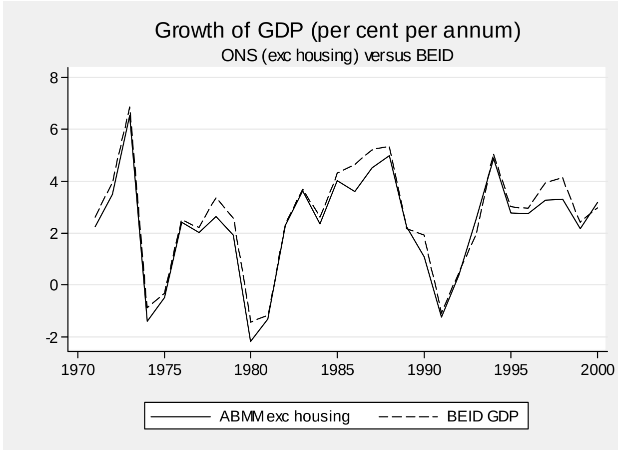


Chart 4.3

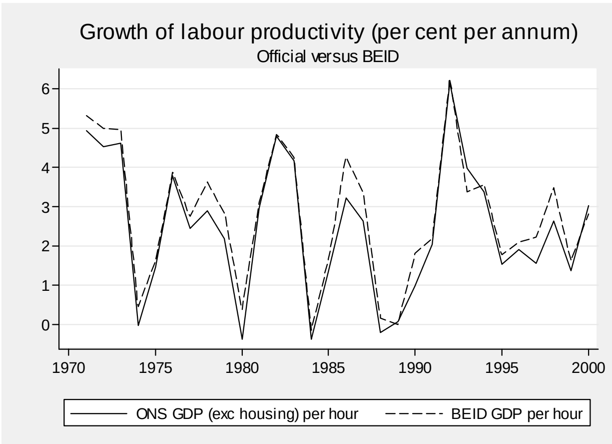
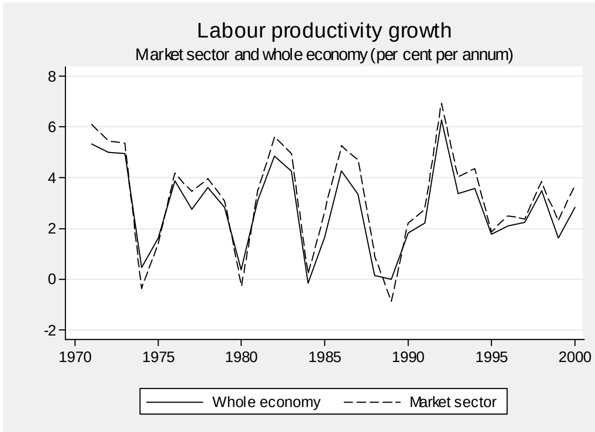


Chart 4.4



5. Structural change

We consider the effect of various forms of structural change on the overall growth of the economy, using from now on the BEID and concentrating on the market sector.

Inter-relatedness

The first form of structural change that we consider is the degree of inter-relatedness of domestic industries. This is measured by the sum of the Domar weights. If this sum is rising, then industries are on average buying proportionately more from each other. Recall that according to equation **(5)**

Aggregate TFP growth rate = Domar-weighted sum of industry TFP growth rates **(5)**

where the *Domar weight* for industry *i* is:

Nominal gross output of industry *i* ÷ Nominal GDP.

For given rates of TFP growth in each industry, a rise in the sum of the Domar weights leads to an increase in the aggregate growth rate of TFP. In economic terms, this situation could arise if the demand for purchased inputs is elastic and if their relative price is falling (Oulton (2001a)). Chart 5.1 shows that the Domar sum has indeed been rising (apart from a dip in the early 1980s), by some 12% between 1970 and 2000. Suppose that the Domar weights had remained at their average level over 1970-74 throughout our period. What would have been the effect on the growth of TFP in the market sector, assuming hypothetically that the industry TFP growth rates had remained unchanged? Using equation **(5)**, we find that as a result of the actual rise in the Domar weights compared with this hypothetical alternative of constant weights, TFP growth in the market sector would have been changed by the following amounts:

1970-1979:	+0.20% per year
1979-1990:	-0.28% per year
1990-2000:	+0.33% per year

So this form of structural change has had a significant effect on aggregate TFP performance.

Shifts in the composition of output

A second aspect of structural change is a shift in the pattern of output towards industries with a high or low *level* of labour productivity. This composition effect can lead to the growth rate of aggregate labour productivity diverging from the average growth rate in the individual industries. Define average labour productivity (ALP) in industry *i* as real value added per hour worked:

$$Q_i = V_i / H_i$$

and at the aggregate level define it as:

$$Q = V / H$$

where V is value added, H is hours worked, and $H = \sum_{i=1}^{n} H_i$. Let the share of the *i*th industry's value added in aggregate value added (nominal GDP) be:

$$s_i = p_i^V V_i / p_V V, \quad \sum_{i=1}^{n} s_i = 1$$

where p_i^V is the price of value added in industry *i* and p_V is the price of GDP. Let the share of hours worked in industry *i* in aggregate hours worked be:

$$r_i = H_i / H, \quad \sum_{i=1}^{n} r_i = 1.$$

By definition, the growth of aggregate labour productivity is:

$$\hat{Q} = \hat{V} - \hat{H}$$

and we can show (see Annex C) that this can be decomposed as follows:

$$\hat{Q} = \sum_i s_i \hat{Q}_i + \sum_i r_i \left(\frac{p_{iV} Q_i}{p_V Q} - 1 \right) (\hat{H}_i - \hat{H}) .$$

The first sum on the right-hand side is the contribution of productivity growth within industries, the 'within' effect. The second sum is the shift effect. It is positive if employment is shifting towards industries with a high *level* of labour productivity. The shift effect would be zero *either* if the productivity level (in value terms) were the same in all industries *or* if the growth rate of labour input were the same in all industries. Chart 5.2 shows aggregate ALP growth together with the within and shift effects for the whole economy. The shift effect increased productivity growth by 0.07 percentage points per year over 1979-90 and reduced it by 0.13 percentage points per year over 1990-2000; see Table 6.3 below for similar results for the market sector. Hence almost all of aggregate labour productivity growth has been due to productivity growth within industries.

Chart 5.1

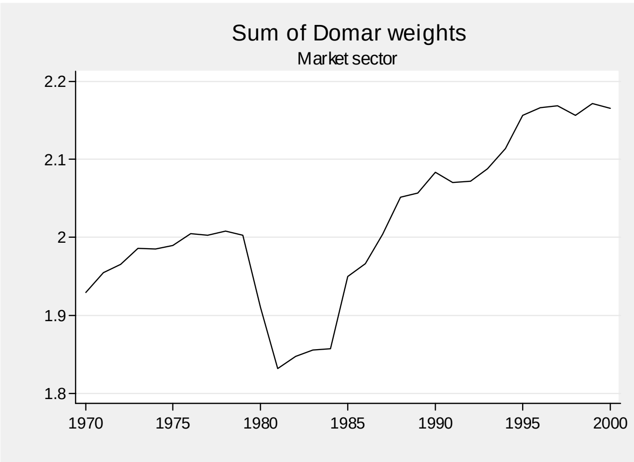
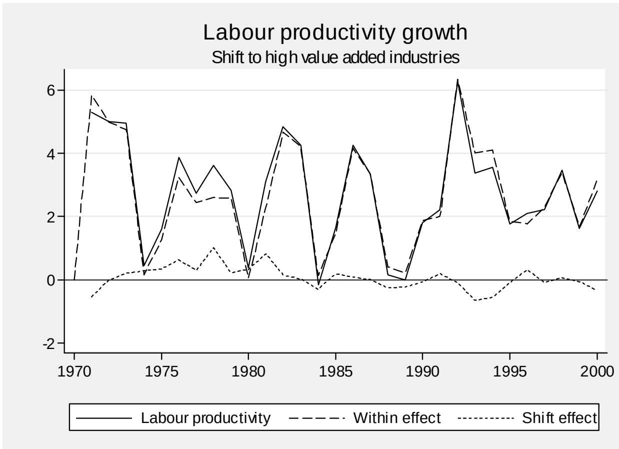


Chart 5.2



6. A growth accounting analysis of the market sector

Table 6.1 shows the growth rate of labour productivity in the market sector and its components. What we call here the Solow residual is calculated as:

Solow residual = Growth of output per hour *minus* Physical and human capital deepening.

Recall that the relationship between the Solow residual and aggregate TFP growth was given in equation **(6)** in Section 2 above as:

Solow residual = Aggregate TFP growth *plus* Reallocation

where reallocation is calculated as the residual and is positive if inputs are moving from low to high return industries. The growth of output per hour is calculated as a Törnqvist index of the industry value added growth rates *minus* the growth rate of hours worked in the market sector. Physical capital deepening is calculated as a Törnqvist index of the industry growth rates of capital services *minus* the growth rate of hours worked, all multiplied by the capital share. Human capital deepening is estimated as the growth of labour quality in the whole economy (from Bell, Burriel-Llombart and Jones (2005)), multiplied by labour's share of market sector GDP. Aggregate TFP growth in the market sector is built up from the industry TFP growth rates by Domar aggregation: see equation **(5)** above.

Using our dataset, labour productivity in the market sector was growing at 3.62% per year in 1970-79, at 2.62% per year in 1979-90 and at 3.46% in 1990-2000 (Table 6.1, column 1). The figure for the first of these three decades is flattered a bit by the period 1970-73, the last years before the first oil shock after which growth slowed down. While labour productivity grew more rapidly in the 1990s than in the 1980s, nevertheless growth slowed after 1995. It is worth noting in passing that while labour productivity (and output too) have been rising over these three decades, total hours worked have been falling at an annual average rate of 0.39% per year. In the 1990s hours first fell then rose but without recovering their former level (Table 6.1, column 7, and Chart 6.1). On average, though the number of workers has been rising, hours per worker have been falling. This is due partly to the rise in part time employment, partly to a fall in hours worked per full-time worker.

On average, TFP growth was quite high in the 1970s, fell in the 1980s, and recovered in the 1990s (Table 6.1). However, like labour productivity growth, it fell in the second half of the 1990s: see Chart 6.2. The latter chart also shows that the time pattern of TFP growth is very similar to that of labour productivity. The simple correlation between the two growth rates, 1970-2000, is 0.90. This suggests that a significant part of the variation of TFP may be cyclical. Recall that our TFP estimates are not adjusted for variations in input utilisation. Table 6.1 and Chart 6.4 show that the effect of reallocation has been negative since 1979, so that the Solow residual is somewhat lower than TFP growth.

In the 1990s physical capital deepening occurred at a faster rate than in the preceding 20 years. Growth was particularly rapid post 1995 (Table 6.1 and Chart 6.5). Capital deepening results partly from an increase in the capital intensity of individual industries (the 'within' effect) and partly from a shift towards or away from industries with a higher *level* of capital intensity (the 'shift' effect): see equation **(6)**. Charts 6.6, 6.7, and 6.8 show that the shift effect is negligibly small whether we look at ICT, non-ICT or total capital deepening. In other words, capital deepening in the market sector derives from a general increase in capital intensity, not from structural change.

The contribution of human capital deepening has been rising steadily, though in contrast to physical deepening there was some decline in its growth rate post 1995 (see Chart 6.3).[13] It is often asserted that the fall in the unemployment rate that occurred from 1993 onwards, by drawing in less qualified workers, caused a decline in the quality of the labour force. In fact, Chart 6.3 shows that labour quality growth has been positive throughout the 1990s. The explanation is that labour quality growth is the result of a number of factors, not just changes in the unemployment rate. Amongst these are the retirement of older, less well educated workers, the entry of younger, better

(13) Note that human capital deepening is assumed zero prior to 1976 due to lack of data.

educated workers, and the ageing of the labour force, which makes more experienced workers a higher proportion of the total — all factors making for a rise in labour quality.

Table 6.2 shows the relative importance of each component in accounting for labour productivity growth. Since 1979, input growth (capital deepening plus the labour quality contribution) has accounted for about three quarters of labour productivity growth, while capital deepening alone has accounted for more than half. TFP growth accounted for 28% of labour productivity growth in 1979-90 and for 35% in 1990-2000. Over these two decades the reallocation effect was negative, though fairly small in absolute size.

Table 6.1
Contributions to the growth of output per hour in the market sector: average annual growth rates, % per annum

	Output per hour worked	Physical capital deepening	Human capital deepening	Solow residual	Reallocation	TFP	*Memo item: hours*
Period	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1970-2000	3.20	1.77	0.36	1.07	-0.08	1.15	*-0.39*
1970-1979	3.62	1.86	0.02	1.74	0.17	1.57	*-1.18*
1979-1990	2.62	1.58	0.39	0.65	-0.08	0.73	*0.43*
1990-2000	3.46	1.89	0.64	0.92	-0.30	1.22	*-0.59*
1990-1995	3.99	1.62	0.84	1.53	-0.19	1.72	*-1.97*
1995-2000	2.93	2.16	0.45	0.32	-0.40	0.73	*0.78*
Change	*-1.05*	*+0.54*	*-0.39*	*-1.20*	*-0.21*	*-0.99*	+2.76

Notes: (1) Relationship between columns: (a) Col. (4) = Col. (1) – Col. (2) – Col. (3);
(b) Col. (5) = Col. (4) – Col. (6).
(2) TFP growth is measured as the Domar-weighted sum of industry TFP growth rates.

Table 6.2
Contributions to the growth of output per hour in the market sector:% of total

	Physical capital deepening	*of which:* *ICT capital deepening*	*non-ICT capital deepening*	Human capital deepening	Solow residual	Reallocation	TFP	Total
Period	%	%	%	%	%	%	%	%
1970-2000	55.3	*22.5*	*32.8*	11.3	33.4	-2.4	35.8	100.0
1970-1979	51.4	*12.9*	*38.5*	0.4	48.2	4.7	43.5	100.0
1979-1990	60.3	*26.3*	*34.1*	15.0	24.7	-3.0	27.7	100.0
1990-2000	54.7	*28.2*	*26.4*	18.6	26.7	-8.6	35.3	100.0
1990-1995	40.7	*14.7*	*26.0*	21.0	38.3	-4.8	43.1	100.0
1995-2000	73.6	*46.6*	*27.0*	15.4	11.0	-13.7	24.8	100.0
Change	*+33.0*	+31.9	+1.0	*-5.7*	*-27.3*	*-8.9*	*-18.4*	*0.0*

Source: Tables 6.1 and 6.4.

Chart 6.1

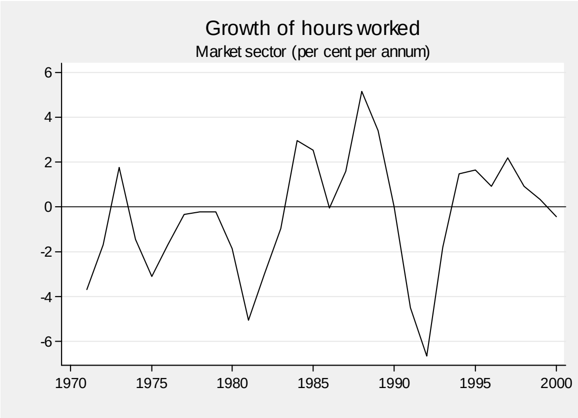


Chart 6.2

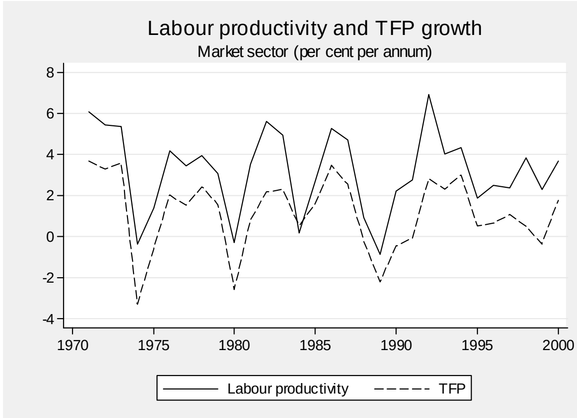


Chart 6.3

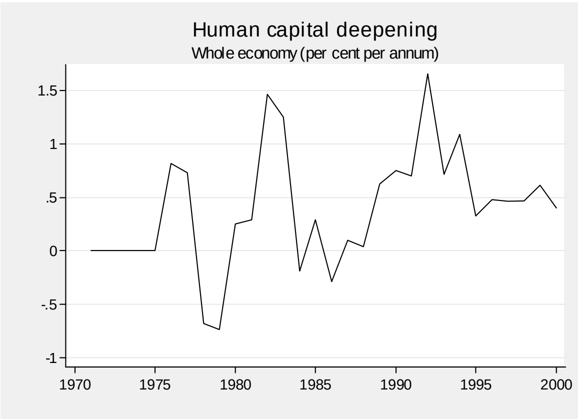


Chart 6.4

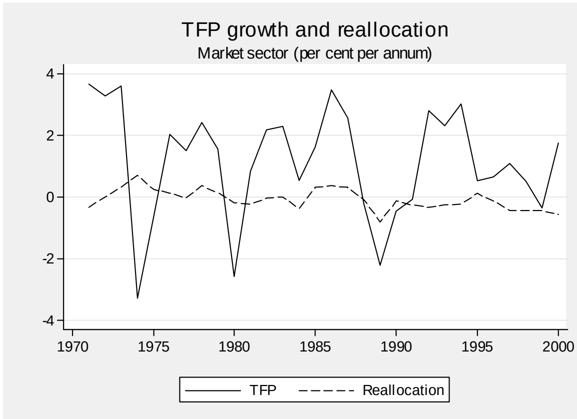


Chart 6.5

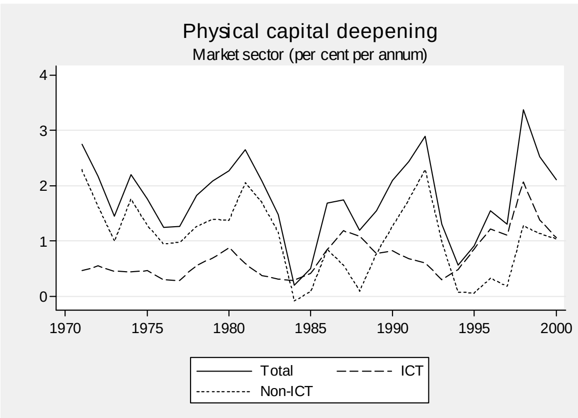


Chart 6.6

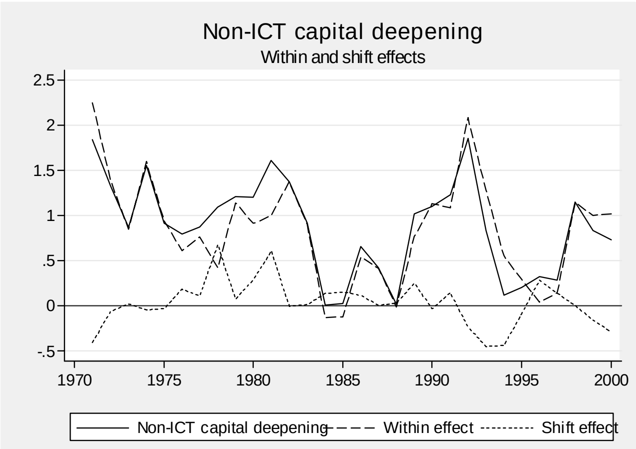


Chart 6.7

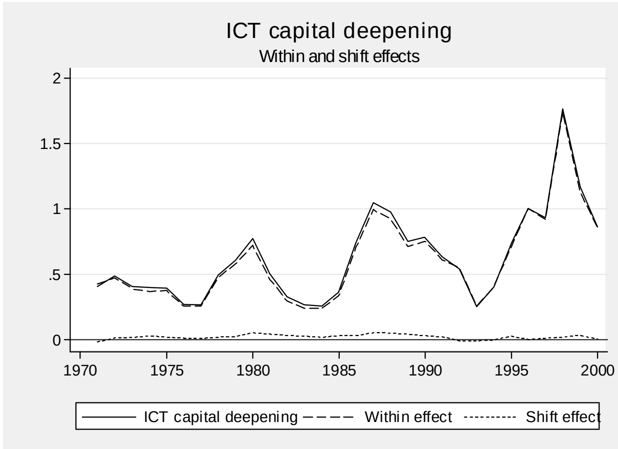
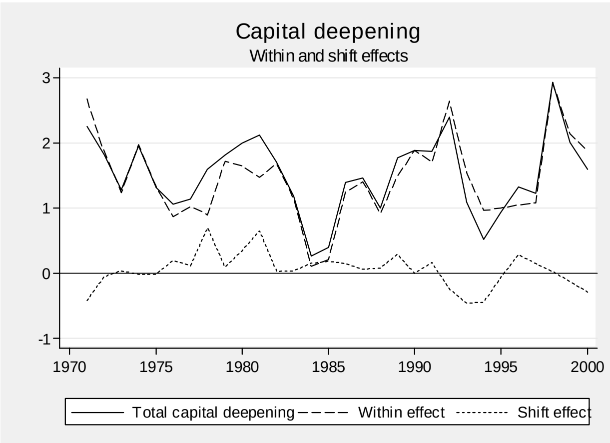


Chart 6.8



We now look more closely at the contributions of the 31 industries that make up the market sector: see Table 6.3. Here the contribution of an industry to labour productivity growth in the market sector is measured by its share in market sector value added multiplied by the growth rate of labour productivity in that industry. Its contribution to TFP growth in the market sector is its Domar weight multiplied by its TFP growth rate. Four industries had negative labour productivity growth in 1979-90 (Hotels & catering, Waste treatment, Manufactured fuels, and Water transport) and two in 1990-2000 (Hotels & catering and Non-metallic mineral products). No less than 12 had negative TFP growth in 1979-90, though this fell to seven in the latest period. The top five industries accounted for over half of labour productivity growth in 1979-90. These five were Chemicals, Vehicles, Finance, Electrical and electronic engineering, and Business services. In the subsequent decade, Finance, Electrical and electronic engineering, and Business services again appeared in the top five but now Chemicals and Vehicles drop out and are replaced by Wholesaling and Communications. So in the 1990s the only manufacturing industry to feature in the top five was the industry in which computers and semiconductors are located.

TFP growth is more concentrated by industry. The top five industries accounted for 96% of growth in 1979-90 and 62% in 1990-2000. In both periods, the largest contribution was made by Electrical and electronic engineering, which accounted for 44% of TFP growth in the first decade and 17% in the second. Finance and Communications were also in the top five for TFP growth in the later period, though not in the earlier one. In the earlier period, all of the top five industries were in the production sector, but in the later period only two of the five were.

Both Wholesaling and Retailing were important contributors to productivity growth in the 1990s. Together, they accounted for 16% of labour productivity growth and 15% of TFP growth in the market sector. But there was not much sign of a significant acceleration in growth over the decade. This makes a striking contrast with the United States where these industries were star performers in the 1990s: TFP growth rose in each by over 2 percentage points (Basu *et al* (2004)).

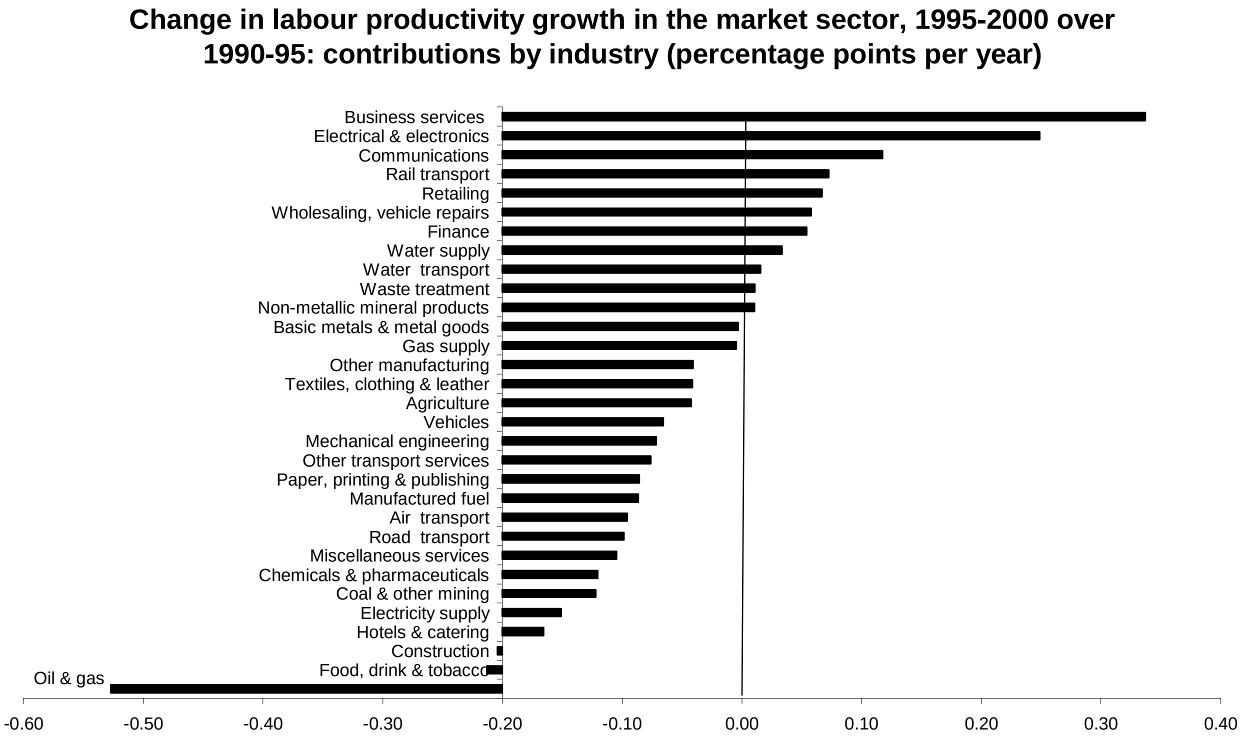
Both TFP and labour productivity growth were higher on average in the 1990s than in the 1980s. Nevertheless, as we have seen, productivity growth slowed down in the second half of the 1990s. Chart 6.9 shows the contribution of each industry to the *change* in labour productivity growth, comparing 1995-2000 with 1990-95; Chart 6.10 does the same thing for TFP growth. Labour productivity growth slowed down in 20 industries and accelerated in 11; the accelerators raised growth by 1.01% per year, while the decelerators lowered it by 2.31% per year. TFP growth slowed down in 21 industries; these industries lowered growth by 1.53% per year. Electrical and electronic engineering, Retailing, Finance, and Communications all featured amongst the industries with accelerating TFP, while Wholesaling was amongst the decelerators.

Table 6.3
Contributions to the growth rates of labour productivity and TFP in the market sector, by industry, 1979-90 and 1990-2000 (percentage points per year)

Industry		Labour productivity		TFP	
Number	*Name*	*1979-1990*	*1990-2000*	*1979-1990*	*1990-2000*
1	Agriculture	0.044	0.065	0.045	0.021
2	Oil & gas	0.078	0.219	-0.054	0.129
3	Coal & other mining	0.105	0.037	0.069	0.025
4	Manufactured fuel	-0.004	0.012	-0.006	0.011
5	Chemicals & pharmaceuticals	0.130	0.167	0.085	0.099
6	Non-metallic mineral products	0.016	-0.008	-0.009	-0.013
7	Basic metals & metal goods	0.102	0.046	0.078	0.004
8	Mechanical engineering	0.073	0.032	0.031	-0.005
9	Electrical & electronics	0.399	0.293	0.320	0.208
10	Vehicles	0.188	0.085	0.148	0.047
11	Food, drink & tobacco	0.105	0.081	0.038	0.025
12	Textiles, clothing & leather	0.047	0.056	0.022	0.021
13	Paper, printing & publishing	0.059	0.035	0.007	-0.021
14	Other manufacturing	0.055	0.021	0.027	-0.019
15	Electricity supply	0.071	0.145	0.043	0.047
16	Gas supply	0.033	0.105	0.010	0.060
17	Water supply	0.007	0.031	-0.002	-0.030
18	Construction	0.018	0.198	0.041	-0.002
19	Wholesaling, vehicle repairs & sales	0.119	0.304	-0.038	0.082
20	Retailing	0.119	0.282	0.008	0.100
21	Hotels & catering	-0.029	-0.032	-0.059	-0.102
22	Rail transport	0.012	0.059	0.006	0.046
23	Road transport	0.068	0.035	0.051	0.017
24	Water transport	-0.001	0.034	-0.001	0.024
25	Air transport	0.006	0.036	0.015	0.016
26	Other transport services	0.002	0.068	-0.020	0.016
27	Communications	0.107	0.300	0.050	0.149
28	Finance	0.190	0.283	-0.058	0.168
29	Business services	0.426	0.561	-0.024	0.066
33	Waste treatment	-0.016	0.019	-0.028	0.011
34	Miscellaneous services	0.051	0.106	-0.071	0.021
	Market sector: within component	2.58	3.67	0.73	1.22
	Market sector: reallocation	0.04	-0.21	—	—
	Market sector: total	2.62	3.46	0.73	1.22

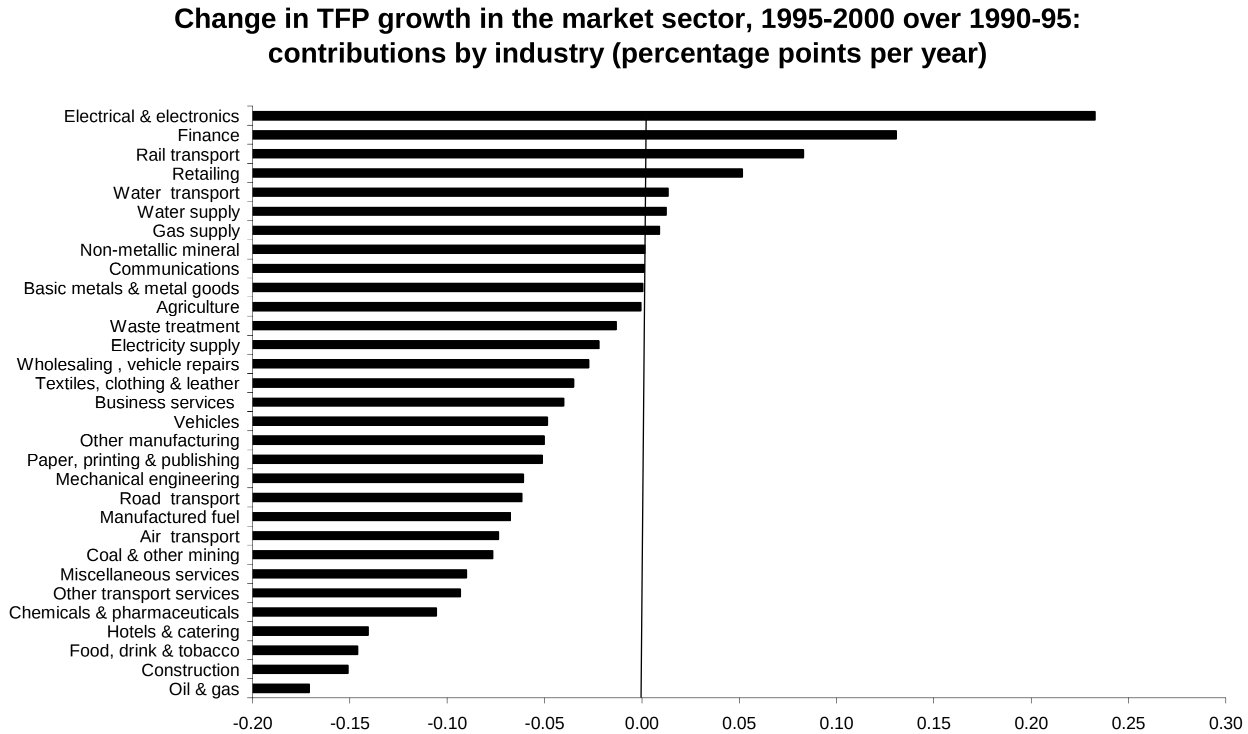
Note: See Table 3.1 for definitions of the industries in terms of the 1992 SIC. For TFP, the sum of the contributions gives TFP growth in the market sector (last line). For labour productivity growth, the sum of the contributions gives the within component. In addition there is the relocation component, measuring the shift towards or away from industries with a high level of labour productivity (see Section 5 and Chart 5.2). The sum of the within component and the reallocation component gives labour productivity growth in the market sector (as in Table 6.1, column 1).

Chart 6.9



Note: The contribution of any industry to aggregate labour productivity growth in a given period is the share of that industry in GDP multiplied by its labour productivity growth in that period, ie the 'within' measure.

Chart 6.10

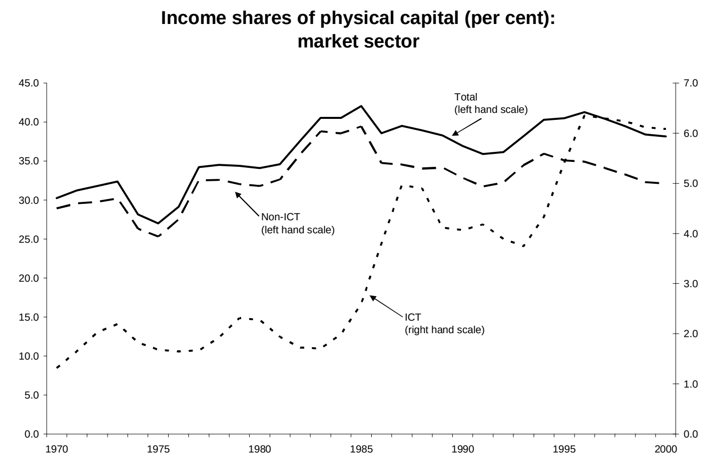


Note: The contribution of any industry to aggregate TFP growth in a given period is the Domar weight of that industry multiplied by its TFP growth rate in that period.

The role of ICT capital
We now turn to consider more specifically the role of ICT capital. Table 6.4 shows that ICT capital deepening accounted for a quarter of all physical capital deepening in the first of our decades, 1970-79 (see also Chart 6.5). By the third decade, 1990-2000, the share of ICT capital deepening had doubled. In the last five years of the century, the ICT share was nearly two thirds.(14) So contrary to Solow's joke, we could certainly have detected an important role for ICT even in the 1970s, if only we had known then how to look for it.

The contribution of ICT capital to the growth of labour productivity is the growth of ICT capital services per hour worked multiplied by the income share of ICT. Table 6.5 shows this decomposition. Over the three decades, ICT capital services per hour have grown at a remarkable 22.06% per year, while non-ICT services per hour grew at only 3.33% per year. Interestingly, ICT capital services were growing more rapidly in the 1970s than in the 1990s. But their contribution to overall deepening was lower. This was because in the 1970s the share of ICT capital in income (ie profit attributable to ICT assets as a proportion of GDP) was less than 2%, while by the 1990s it had tripled to more than 5%; in the last five years of the century it averaged 6% (Chart 6.11).

Chart 6.11



We can now evaluate the importance of ICT capital as a source of productivity growth in the UK market sector.(15) The results are shown in Table 6.2. ICT capital accounted for 13% of growth in 1970-79, 26% in 1979-90, and 28% in 1990-2000. In 1995-2000 the proportion rises to 47%. ICT capital, despite only being a small fraction of the total capital stock, contributed as much to growth as non-ICT capital in 1990-2000 and getting on for twice as much in 1995-2000.

Finally, it is important to note that ICT capital deepening was concentrated in a small number of industries in the 1990s (Chart 6.12). One industry, Business services, accounted for over a third of the total (34%). Next in order came Finance (14%), Communications (12%), Wholesaling (10%), and Retailing (5%). These top five industries, all private services, accounted for three quarters of the total. Amongst manufacturing industries, only the ICT-producing industry (Electrical

(14) Similar results for the whole economy were presented in Oulton (2001b).
(15) The proportion of labour productivity growth accounted for by ICT capital is the share of ICT capital in total capital deepening (Table 6.4) multiplied by the latter's share in accounting for labour productivity growth (Table 6.2).

engineering and electronics) and Paper, printing and publishing had a significant role. In total, manufacturing industries accounted for only 14% of ICT capital deepening in the market sector. Hence any study concentrating solely on manufacturing will miss the greater part of the impact of ICT.

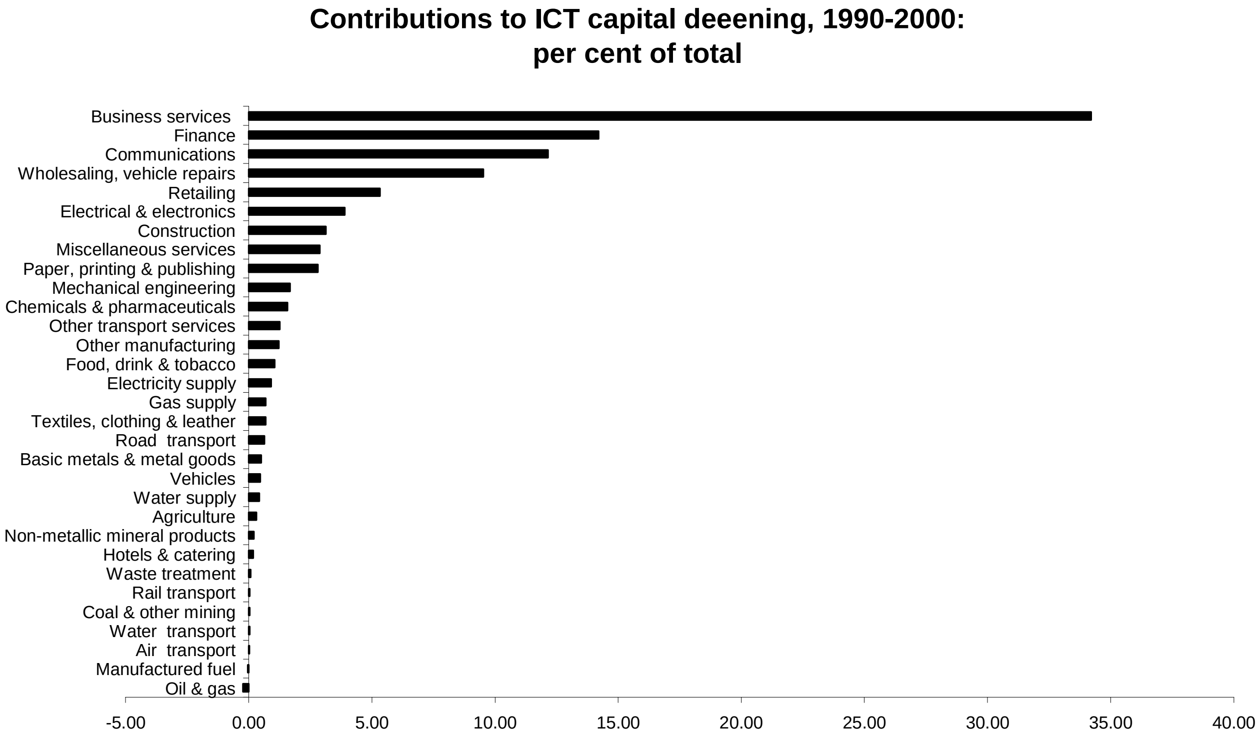
Table 6.4
ICT and non-ICT capital deepening in the market sector

	Capital deepening: average annual growth rates, % per annum				Proportion of total capital deepening, %		
	ICT capital	Non-ICT capital	Total capital		ICT	Non-ICT	Total capital
Period	(1)	(2)	(3)		(4)	(5)	(6)
1970-2000	0.72	1.05	1.77		40.6	59.4	100.0
1970-1979	0.47	1.39	1.86		25.2	74.8	100.0
1979-1990	0.69	0.89	1.58		43.5	56.5	100.0
1990-2000	0.98	0.91	1.89		51.6	48.4	100.0
1990-1995	0.59	1.04	1.62		36.1	63.9	100.0
1995-2000	1.37	0.79	2.16		63.3	36.7	100.0
Change	*+0.78*	*-0.24*	*+0.54*		*+27.2*	*-27.2*	*0.0*

Table 6.5
Sources of capital deepening in the market sector:
income shares and growth rates of ICT and non-ICT capital services

	Income shares (% of market sector GDP)				Capital services per hour: growth rates (% per annum)		
Period	ICT capital	Non-ICT capital	Total capital		ICT capital	Non-ICT capital	Total capital
1970-2000	3.39	32.84	36.23		22.06	3.33	5.00
1970-1979	1.83	29.48	31.30		25.57	4.76	5.98
1979-1990	3.03	34.95	37.98		22.89	2.64	4.27
1990-2000	5.15	33.53	38.69		18.01	2.79	4.94
1990-1995	4.27	33.71	37.98		13.79	3.20	4.39
1995-2000	6.08	33.61	39.69		22.22	2.39	5.48
Change	*+1.81*	*-0.10*	*+1.71*		*+8.44*	*-0.80*	*+1.09*

Chart 6.12



A comparison with the United States

We start by comparing the level of ICT capital in the United Kingdom with that in the United States. For the purpose of making this comparison, we need to apply as far as possible the same methodology to both countries. So we employ the same US price indices to deflate investment in computers and software in both countries (but adjusted for changes in the pound-dollar exchange rate) and we use BEA depreciation rates. We present estimates for 1992 onwards only, since the UK ICT investment data are less reliable prior to 1989 (given the high rates of depreciation assumed, three years suffices to generate a capital stock estimate).

For the United States, we use the BEA's estimates of the private net stocks of computers in current prices (from their Fixed Assets Tables). For the United Kingdom, there are no comparable official estimates. So we have constructed our own, using similar methods to those of the BEA. We estimate real investment in constant prices by deflating nominal investment in current prices by the official US price indices for 'computers and peripherals' and for software, converted to pounds sterling using the current exchange rate. For communications equipment we estimate real investment in constant prices by deflating nominal investment in current prices by the official UK price index.[16] The nominal investment series are those of the Office for National Statistics. We then estimate the real stocks of these assets assuming geometric depreciation occurs at 31.5% per

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[16] Telecommunications equipment in the United Kingdom is Industry 32.2 (SIC92). In the United States (following the classification in Jorgenson, Ho and Stiroh (2004)) communications equipment is in Industry 366 (SIC87). The US industry appears to encompass more than the UK industry so we use the UK price deflator for the United Kingdom; the ONS code is PQGT (PPI:3220000000) which refers to 'Television & radio transmitters, apparatus for telephony & telegraphy'.

annum for computers, at 40.0% per annum for software and at 11% per annum for communications equipment.[17] We convert these stocks (for computers and software) to current prices, using again the US prices converted to sterling terms. Finally, we convert all the stocks now valued in current pounds sterling to dollars, using the current dollar-pound exchange rate. For the United Kingdom, we estimate the stocks for each of our 34 industries. The private stock is then the aggregate stock less the stock held by the government sector (industries 30, 31 and 32).

In Table 6.6, we compare the stocks of computers and software in the market sectors of the UK and US economies. At the end of 1992 the US stock of computers was over six times that of the United Kingdom. In per capita terms it was 1.40 times the UK level. The software gap was wider. The US stock was nearly eight times the UK one at end-1992, or 107% higher in per capita terms. By the end of 2000 the per capita computer gap, though still in favour of the US, had narrowed to 5%. But in software the gap was nearly the same in 2000 as it had been in 1992. Recall that this gap is after we have applied the 'times three' adjustment to the official UK software investment series: without this adjustment the per capita gap would be over 400%. Oulton (2001b) argued that the true adjustment to UK software investment could be as high as a factor of 4.1, rather than 3 (see above). If so, the US-UK per capita ratio would fall to 1.26, suggesting a still substantial gap of 26%.

That there is a large gap in software is confirmed by physical measures. For example, in July 2000 the United States had 46.5 web sites per thousand inhabitants, compared with 24.2 per thousand in the United Kingdom, a ratio of 1.92.[18] This suggests that the United Kingdom's software deficiency lies in comparatively low use of the Internet and perhaps too of corporate intranets.

The biggest gap of all is in telecoms, though here two qualifications are in order. First, it is possible that there was over-investment in telecoms in the United States in the latter half of the 1990s, in part because unexpected developments in technology made it possible to get more capacity from a fibre optic cable. Second, because the US population is more dispersed, more miles of fibre may be required to achieve the same level of service per capita. More research is required to assess the importance of these qualifications.

Next we consider the ICT income share. This is now about the same as in the United States (Basu *et al* (2004), Tables 6 and 7), so on this measure the United Kingdom has caught up. As we have just seen, ICT capital stocks per capita are still significantly lower in the United Kingdom. So the fact that income shares are similar reflects also the relatively low level of other types of capital in the United Kingdom. Nevertheless, the income share is a crucial number from a growth accounting perspective since it is the weight applied to the growth rate of ICT capital services in order to determine the contribution of ICT capital to growth. The fact that the income shares are now very

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[17] Our method allows for depreciation to occur throughout the year, as in the BEA's methodology: see U.S. Department of Commerce (1999, Box on page M-5). Our depreciation rate for computers is the same as that used by Jorgenson and Stiroh (2000a,b); it is an average of the rates employed by the BEA for products designated 'computers and peripherals'. Our rate for software is an average of the rates employed by the BEA for pre-packaged software (55%), and custom and own-account software (33%), giving each of these three components an equal weight: see Herman (2000), page 19. Elsewhere in this paper we use 31.5% as the rate for software, as this is widely used in the academic literature, but here we need to be as close as possible to BEA methodology. Our rate for communications equipment is the same as the rate employed by the BEA for 'other industries': see Fraumeni (1997), Table 3.
[18] Source: OECD (2002), page 41.

similar means that a given growth in ICT capital would be expected to have the same impact on labour productivity growth in the two countries. [19]

It is interesting to compare these results for the United Kingdom with those of van Ark *et al* (2002), the most comprehensive attempt to date to compare the European Union (EU) as a whole with the United States. Their study uses aggregate national accounts data and looks particularly at the role of ICT.[20] Their results are for 12 of the (then) 15 EU countries comprising 95% of EU GDP in 2000 (Belgium, Luxembourg and Greece are excluded) and are for 1980-2000. They cover the three types of ICT — computers (more precisely, the broader category of office machinery), software and communication equipment — and use changes in the relative price of ICT and equipment in the United States to adjust European price indices to a more comparable basis.[21] They find that growth rates of ICT capital have been similar in both the EU and the United States over 1980-2000 and even over 1995-2000. But in the EU the level of ICT investment was lower both as a proportion of total fixed investment and of GDP. Consequently ICT stocks as ratios to GDP are much lower and so the crucial income share of ICT — the proportion of GDP attributable to the services of ICT capital (ie the profits earned by ICT assets as a share of GDP) — is also much lower in the EU. So even if ICT capital services have been growing at about the same rate in the EU and the United States, as van Ark *et al* (2002) find, the ICT contribution via capital deepening is smaller in the EU.[22]

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(19) It may seem counterintuitive that the income share of ICT is the same while per capita stocks are higher in the United States, but a simple argument shows how this can occur. Using the standard Hall-Jorgenson formula, the income share of ICT capital in GDP is $(r+\delta_{ICT}-\pi_{ICT})(p^A_{ICT}A_{ICT}/pY)$ where r is the nominal rate of return, δ_{ICT} is the rate of depreciation of ICT capital, π_{ICT} is the rate of growth of the ICT asset price, A_{ICT} is the stock of ICT capital, p^A_{ICT} is its asset price, Y is real GDP and p its price. The user cost part of this expression, $(r+\delta_{ICT}-\pi_{ICT})$, is similar in the two countries, mainly by construction. The other part, the ICT capital-output ratio, $(p^A_{ICT}A_{ICT}/pY)$, can also be similar, even if ICT stocks are much higher in the United States, provided that GDP is also proportionately higher. Note that this argument is illustrative since in practice we calculate the ICT income share by summing the separately calculated income shares of computers, software and communications equipment.

(20) Earlier comparisons by Daveri (2002) and Schreyer (2000) used private sector sources for ICT investment and stocks. Colecchia and Schreyer (2002) use national accounts data. All these results seem broadly consistent with those of van Ark *et al* (2002). Alternative estimates for the G7 are in Jorgenson (2004).

(21) Their results cover the United Kingdom too but there are some differences from the UK results presented here. In particular, they do not make the upward adjustment to UK software investment which we have argued is justified.

(22) See also O'Mahony and van Ark (2003) who report similar findings.

Table 6.6
Ratio of US to UK stocks of ICT per capita in the market sector (end-year)

Year	*Computers*	*Software*	*Telecoms*
1992	1.42	2.07	7.79
1993	1.47	2.15	7.86
1994	1.36	2.08	6.64
1995	1.25	1.91	5.19
1996	1.21	1.85	4.21
1997	1.18	1.94	3.56
1998	1.00	1.81	3.03
1999	1.08	1.88	2.92
2000	1.05	2.00	2.93

Sources: United Kingdom: Own calculations, based on nominal investment from the UK *Annual Supply and Use Tables* and BEA price indices for computers and software, adjusted for exchange rate changes. UK price index used for communications equipment. Software investment has been multiplied by three (see text). Stocks estimated by assuming depreciation to be geometric at 31.5% per annum for computers, 40.0% per annum for software and 11% per annum for communications equipment. UK stocks in constant prices revalued to current pounds and then to US dollars at current dollar-pound exchange rate.
United States: BEA, Fixed Assets Table 2.1 (downloaded on 16 December 2002 from www.bea.gov).

Note: Official data for US government ICT stocks not available, hence market sector stocks are compared. In both countries, market sector stocks exclude ICT assets owned by households as consumer durables. For the United Kingdom, the market sector is defined as all industries except for the government sector (Public administration and defence, Education, and Health and social work). For the United States, the market sector is defined as 'private'. Per capita stocks employ mid-year population figures.

7. Testing the growth accounting assumptions

The preceding section has demonstrated using growth accounting that ICT capital deepening has played a major role in labour productivity growth. But not everyone finds this methodology beyond dispute. The basic growth accounting assumption is that the elasticity of output with respect to a given input equals the share of that input in revenue: see eg Hulten (2001). This is another way of saying that inputs are paid the value of their marginal products, which in turn implies perfect competition and constant returns to scale. But since we have panel data on 34 industries over 31 years, we can test this assumption econometrically. The usual approach is to regress the growth of output per hour on the growth rates of the inputs per hour, with fixed effects and time period dummies to allow for differences between industries and across time in TFP growth; the growth of hours would also be entered to test for constant returns to scale. So we would test the following hypothesis:

$$\Delta_s \ln(V_{it}/H_{it}) = \alpha_i + \lambda_t + \beta^{ICT}\Delta_s \ln(K_{it}^{ICT}/H_{it}) + \beta^N \Delta_s \ln(K_{it}^N/H_{it}) + \beta^L \Delta_s \ln(L_{it}/H_{it})$$

$$+ \gamma^H \Delta_s \ln H_{it} + \varepsilon_{it}$$

where K_{it}^{ICT} is ICT capital input, K_{it}^N is non-ICT capital input, L_{it} is quality-adjusted labour input, α_i is a fixed effect, λ_t is a time period effect, Δ_s indicates an *s* period difference (eg $\Delta_s V_{it} = V_{it} - V_{i,t-s}$) and ε_{it} is an error term. It uses value added rather than gross output, since the former is more reliably measured. Theory suggests that $0 < \beta_{ICT}, \beta_N, \beta_L < 1$ and $\beta_{ICT} + \beta_N + \beta_L = 1$, and that under constant returns to scale $\gamma^H = 0$.

The trouble with this specification is that it requires the coefficients on the inputs to be not only constant across time but also identical between industries. There is no need for this since the TFP estimates have been derived without making this restrictive assumption. So we test instead the more general specification:

$$\begin{aligned}\Delta_s \ln(V_{it}/H_{it}) = \alpha_i + \lambda_t + \gamma^{ICT}[\beta_{it}^{ICT}\Delta_s \ln(K_{it}^{ICT}/H_{it})] + \gamma^N[\beta_{it}^N \Delta_s \ln(K_{it}^N/H_{it})] \\ + \gamma^L[\beta_{it}^L \Delta_s \ln(L_{it}/H_{it})] + \gamma^H \Delta_s \ln H_{it} + \varepsilon_{it}.\end{aligned} \qquad \textbf{(10)}$$

The variables on the right-hand side in square brackets now measure capital deepening. We expect the coefficients on these variables to be equal to one, ie $\gamma^{ICT} = \gamma^N = \gamma^L = 1$, and (as before) the coefficient on the growth of hours to be zero, ie $\gamma^H = 0$.

Before running this regression, we first check for the order of integration of the variables in our analysis, using the test statistic devised by Levin, Lin and Chu (2002) which is a panel version of the Dickey-Fuller and augmented Dickey-Fuller tests. We expect all the variables (measured in log levels) to be I(1). This is largely borne out by Table 7.1. With or without a lag of the variable under test and with or without a linear trend included, at the 5% level we cannot reject the null that the variables are I(1), with two exceptions. The exceptions are intermediate input and intermediate input per hour, where only with a trend and no lags can the null not be rejected. These results justify the use of first differences in equation **(10)**.

Table 7.2 shows the results of running the regression of equation **(10)** on 30 industries over two time periods, 1979-2000 and 1990-2000. There are 30 not 34 industries since we have excluded the three industries in the government sector and also rail transport (industry 22). Various experiments showed rail transport to be an outlier; also it is an industry heavily influenced by government. The reason for looking at the shorter time period (1990-2000) is that ICT capital is better measured at the industry level over the 1990s and also has a much higher income share than in the 1980s (see Table 6.5). These results were estimated by the least squares dummy variable (LSDV) method, ie OLS with fixed effects and time period dummies.[(23)] However, a problem with OLS is that the explanatory variables cannot reasonably be assumed to be exogenous (Griliches and Mairesse (1998)). For example a favourable shock to technology (an increase in TFP growth) will likely induce additional capital deepening. So instrumental variables (IV) would be preferable to OLS. We experimented with IV using either one or two lags of the right-hand side variables as

[(23)] Despite the fact that the dependent variable is a log difference (growth rate), the Wooldridge (2002) test for first order serial correlation suggests that this is absent in our data. Also, for each regression in Table 7.2 we can strongly reject the null hypothesis that all the fixed effects are zero (ie that there is a common constant).

instruments. But the results were very different from OLS and highly implausible, eg large negative coefficients on non-ICT capital. We return to this issue below.[(24)]

Table 7.2 shows that the coefficient on ICT capital deepening is quite close to one, while that on non-ICT capital deepening is substantially below one (at least when hours growth is included), whether we consider 1990-2000 or 1979-2000. ICT capital deepening is not significant over the longer period, but this may be because it is poorly measured at the industry level over 1979-89. Using an *F* test we can reject the null hypothesis that the coefficients on the capital deepening variables are equal to one at the 5% level or better. Also the coefficient on hours growth is negative and significant. Taken literally, this implies decreasing returns to scale at the industry level, which is hard to accept. There is a strong economic presumption in favour of the opposite hypothesis: constant or possibly increasing returns. An alternative explanation for the negative coefficient on hours growth is downsizing: other things equal, industries that cut their labour forces (whether by outsourcing or as a result of cutting output) experience faster growth of labour productivity. These results appear to be not very supportive of the growth accounting assumptions.[(25)]

So far we have measured growth rates as log first differences. So the results may be influenced either by measurement error or by short-run factors not allowed for in the growth accounting model. We test for this by running the same regression using annualised longer differences: two-, three-, four- or five-year differences (ie setting *s* equal to successively 1, 2, 3, 4, or 5 in equation **(10)**). The results are in Table 7.3. With a one-year difference, the coefficient on ICT capital deepening is less than one (and insignificant over 1979-2000). As we extend the length of the difference, the coefficient rises above one and becomes highly significant.[(26)] The same is true of human capital deepening. On the other hand, the size and significance of the coefficient on non-ICT capital deepening is little changed as the length of the difference is extended. For 1979-2000, the size of the coefficient on hours growth nearly halves as we extend the difference from one to five years.[(27)] *F* tests again suggest that we can reject the null hypothesis that the capital deepening variables are equal to one at better than the 5% level.

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(24) We also tried omitting the human capital deepening variable. The argument for doing so is that labour quality growth is not measured at the industry level but only in aggregate, so this variable only differs between industries insofar as labour's share differs between industries. Arguably therefore, it is better to exclude it and to allow its effect to be absorbed into the year dummies. In practice however omitting this variable had little effect on the other coefficients.

(25) These results appear rather different from those reported by Stiroh (2002b) based on a panel of 20 US manufacturing industries over 1984-99: see his Table 5, particularly the last column headed 'fixed effects'. His regression equation is very similar to ours except that he imposes common elasticities across industries. He finds the coefficients on his two ICT variables (computers plus software and telecoms) to be close to zero and insignificant. On the other hand, with this specification he also finds apparent diminishing returns to scale (the sum of the coefficients on input growth is 0.767 with standard error of 0.081), which is similar to our finding. Without fixed effects, he finds constant returns to scale and a significantly negative coefficient for total ICT, though he attributes this to telecoms. When TFP growth is regressed on the growth rates of the inputs, he finds that (with fixed effects included) all the input variables are insignificant except intermediate input. He interprets his results as consistent with standard growth accounting. There is of course no special reason why his results should agree with ours. His are for the United States which is at a higher level of development of ICT use. Also, his results cover only manufacturing, so the main ICT using-industries are excluded. An additional reason may be that he uses gross output while we use value added in our regressions. Below in Section 7 we also report results rather different from his when TFP is the dependent variable.

(26) Brynjolffson *et al* (2002) also find that the size and significance of ICT rises as the length of the difference increases, though their regression is not the same as the one being run here.

(27) Enforcing constant returns to scale by dropping the growth of hours does not change the picture much, except that the coefficient on non-ICT capital deepening is close to one when a five-year difference is used (for 1979-2000).

The rise in the ICT capital deepening coefficient as we extend the length of the difference can be interpreted in a number of ways. One possibility is measurement error which certainly cannot be ruled out, especially when we recall the problems with measuring ICT prices and the volatility of ICT investment. Presumably, the effect of measurement error diminishes as the length of the difference increases. Another possibility is that for one reason or another the impact of ICT investment is partially hidden, either because of long lags between investment and payoff, or because of adjustment costs, or because of the need for complementary investment. At the moment we cannot distinguish between these alternative hypotheses, but we return to this issue below.

Earlier we argued that OLS regressions may be biased as the error is likely to be positively correlated with capital deepening. If so, OLS will overstate the size of the capital deepening coefficients. A way of assessing the importance of this possibility is to run repeated cross-section regressions. If the coefficients appear to be high when the error is high, then we must take the possibility of upward bias seriously. Chart 7.1 shows the time pattern of the coefficients when we use five-year differences and Chart 7.2 shows the corresponding t ratios.[(28)] The ICT coefficient is significant in 10 out of 17 years and most of the time easily exceeds one. Interestingly, it is highest in the 1980s when ICT capital was quantitatively much less significant. It shows a strong upward trend from 1994-2000. The non-ICT capital coefficient is much smaller, is indeed less than one in every year, and is only positive and significant in one out of the 17 years. Chart 7.3 plots the ICT coefficient against an estimate of the true error. For the latter, we employ the mean across the 30 industries of the TFP growth rate, calculated in the usual way.[(29)] If the growth accounting assumptions are correct, then this measure gives the true size of the shock. Chart 7.3 shows that the relationship between the shock and the ICT coefficient is actually negative: the correlation coefficient is -0.35.

It would be naïve to claim that our OLS regressions can uncover the true coefficients in the underlying production function. Nevertheless we have found some firm evidence that labour productivity responds to ICT investment, and to a greater extent than would be suggested by the growth accounting model. If there is a puzzle, it relates to the response of productivity to non-ICT investment. Here the regression results suggest that the response is lower than suggested by growth accounting, implying contrary to that model that the rate of return is lower to non-ICT than to ICT capital.

(28) The first observation in these charts is for 1984, so this is from a cross-section regression of the growth of real value added per head on the same set of variables as in Table 7.3 over 1979-84. The last observation is for 2000, when the same regression is run for 1995-2000. The standard errors from which the t ratios are calculated are robust.

(29) To be comparable with the coefficient, the TFP growth rate for each industry is the average growth rate over five years, on a value added basis (ie it is TFP growth on a gross output basis multiplied by the industry's ratio of gross output to value added). We use a simple average across industries since the regression coefficient was estimated giving equal weight to each industry.

Table 7.1
Testing for the order of integration:
probability of Levin-Lin-Chu test statistic exceeding the value found

	No lags of variable tested		One lag of variable tested	
Variable	No trend	Trend	No trend	Trend
Gross output	0.834	0.838	0.644	0.112
Value added	0.941	0.711	0.765	0.630
ICT capital input	1.000	1.000	0.968	0.030
Non-ICT capital input	0.950	0.879	0.325	0.000
Intermediate input	0.001	0.827	0.005	0.003
Labour input	0.999	0.617	0.995	0.126
Value added per hour	0.992	0.646	0.956	0.551
ICT capital input per hour	1.000	1.000	0.992	0.284
Non-ICT capital input per hour	0.998	0.998	0.226	0.113
Intermediate input per hour	0.003	0.617	0.002	0.021
Hours	0.999	0.617	0.995	0.126

Note: Levin, Lin and Chu (2002) tests of order of integration in panel data. The null hypothesis is that the variable is I(1). All variables tested are in logs. All tests include a constant.

Table 7.2
Regressions to test growth accounting assumptions:
dependent variable is growth of real value added per hour

	1979-2000	1979-2000	1979-2000	1990-2000	1990-2000	1990-2000
ICT capital deepening	0.804	0.804	0.894	0.904*	0.940*	0.975
	(0.494)	(0.494)	(0.529)	(0.407)	(0.408)	(0.499)
Non-ICT capital deepening	0.546**	0.587**	1.463**	0.588**	0.665**	1.802**
	(0.140)	(0.133)	(0.100)	(0.138)	(0.127)	(0.096)
Human capital deepening	-1.861	—	—	-3.639	—	—
	(2.051)			(2.547)		
Hours growth	-0.656**	-0.640**	—	-0.710**	-0.672**	—
	(0.071)	(0.069)		(0.064)	(0.059)	
Observations	630	630	630	300	300	300
Number of industries	30	30	30	30	30	30
R^2 overall	0.43	0.43	0.33	0.70	0.69	0.52
Test that coefficients on deepening variables all equal one (H_0: all coefficients equal one)						
F	3.79	5.24	11.07	3.25	3.66	37.29
Prob > *F*	0.01	0.01	0	0.02	0.03	0
Wooldridge (2002) test for serial correlation in panels (H_0: no first order autocorrelation)						
F(1,29)	0.67	0.37	0.04	0.35	0.35	1.72
Prob > *F*	0.42	0.55	0.84	0.55	0.56	0.20

Note: Test of equation **(10)**. Standard errors in parentheses. Method of estimation is OLS; time dummies and fixed effects included but not reported. Wooldridge test calculated using the ‘xtserial’ command in Stata (Drukker (2003)).
* significant at 5%; ** significant at 1%.

Table 7.3
Regressions to test growth accounting assumptions: dependent variable is growth of real value added per hour over one, two, three, four or five years

1979-2000

	Length of period (years)				
	One	Two	Three	Four	Five
ICT capital deepening	0.804	1.063**	1.214**	1.482**	1.721**
	(0.494)	(0.393)	(0.365)	(0.397)	(0.430)
Non-ICT capital deepening	0.546**	0.564**	0.542**	0.551**	0.623**
	(0.140)	(0.110)	(0.104)	(0.110)	(0.115)
Human capital deepening	-1.861	-2.392	-0.166	3.356*	6.747**
	(2.051)	(1.684)	(1.485)	(1.632)	(1.850)
Hours growth	-0.656**	-0.638**	-0.595**	-0.485**	-0.362**
	(0.071)	(0.057)	(0.055)	(0.059)	(0.060)
Observations	630	630	630	630	630
Number of industries	30	30	30	30	30
R^2 (overall)	0.44	0.52	0.5	0.39	0.32
Test of null hypothesis that coefficients on deepening variables all equal one					
F	3.79	5.38	6.92	9.86	12.72
Prob > *F*	0.01	0	0	0	0

1990-2000

	Length of period (years)				
	One	Two	Three	Four	Five
ICT capital deepening	0.904*	1.399**	1.537**	1.632**	1.662**
	(0.407)	(0.321)	(0.292)	(0.292)	(0.307)
Non-ICT capital deepening	0.588**	0.681**	0.746**	0.749**	0.663**
	(0.138)	(0.118)	(0.115)	(0.118)	(0.124)
Human capital deepening	-3.64	-3.836	-2.238	-0.99	-1.322
	(2.547)	(2.537)	(2.325)	(2.400)	(2.520)
Hours growth	-0.710**	-0.662**	-0.627**	-0.626**	-0.680**
	(0.064)	(0.056)	(0.057)	(0.061)	(0.065)
Observations	300	300	300	300	300
Number of industries	30	30	30	30	30
R^2 (overall)	0.76	0.81	0.81	0.78	0.74
Test of null hypothesis that coefficients on deepening variables all equal one					
F	3.25	3.03	2.89	3.25	4.61
Prob > *F*	0.02	0.03	0.04	0.02	0.00

Note: Test of equation **(10)**. Standard errors in parentheses. Method of estimation is OLS; time dummies and fixed effects included but not reported.
* significant at 5%; ** significant at 1%.

Chart 7.1

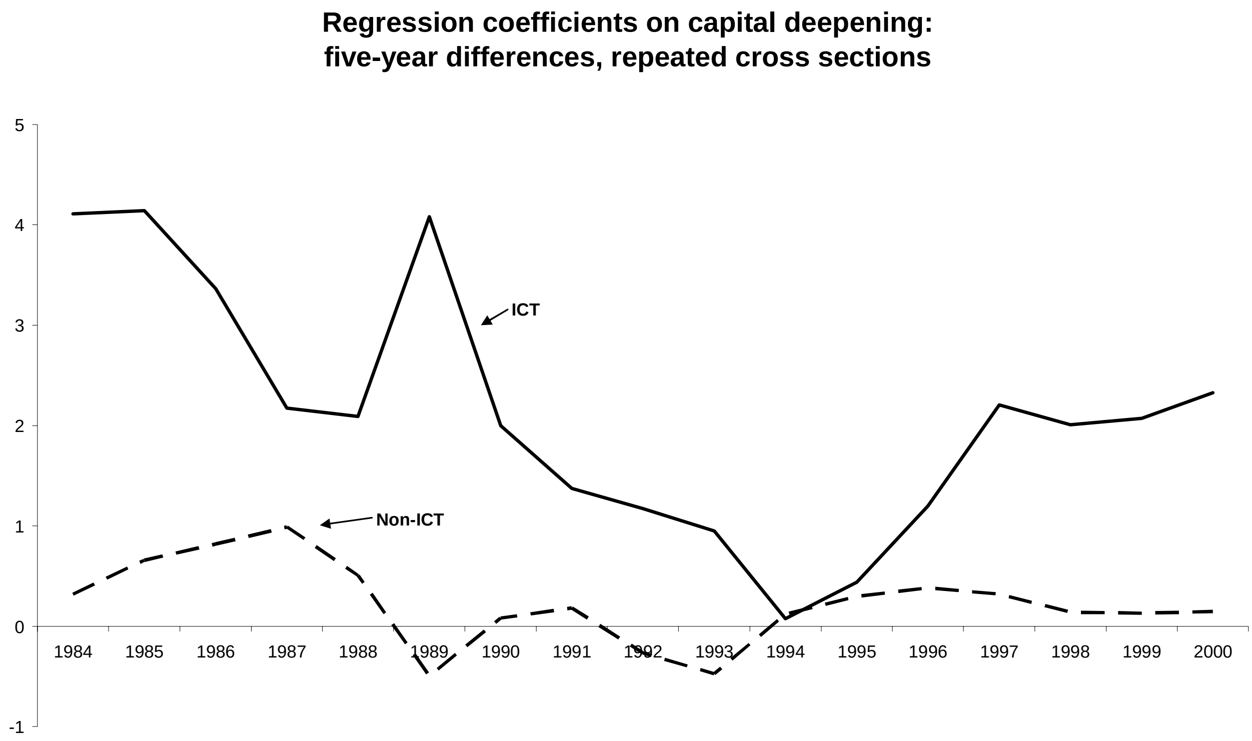


Chart 7.2

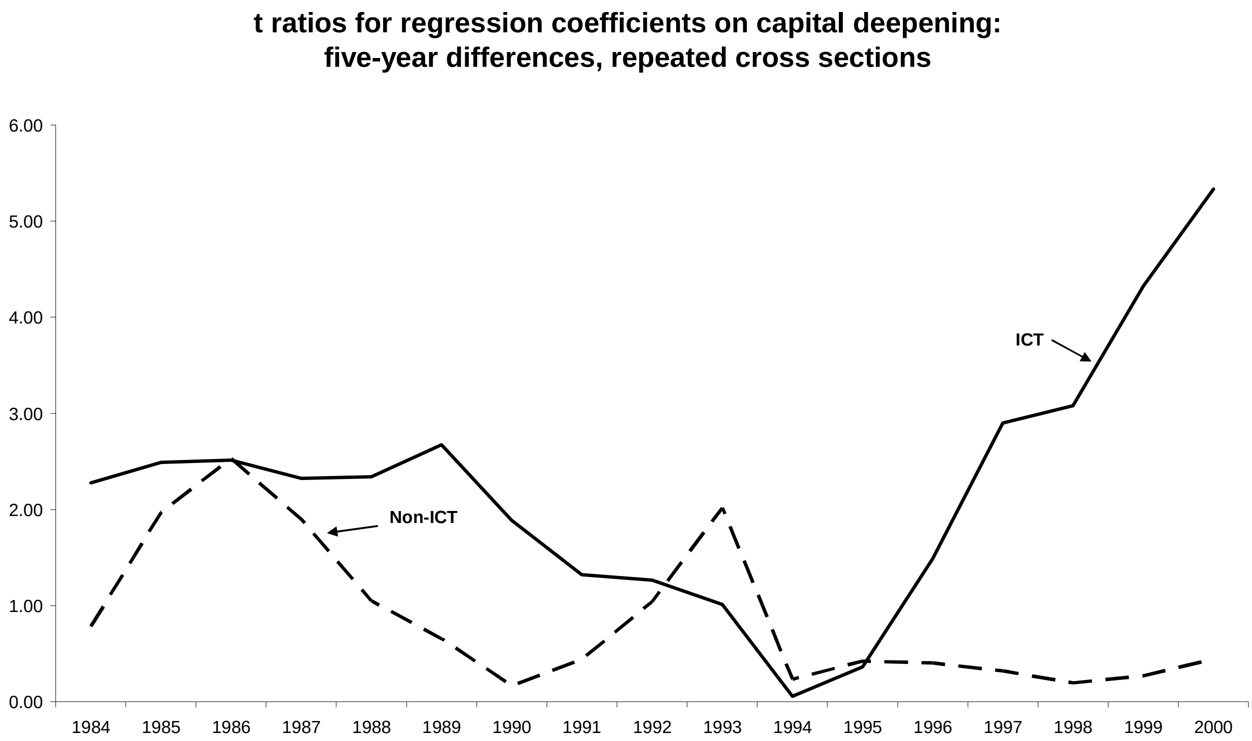
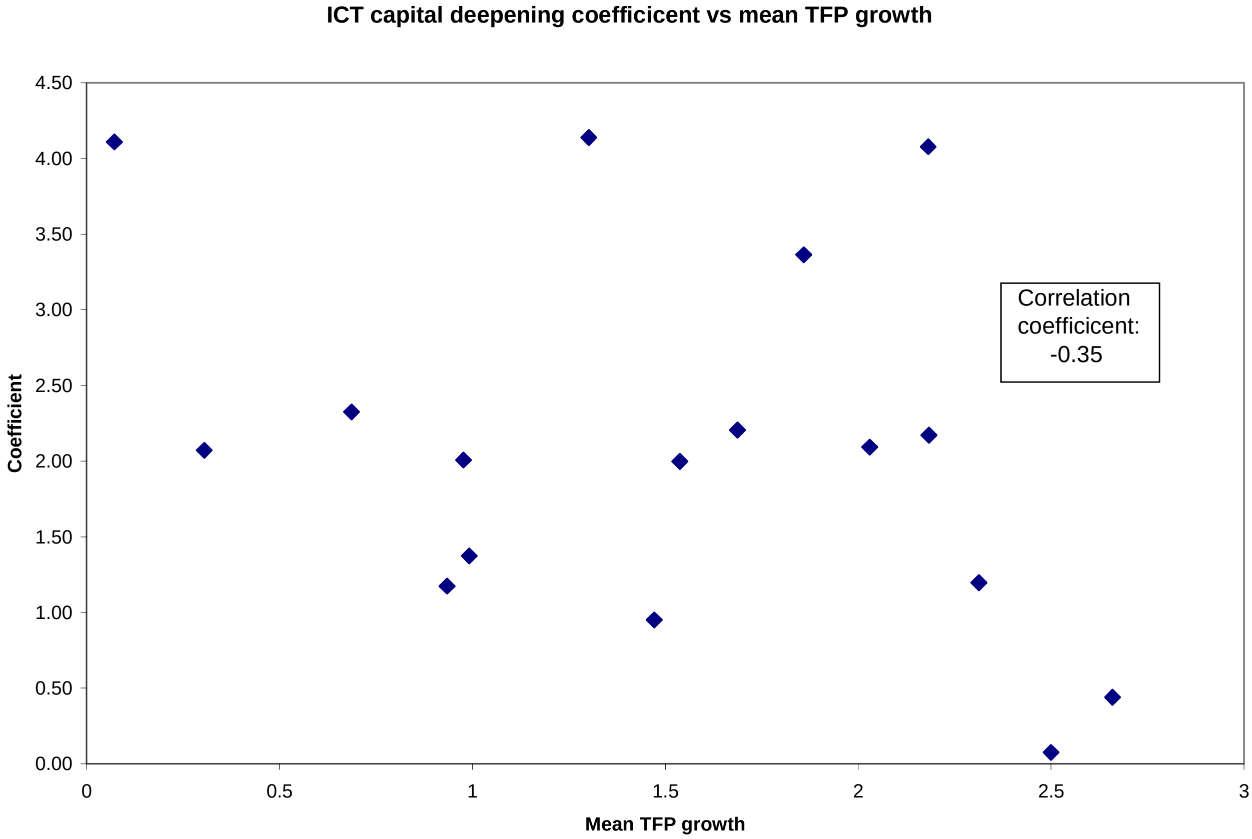


Chart 7.3



8. Complementary investment and capital

It is frequently argued that ICT is a general purpose technology (GPT). The concept of a GPT has several implications. First, adoption of such a technology entails experimentation which may lead to innovation by the adopting firms, which in turns shows up as TFP growth. Second, as well as innovating themselves, firms can learn from the (successful or unsuccessful) innovation efforts of others, so there are spillover effects (Bresnahan and Trajtenberg (1995)). Third, successful implementation of an ICT project requires reorganisation of the firm around the new technology (Helpman and Trajtenberg (1998); Yang and Brynjolffson (2001); Brynjolffson *et al* (2002)). It is this third effect on which we concentrate.

Reorganisation incurs costs, whether in the shape of fees paid to consultants, management time or expenditure on the retraining of workers. Much anecdotal evidence supports this view: it is often claimed that the total cost of an ICT project can be four or more times the amount paid for the equipment and software. Yang and Brynjolffson (2001, Table 2) cite evidence that the total start-up cost (ie incurred within the first year) of an Enterprise Resource Planning (ERP) suite is five times the cost of the hardware and software licences. Based on econometric evidence of the effect on stock prices of ICT investment, Brynjolffson *et al* (2002) suggest that as much as $9 of total investment is associated with $1 of ICT investment. This additional expenditure could be interpreted simply as adjustment costs, which are particularly high perhaps in the case of ICT. These adjustment costs could be estimated econometrically (as in Groth (2005)). Here we explore a different view and argue that by incurring current costs, the firm acquires a capability that helps it to absorb new technology in the future. In other words, the investment in reorganisation creates a stock that yields future benefits. The empirical difficulty is that this investment is not measured as such in the national accounts.

We therefore start by considering the effect on conventional measures of TFP growth if a type of capital that helps to produce output is omitted from the calculation. We assume that this missing asset, which we call complementary capital, is produced by the firm itself with the aid of some of its own labour and capital, together perhaps with some of the bought-in inputs. So expenditure on this asset is counted in the national accounts, but misclassified as intermediate consumption. The effect on the estimation of TFP is quite complex. On the one hand, past investment in complementary capital yields current benefits, but the contribution of complementary capital is omitted by the conventional estimate of TFP growth. If complementary capital is growing more rapidly than other types, then the conventional estimate is too high. On the other hand, the conventional estimate overstates the amount of resources going into current output since it includes as a current cost resources that are in fact being used to add to or replace complementary capital; hence on this count the conventional estimate of TFP growth is too low. So roughly speaking, whether on net the conventional TFP measure is too high or too low depends on how high the growth rate of *investment* in complementary capital is compared to the growth rate of the *stock* of complementary capital. In a steady state, the growth rates of investment and of the stock must of course be equal. But as we show, in a boom, the growth rate of investment will exceed that of the stock. Hence we would expect a downward bias in the conventional measure during a boom. The remainder of this section is devoted to setting out these ideas more rigorously.

Consider a simple model in which there are two types of output, ordinary and complementary, indexed by *O* and *C* respectively.[30] Ordinary output can be either consumed or invested, complementary output can only be invested. In the conventional accounting system, complementary investment is (erroneously) treated as an intermediate input. In symbols, the conventional accounting relationship at the aggregate level (in a closed economy) is:

$$pY = wL + p^K K_O \qquad \textbf{(11)}$$

where K_O is ordinary capital and p^K is the conventional rental price. (This equation also holds for a firm or industry if for simplicity we ignore intermediate inputs.) Conventional profit is $p^K K_O$, which can be derived as a residual. It is assumed that we can measure the services of ordinary capital K_O so the conventional rental price p_K can then also be derived: $p^K = (pY - wL)/K_O$. The true accounting relationship is:

$$pY = wL_O + p_O^K K_O + p_C^K K_C \qquad \textbf{(12)}$$

where L_O is labour devoted to producing ordinary output, p_O^K is the true rental price of ordinary capital, and p_C^K is the rental price of complementary capital K_C. Equation **(12)** assumes for

[30] This model draws on Basu *et al* (2004); see also Yang and Brynjolfsson (2001).

simplicity that the whole of the complementary capital stock is employed in the production of ordinary output. In addition, we now have a second accounting relationship for the production of complementary capital, which equals gross investment in complementary capital (I_C). For simplicity we assume that only labour is required to produce complementary output:

$$p_C^A I_C = wL_C \qquad \textbf{(13)}$$

where p_C^A is the asset price of complementary capital, L_C is labour devoted to the output of complementary capital, and $L_C + L_O = L$. Conventional nominal GDP is pY but true GDP is:

$$p_Z Z = pY + p_C^A I_C \qquad \textbf{(14)}$$

where p_Z is the price and Z the volume of true GDP. Under the conventional system of accounts, some part of the labour force is considered to be involved in the production of an intermediate input. Expenditure on this input is classified as intermediate consumption and hence gets netted out of GDP. Under what is by hypothesis the true system, it is recognised that this type of expenditure is in fact an investment, and so should be included in GDP.[31] Conventional aggregate profit is $pY - wL$, while true aggregate profit is $p_Z Z - wL$. Hence from **(13)** and **(14)** true aggregate profit and true total investment exceed their conventional counterparts by the amount wL_C. This is not directly observable unless we know the proportion of the total labour force devoted to complementary output.

Moving from accounting to economics, the conventional system implies a production function of the following form:

$$Y = \exp(\mu_Y t) f(K_O, L) \qquad \textbf{(15)}$$

where μ_Y is the TFP growth rate. The true system implies two production functions:

$$Y = \exp(\mu_Y t) g(K_O, K_C, L_O) \qquad \textbf{(16)}$$

$$I_C = \exp(\mu_C t) h(L_C) \qquad \textbf{(17)}$$

where μ_C is the TFP growth rate in the production of complementary output. We also assume that the relationship between the rental price and the asset price of complementary capital is given by the Hall-Jorgenson formula:

$$p_C^K = (r + \delta_C - \pi_C) p_C^A \qquad \textbf{(18)}$$

where r is the real rate of return (in terms of ordinary output), δ_C is the rate of depreciation on complementary capital, and π_C is the growth of the asset price of complementary capital relative to

(31) The situation depicted in equations **(11)-(14)** could be used to illustrate the contrast between the treatment of software purchases under SNA68, where such purchases were treated as intermediate consumption, and that under SNA93 (and ESA95) where they are now treated as investment.

the price of ordinary output ($\pi_C = \hat{p}_C^A - \hat{p}$). Finally, we assume that complementary capital accumulates in the usual way:

$$\dot{K}_C = I_C - \delta_C K_C \qquad \textbf{(19)}$$

We are now in a position to derive the difference between TFP growth in the production of ordinary output as conventionally measured and the true rate. The conventional measure, denoted by μ_Y^{conv} is, using **(11)** and **(15)**,

$$\mu_Y^{conv} = \hat{Y} - (wL/pY)\hat{L} - (p^K K_O / pY)\hat{K}_O$$

where hats denote growth rates (eg $\hat{K}_O = \dot{K}_O / K_O$). The true measure ($\mu_Y^{true}$) is, from **(12)** and **(16)**,

$$\mu_Y^{true} = \hat{Y} - (wL_O / pY)\hat{L}_O - (p_O^K K_O / pY)\hat{K}_O - (p_C^K K_C / pY)\hat{K}_C .$$

The error made by the conventional measure is therefore:

$$\mu_Y^{conv} - \mu_Y^{true} = \left(\frac{p_C^K K_C}{pY}\right)\hat{K}_C + \left(\frac{wL_O}{pY}\right)\hat{L}_O - \left(\frac{wL}{pY}\right)\hat{L} - \left(\frac{(p^K - p_O^K)K_O}{pY}\right)\hat{K}_O . \qquad \textbf{(20)}$$

Let the ratio of labour used in complementary output to labour used in ordinary output be *v*: $v = L_C / L_O$. So $\hat{L} = v(1+v)^{-1}\hat{L}_C + (1+v)^{-1}\hat{L}_O$. Let the share of profits generated by complementary capital in the value of ordinary output (the income share of complementary capital) be denoted by s_C: $s_C = p_C K_C / pY$. Let the true share of labour in ordinary output be denoted by s_L: $s_L = wL_O / pY$. Note too that, using equations **(13)** and **(17)**,

$$\hat{L}_C = \hat{I}_C - \mu_C .$$

Then substituting these relationships into **(20)**, we find that the error made by the conventional approach in measuring TFP growth in the production of ordinary output is:

$$\mu_Y^{conv} - \mu_Y^{true} = [s_C \hat{K}_C - vs_L \hat{I}_C] - [s_C - vs_L]\hat{K}_O + vs_L \mu_C . \qquad \textbf{(21)}$$

Clearly the error will be non-zero even in a steady state (when $\hat{K}_C = \hat{I}_C$) and even if the two types of capital are growing at the same rate ($\hat{K}_C = \hat{K}_O$); in this case the error equals $vs_L \mu_C$ which is positive if $\mu_C > 0$. Note that, from **(13),** $vs_L = wL_C / pY = p_C^A I_C / pY$, the proportion of output devoted to investment in complementary capital (in current prices). Let i_C denote this proportion: $i_C = p_C^A I_C / pY$. So the term $vs_L \hat{I}_C = i_C \hat{I}_C$ in **(21)** could be called 'complementary investment deepening', by analogy with the term $s_C \hat{K}_C$ that we call 'complementary capital deepening'; complementary investment deepening is the growth rate of complementary investment weighted by the ratio of complementary investment to output (in current prices). We can then rewrite equation **(21)** in more convenient form as:

$$\mu_Y^{conv} - \mu_Y^{true} = [s_C \hat{K}_C - i_C \hat{I}_C] - [s_C - i_C]\hat{K}_O + i_C \mu_C . \qquad \textbf{(22)}$$

We can also note that there is a relationship between the output share of complementary investment (i_C) and the income share of complementary capital (s_C). Using equations **(18)** and **(19)**, we find that:

$$s_C = \left[\frac{r + \delta_C - \pi_C}{\hat{K}_C + \delta_C} \right] i_C . \qquad \textbf{(23)}$$

The size of the error in **(22)** is then going to be roughly proportional to i_C. It will also depend on the magnitude of capital deepening relative to investment deepening. But the more interesting question is: suppose there is an investment boom in complementary capital, but there is no change in true TFP growth rates. Will the error rise or fall? We show that it will most likely fall algebraically, ie conventionally measured TFP growth will appear to decline. The main reason is that when the growth rate of the stock of complementary capital is rising (say towards a new, higher equilibrium rate), the growth rate of investment exceeds the growth rate of the stock. So it is possible for investment deepening to exceed capital deepening and for the gap between the two to be getting wider.

The proof that the growth rate of investment exceeds that of capital when the latter is positive and increasing is as follows. Assume that time is continuous and that the first and second derivatives of the stock of complementary capital with respect to time always exist (ie the growth rate does not jump). By differentiating equation **(19)** with respect to time and noting that:

$$\frac{d\hat{K}_C}{dt} = \frac{\ddot{K}_C}{K_C} - \hat{K}_C{}^2 ,$$

we find that the relationship between the growth rate of investment and the growth rate of the stock is:

$$\hat{I}_C = \frac{(d\hat{K}_C / dt)}{\hat{K}_C + \delta} + \hat{K}_C . \qquad \textbf{(24)}$$

So $\hat{I}_C = \hat{K}_C$ in equilibrium when the growth rate is constant ($d\hat{K}_C / dt = 0$), but $\hat{I}_C > \hat{K}_C$ if the growth rate of the stock is positive and rising $(\hat{K}_C > 0,\ d\hat{K}_C / dt > 0)$. QED

Consider an initial equilibrium where the desired and actual growth rates of a stock are equal. Now suppose that the desired growth rate increases. Assume that the actual growth rate adjusts only gradually towards the new higher desired level. For example, though this is not essential to the argument, we could assume the familiar partial adjustment mechanism:

$$d\hat{K}_C / dt = \lambda(\hat{K}_C^* - \hat{K}_C) \qquad 0 < \lambda < 1 \qquad \textbf{(25)}$$

where $\hat{K}_C^*$ is the desired growth rate. Then the growth rate rises asymptotically towards its new equilibrium rate and along the adjustment path the growth rate of investment exceeds that of the stock. This creates a downward bias in the conventional measure of TFP growth during such a transition period. The reason this is relevant to recent economic history is that ICT investment boomed in the latter half of the 1990s. So if this led to a boom in complementary investment too, then the conventional measure of TFP growth will have had a downward bias during this period.[32]

To make this notion more precise, we employ equation **(22)**. We calculate the error for two time periods, for a range of parameter values. In the first period the economy is assumed to be in equilibrium, so the growth rates of investment and capital are equal. In the second period the desired growth rate of complementary capital is assumed to have risen. We then calculate the *change* in the error between these two periods. We consider eight different cases: low and high growth, low and high depreciation rates, and low and high investment ratios. For the low investment ratio, we assume that the ratio is the same for complementary investment as for ICT investment. For the high one, we use four times the ICT ratio; the evidence cited above suggest this is not an outlandishly high figure. The low depreciation rate is that of machinery and equipment, the high one that for ICT assets. Table 8.1 shows the results (see the note to this table for more detail about the parameter values).

In every case the change in the error is negative, ie TFP growth appears to slow down. By construction, the change in the high investment ratio case is four times the size in the low ratio case (ignoring rounding). As expected, the change is larger in absolute value in the high growth case and also when depreciation is low. When depreciation is high the change is small. But with low depreciation and high growth, the size of the change can be very significant, eg an apparent slowdown in TFP growth of 0.72 percentage points per annum. Unfortunately we have little knowledge of the true size of the crucial parameters involved here. We therefore turn to econometric evidence.

[32] Similar considerations have led Gordon (2003) to conclude that the further increase in productivity growth experienced by the United States after 2000 may have been due to a slowdown in complementary investment, accompanying the slowdown in ICT investment.

Table 8.1
Change in error in conventional TFP measure, following on change in desired growth rate of complementary capital (percentage points per annum)

	δ_C = 13%		δ_C = 31.5%	
Increase in desired growth rate of complementary capital	$i_C = i_{ICT}$	$i_C = 4 \times i_{ICT}$	$i_C = i_{ICT}$	$i_C = 4 \times i_{ICT}$
From 3% to 5% p.a.	-0.06	-0.23	-0.01	-0.05
From 10 to 20% p.a.	-0.18	-0.72	-0.03	-0.10

Note: Calculated from equation **(22)** as the difference between the averages over two consecutive five-year periods. The first period is assumed to be an equilibrium. The growth of capital in the second period is calculated from a discrete version of equation **(25)** with $\lambda = 1/3$. The growth of investment in the second period is calculated from a discrete version of equation **(24)**. The ratio of ICT investment to GDP in the market sector, i_{ICT}, was 0.026 in 1990-95 and 0.039 in 1995-2000. For the low growth case we set μ_C = 1.1, which was the average growth rate of TFP in the market sector over 1990-2000 and for the high growth case we set it to 10% p.a. Conformably to these values, we set $\pi_C = 0$ for the low growth case and $\pi_C = -8.9$ for the high growth case. We set $\hat{K}_O$ equal to 1.54 % p.a. in the first period and 3.14% p.a. in the second; these are the growth rates of non-ICT capital in 1990-95 and 1995-2000 respectively. Finally, *r* is set to 6%.

Econometric evidence

We estimate equation **(22)** on panel data, after taking first differences and rearranging:

$$\Delta\mu_Y^{conv} = \Delta s_C \hat{K}_C - \Delta i_C \hat{I}_C - \Delta[s_C - i_C]\hat{K}_O + \Delta i_C \mu_C + \Delta\mu_Y^{true} . \quad \textbf{(26)}$$

The time periods are taken to be 1990-95 and 1995-2000, so the left-hand side is the *change* in TFP growth, 1995-2000 over 1990-95. We have no direct measures of complementary capital and investment so we need empirical proxies.(33) The whole thrust of the argument has been that complementary investment is related to, and induced by, ICT investment. So we use ICT investment and capital as the proxies. Our estimating equation is then:

$$\Delta\mu_{it} = \beta_0 + \beta_1 \Delta[s_{it}^{ICT} \hat{K}_{it}^{ICT}] + \beta_2 \Delta[i_{it}^{ICT} \hat{I}_{it}^{ICT}] + \varepsilon_{it} . \quad \textbf{(27)}$$

Here the dependent variable is the change in the TFP growth rate and any terms in **(26)** other than capital deepening and investment deepening are assumed to be absorbed by the constant and the error term (ε_{it}). We expect $\beta_1 > 0, \beta_2 < 0$. The results of estimating this equation on our cross-section of industries are in Table 8.2. Initially we omit the government sector (industries 30, 31 and 32), agriculture (industry 1)(34) and also rail transport (industry 22), which has implausibly high labour productivity growth in the 1990s, leaving 29 industries in all. When only capital deepening but not investment deepening is entered, its coefficient is significant and has the expected sign,

(33) For a recent attempt to measure intangible investment in the United States (using a wider definition than here), see Corrado *et al* (2004).
(34) For comparability with the results in Basu *et al* (2004) which are for the non-farm business sector.

though the goodness of fit is poor.[35] When investment deepening is included as well, as our theory suggests it should be, its coefficient is negative as expected and is highly significant (column 2). Moreover, the size of the coefficient on capital deepening more than doubles while becoming more significant, and the goodness of fit more than doubles too. Columns (3) and (4) show that these results do not depend on outliers: omitting industries that appear on standard tests to be influential has little effect on the size and significance of the deepening coefficients. The semiconductor and computer industries, part of industry 9, might be thought to be special, but omitting industry 9 also makes little difference (column 5).[36]

These results are highly suggestive. But there is an important qualification. Multiplying the cross-industry means of capital and investment deepening by their respective coefficients, we find (using column 5 of Table 8.2) that capital deepening would have raised TFP growth on average by 0.85% per annum, while investment deepening would have lowered it by 0.45% per annum, for a net positive effect of 0.40% per annum. So though investment deepening did serve to retard measured TFP growth, it cannot on the face of it account for the whole of the fall in TFP growth.

On the other hand, one would expect endogeneity considerations to be particularly important in this equation, in a way that works against finding results consistent with the complementary investment hypothesis, even if true. In this specification, we regress the TFP acceleration on the contemporaneous investment acceleration. Because investment is endogenous, a positive industry-specific technology shock could lead to higher investment as well as higher TFP, thereby biasing the coefficient on investment upward. Hence, the true investment coefficient may be more negative than we find in our OLS regression.

It appears that the rapid growth of ICT investment after 1995—which was higher than the growth of the ICT capital stock—appreciably retarded the measured growth of productivity. Comparing the second with the first half of the 1990s, the change in TFP growth is positively and significantly related to the change in ICT capital deepening. But it appears significantly and negatively associated with ICT *investment* growth. In the long run, of course, ICT capital and investment must grow at the same rate. So this suggests one reason for thinking that TFP growth must eventually recover.

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[35] This contrasts with results for TFP reported by Stiroh (2002b) for US manufacturing industries over the period 1984-99. He finds the growth of ICT capital services to be insignificant (see his Table 5, bottom panel, last column); he does not test for ICT investment deepening. Apart from other differences, his result may be influenced by the fact that he uses first differences of annual data. We have already reported that the effect of ICT becomes larger as the period over which growth rates are measured is increased.

[36] The results in column (5) are very similar to those reported for the United Kingdom in Basu *et al* (2004), Table 9. The small numerical differences between those results and the ones here are due to the former using labour input unadjusted for quality change, whereas the present ones use quality-adjusted labour; the present estimates also use slightly revised data.

Table 8.2
TFP growth and the influence of ICT capital and investment deepening: cross-section regression tests of equation (27)

Independent variables	(1)	(2)	(3)	(4)	(5)
Change in ICT capital deepening	2.020*	5.061**	5.135**	4.536*	4.706**
	(0.941)	(1.250)	(0.827)	(1.722)	(1.163)
Change in ICT investment deepening	—	-1.909**	-1.948**	-1.840**	-1.737**
		(0.471)	(0.375)	(0.647)	(0.451)
Constant	-1.238**	-1.325**	-1.008**	-1.124**	-1.392**
	(0.355)	(0.304)	(0.208)	(0.369)	(0.299)
N	29	29	26	26	28
R^2	0.18	0.42	0.55	0.35	0.41

Note: Dependent variable is the change in TFP growth, 1995-2000 over 1990-95. Robust standard errors in parentheses. All regressions omit industries 1, 22, and 30-32. Additionally, column (3) omits industries 2, 3, and 29 which the DFbeta test suggests are influential; column (4) omits industries 3, 25, and 27 which the COVRATIO test suggests are influential; and column (5) omits industry 9 which includes semiconductor and computer output.
* Significant at 5% level or better.
** Significant at 1% level or better.

9. Conclusions

This paper has used a new industry-level dataset to consider the role of structural change and ICT in explaining productivity growth in the United Kingdom, 1970-2000, though mainly concentrating on the period since 1979. The main conclusions are as follows.

A number of different forms of structural change were described and quantified. Two were found to have played a significant role. First, the degree of interrelatedness of domestic industries has risen and this has raised productivity growth to a significant extent, at least in the 1970s and the 1990s. Second, a shift in the composition of output towards industries with a relatively low level of labour productivity had a negative effect in 1990-2000, reducing aggregate labour productivity growth by 0.13% per year (0.21% per year in the market sector). Despite this adverse shift, aggregate labour productivity growth was predominantly due to labour productivity growth in individual industries.

Using the growth accounting methodology, we found that the accumulation of ICT capital has played an increasingly important role in accounting for labour productivity growth in the market sector. ICT capital accounted for 13% of growth in 1970-79, 26% in 1979-90, and 28% in 1990-2000. In 1995-2000 the proportion rises to 47%. ICT capital, despite only being a small fraction of the total capital stock, contributed as much to growth as non-ICT capital in 1990-2000 and getting on for twice as much in 1995-2000. This is because ICT capital per hour worked has been rising rapidly and also because the income share of ICT capital has tripled since the 1970s. The income share is now about the same as in the United States, though stocks of software and communications equipment per capita are lower in the United Kingdom. We also found that the growth rates of both labour productivity and of TFP fell in the second half of the 1990s, by about 1 percentage point.

The growth accounting approach makes strong assumptions. We therefore employed the dataset to test these assumptions econometrically. The strength of the association between labour productivity growth and ICT capital deepening rises as the period over which growth is measured is lengthened, eg from one to five years; the association is larger than growth accounting would suggest. No such strengthening effect is found for non-ICT capital. While these results are not wholly in accordance with growth accounting, they certainly give no ground for believing that growth accounting is overstating the impact of ICT.

We argued that ICT investment requires complementary investment in organisational change and retraining to make it effective. Such complementary investment is potentially large but not measured as such in the national accounts; instead it is classified as intermediate consumption. In a boom, investment rises more rapidly than capital, leading (simulation suggests) to a potentially significant fall in TFP growth as conventionally measured, even if the true rate remained constant. Econometric evidence supports this conclusion and suggests that the ICT investment boom of the 1990s significantly retarded the conventional measure of TFP growth.

References

Ahmad, N, Lequiller, F, Marianna, P, Pilat, D, Schreyer, P, and Wölfl, A (2003), 'Comparing labour productivity growth in the OECD area', *OECD Statistics Working Paper 2003/5*, Paris: OECD.

van Ark, B, Melka, J, Mulder, N, Timmer, M and Ypma, G (2002), 'ICT investment and growth accounts for the European Union, 1980-2000', Final Report on 'ICT and growth accounting' for the DG Economics and Finance of the European Commission, Brussels; downloaded from http://www.eco.rug.nl/GGDC/dseries/Data/ICT/euictgrowth.pdf.

Basu, S, Fernald, J G, Oulton, N and Srinivasan, S (2004), 'The case of the missing productivity growth: or, does information technology explain why productivity accelerated in the United States but not the United Kingdom?', chapter 1 of *NBER Macroeconomics Annual 2003*, Gertler, M and Rogoff, K (eds), Cambridge, MA: The MIT Press.

Baumol, W J and Wolff, E N (1984), 'On interindustry differences in absolute productivity', *Journal of Political Economy*, Vol. 92 (December), pages 1,017-34.

Bell, V, Burriel-Llombart, P and Jones, J (2005), 'A quality-adjusted labour input series for the United Kingdom (1975-2002)', *Bank of England Working Paper*, forthcoming.

Bresnahan, T F and Trajtenberg, M (1995), 'General purpose technologies: "engines of growth?"', *Journal of Econometrics*, Vol. 65 (Special issue, January), pages 83-108.

Brynjolffson, E, Hitt, L M and Yang, S (2002), 'Intangible assets: computers and organisational capital', *Brookings Papers on Economic Activity: Macroeconomics*, No. 1, pages 137-99.

Colecchia, A and Schreyer, P (2002), 'ICT investment and economic growth in the 1990s: is the United States a unique case? A comparative study of nine OECD countries', *Review of Economic Dynamics*, Vol. 5(2), pages 408-42.

Corrado, C, Hulten, C, and Sichel, D (2004), 'Measuring capital and technology: an expanded framework', *mimeo*, forthcoming in Corrado, C, Haltiwanger, J and Sichel, D (eds), *Measuring Capital in the New Economy*, Chicago: University of Chicago Press.

Daveri, F (2002), 'The new economy in Europe', *Oxford Review of Economic Policy*, Vol. 18 (Autumn), pages 345-62.

Domar, E D (1961), 'On the measurement of technological change', *Economic Journal*, Vol. LXXI, pages 709-29.

Drukker, D M (2003), 'Testing for serial correlation in panel models', *Stata Journal*, Vol. 3, no. 2, pages 168-77.

Fraumeni, B M (1997), 'The measurement of depreciation in the U.S. national income and product accounts', *Survey of Current Business*, (July), pages 7-23.

Gordon, R J (2003), 'Exploding productivity growth: context, causes, and implications', *Brookings Papers on Economic Activity*, No. 2, pages 207-79.

Griliches, Z and Mairesse, J (1998), **'**Production functions: the search for identification', in *Econometrics and economic theory in the twentieth century: the Ragnar Frisch Centennial Symposium*, pages 169-203, Cambridge University Press.

Groth, C (2005), 'Capital adjustment costs in the United Kingdom', *Bank of England Working Paper*, forthcoming.

Groth, C, Gutierrez-Domenech, M and Srinivasan, S (2004), 'Measuring total factor productivity for the United Kingdom', *Quarterly Bulletin*, Spring, pages 63-73.

Helpman, E and Trajtenberg, M (1998), 'A time to sow and a time to reap: growth based on general purpose technologies', in Helpman, E (ed), *General Purpose Technologies and Economic Growth*, Cambridge, MA: The MIT Press.

Herman, S W (2000), 'Fixed assets and consumer durable goods', *Survey of Current Business* (April), pages 17-30.

Hulten, C R (2001), 'Total factor productivity: a short biography', in Hulten, C R, Dean, E R and Harper, M J (eds), *New Directions in Productivity Analysis*, Chicago: The University of Chicago Press for the National Bureau of Economic Research.

Jorgenson, D W (1989), 'Capital as a factor of production', in Jorgenson, D W and Landau, R (eds), *Technology and capital formation*, Cambridge, MA: The MIT Press.

Jorgenson, D W (2004), 'Information technology and the G7 economies', Harvard University, *mimeo* (draft of August 5, 2004); available at http://post.economics.harvard.edu/faculty/jorgenson/papers/ handbook.extract.2001update08052004dwj.pdf.

Jorgenson, D W, Gollop, F M and Fraumeni, B M (1987), *Productivity and U.S. Economic Growth*, Cambridge, MA.: Harvard University Press.

Jorgenson, D W and Griliches, Z (1967), 'The explanation of productivity change', *Review of Economic Studies*, Vol. 34, pages 249-83, reprinted in Jorgenson, D W, *Productivity: Volume 1: Postwar U.S. Economic Growth.* Cambridge, MA: The MIT Press.

Jorgenson, D W, Ho, M S and Stiroh, K J (2004), **'**Growth in U.S. industries and investments in information technology and higher education', forthcoming in Corrado, C, Haltiwanger, J and Hulten, C R (eds), *Measuring Capital in the New Economy*, Chicago: University of Chicago Press.

Jorgenson, D W and Stiroh, K J (2000a), 'U.S. economic growth at the industry level', *American Economic Review*, Papers and Proceedings, Vol. 90, pages 161-68.

Jorgenson, D W and Stiroh, K J (2000b), 'Raising the speed limit: U.S. economic growth in the information age', *Brookings Papers on Economic Activity,* No. 1, pages 125-211.

Levin, A, Lin, C-F and Chu, C-S J (2002), 'Unit root tests in panel data: asymptotic and finite sample properties', *Journal of Econometrics*, Vol. 108, pages 1-24.

OECD (2001a), *OECD Productivity Manual: A Guide to the Measurement of Industry-Level and Aggregate Productivity Growth*. Paris: OECD.

OECD (2001b), *Measuring Capital: A Manual on the Measurement of Capital Stocks, Consumption of Fixed Capital and Capital Services,* Paris: OECD.

OECD (2002), *Measuring the Information Economy*, Paris: OECD.

Oliner, S D and Sichel, D E, (2000), 'The resurgence of growth in the late 1990s: is information technology the story?', *Journal of Economic Perspectives*, Vol. 14, Fall, pages 3-22.

O'Mahony, M and de Boer, W (2002), 'Britain's relative productivity performance: has anything changed?', *National Institute Economic Review*, No. 179 (January), pages 38-43.

O'Mahony, M and van Ark B (eds) (2003), *EU productivity and competitiveness: an industry perspective*, Luxembourg: European Commission.

Oulton, N (2001a), 'Must the growth rate decline? Baumol's unbalanced growth revisited', *Oxford Economic Papers*, Vol. 53, pages 605-27.

Oulton, N (2001b), 'ICT and productivity growth in the UK', *Bank of England Working Paper no. 140*, available at www.bankofengland.co.uk.

Oulton, N (2002), 'ICT and productivity growth in the UK', *Oxford Review of Economic Policy*, Vol. 18, No. 3, pages 363-79.

Oulton, N (2004), 'A statistical framework for the analysis of productivity and sustainable development' [paper prepared for the Allsopp Review of Statistics for Economic Policymaking], Centre for Economic Performance, *Discussion Paper no. 0629*; available at http://www.hm-treasury.gov.uk/media//BA979/allsopp_oulton_140.pdf and at http://cep.lse.ac.uk/pubs/dp.asp?prog=CEPDP.

Oulton, N and Srinivasan, S (2003), 'Capital stocks, capital services, and depreciation: an integrated framework', *Bank of England Working Paper no. 192*, available at www.bankofengland.co.uk.

Schreyer, P (2000), 'The contribution of information and communication technology to output growth: a study of the G7 countries', *STI Working Papers 2000/2*, Paris: OECD.

Stiroh, K J (2002a), 'Information technology and the U.S. productivity revival: what do the industry data say?', *American Economic Review*, Vol. 92 (December), pages 1,559-76.

Stiroh, K J (2002b), 'Are ICT spillovers driving the New Economy?', *Review of Income and Wealth*, Series 48, No. 1 (March), pages 33-58.

U.S. Department of Commerce (1999), *Fixed Reproducible Tangible Wealth in the United States, 1925-94*, Washington, DC: U.S. Government Printing Office; available at www.bea.gov.

Wooldridge, J M (2002), *Econometric Analysis of Cross Section and Panel Data*, Cambridge, MA: The MIT Press.

Yang, S and Brynjolffson, E (2001), 'Intangible assets and growth accounting: evidence from computer investments'; downloaded from Brynjolffson's website, www.ebusiness.mit.edu/erik, on 14 May 2004.