CENTRE *for* ECONOMIC PERFORMANCE

CEP Discussion Paper No 681

March 2005

Productivity Growth and the Role of ICT in the United Kingdom: An Industry View, 1970-2000

Nicholas Oulton and Sylaja Srinivasan

THE QUEEN'S ANNIVERSARY PRIZES
FOR HIGHER AND FURTHER EDUCATION
2002

THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Abstract
We use a new industry-level dataset to quantify the role of ICT in explaining productivity growth in the UK, 1970-2000. The dataset is for 34 industries covering the whole economy (31 in the market sector). Using growth accounting, we find that ICT capital played an increasingly important, and in the 1990s the dominant, role in accounting for labour productivity growth in the market sector. Econometric evidence also supports an important role for ICT. We also find econometric evidence that a boom in complementary investment in the 1990s could have led to a decline in the conventional measure of TFP growth.

Key words: productivity, TFP, ICT
JEL classification: O470, O520, D240

This paper was produced as part of the Centre's Productivity and Innovation Programme. The Centre for Economic Performance is financed by the Economic and Social Research Council.

Acknowledgements
This paper is a shortened version of the Bank of England Working Paper of the same name. Contact Publications Group, Bank of England, Threadneedle Street, London, EC2R 8AH; telephone 020 7601 4030, fax 020 7601 3298, e-mail mapublications@bankofengland.co.uk

The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or the Centre for Economic Performance. The longer version of this paper, Oulton and Srinivasan (2005), grew out of and draws on joint work with Susanto Basu and John Fernald, to whom we are grateful. We would also like to thank Ian Bond, Rob Elder, Jenni Greenslade, Neal Hatch, Simon Price and participants in the Asia-Pacific Productivity Conference in Brisbane, July 2004, for helpful comments and suggestions.

Nicholas Oulton is an Associate of the Centre for Economic Performance, London School of Economics. E-mail: n.oulton@lse.ac.uk Sylaja Srinivasan is a member of the Structural Economic Analysis Division, Monetary Analysis, Bank of England, Threadneedle Street, London, EC2R 8AH. E-mail: sally.srinivasan@bankofengland.co.uk

Published by

Centre for Economic Performance
London School of Economics and Political Science
Houghton Street
London WC2A 2AE

ISBN 0 7530 1864 0

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 investment in information and communication technology (ICT) in accounting for the growth of productivity in the UK. 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.[1]

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 US 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 UK?

Figure 1 compares growth in labour productivity (output per hour) in the US and the UK since 1979. For the US we use the standard measure of labour productivity in the nonfarm business sector, from the U.S. Bureau of Labor Statistics. For the UK we use our own measure derived from the Bank of England Industry Dataset (BEID), described below in section 2. The UK measure is for what we call the market sector, ie the whole economy

[1] Earlier, whole economy growth accounting studies that included the United Kingdom include Daveri (2002) and Schreyer (2000), who used private sector sources for ICT investment and stocks, and Colecchia and Schreyer (2002) who used national accounts data. All these results are broadly consistent at the aggregate level with those of van Ark *et al* (2002) and O'Mahony and van Ark (2003) who present industry-level estimates using a similar methodology to the one adopted here. Alternative, whole economy estimates for the G7 are in Jorgenson (2004) and Jorgenson *et al* (2004).

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 2) 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 Figure 1. First, productivity grew more rapidly in the UK in both the 1980s and the 1990s. Second, while productivity growth in the US rose by about 1% per annum in the second half of the 1990s, it fell by a similar amount in the UK, even though still remaining higher than in the US. The fact that growth was faster in the UK (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 (1992) 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 UK also experienced a boom in ICT investment in this period and our paper seeks to make a contribution to understanding this puzzle.

Plan of the paper

Section 1 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. Section 2 describes how we constructed our 34 industry dataset. 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 that mainly relate to the measurement of ICT output and investment. So we compare our estimates at the aggregate level with the national accounts. Next section 3 presents a growth accounting analysis of the market sector, ie the whole economy except for the government sector (defined as public administration and 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 4, we test these assumptions econometrically, using our panel of 34 industries. Section 5 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 6 presents our conclusions.

1. 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). Oulton and Srinivasan (2005), Annex B, sets out the approach formally. Here we give an informal treatment.

1.1 The aggregate framework

The starting point is the familiar aggregate growth accounting equation:

Growth of GDP = (Capital's share *times* growth of capital input)
plus (Labour's share *times* growth of labour input) (1)
plus Solow residual

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, sex 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 Solow residual.

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 labour productivity (GDP per hour) = Capital deepening
plus Labour quality contribution *plus* Solow residual. (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.

1.2 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:

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

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 Oulton and Srinivasan (2005), Annex D. It can also be used to derive the growth of industry-level TFP:

$$\begin{aligned}&\text{Growth of TFP in industry } i = \text{Growth of gross output of industry } i \\ &\textit{minus} \text{ share-weighted growth of inputs of } K, L \text{ and } M \text{ into } i\end{aligned} \tag{4}$$

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

$$\text{Aggregate TFP growth rate} = \text{Domar-weighted sum of industry TFP growth rates} \tag{5}$$

where the *Domar weight* for industry i is

$$\text{Nominal gross output of industry } i \div \text{Nominal GDP.}$$

Note that the Domar weights sum to more than 1. The left hand side of equation (5) also equals the Solow residual provided that 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 the Solow residual differs from aggregate TFP growth by terms reflecting the reallocation of capital and labour towards or away from higher value uses (Jorgenson *et al.*, 1987). The relationship between the Solow residual and aggregate TFP growth is then:

$$\text{Solow residual} = \text{Aggregate TFP growth } \textit{plus} \text{ Reallocation} \tag{6}$$

where aggregate 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.

2. 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. The list of industries is shown in Table 3.1. 31 industries (numbers 1-29, 33 and 34) constitute what we call the market sector. 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 Oulton and Srinivasan (2005), Annex A, available at www.bankofengland.co.uk/workingpapers/wp259techannex.pdf.

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. 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.

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. 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 from imports, each deflated by the appropriate price index. Our series for real value added at the industry level derive from the national accounts.[2]

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

[2] In practice the ONS proxies real value added by real gross output. As explained in Oulton and Srinivasan (2005), 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 (Oulton and Srinivasan (2005), Annex A).

Oulton and Srinivasan (2003) for a full account of the methodology, which is based on Jorgenson (1989).

Labour services are measured as hours worked, adjusted for quality. We constrain the growth of total (unadjusted) hours to conform to the official index of aggregate hours worked (ONS code: YBUS). The quality adjustment is borrowed from the whole economy measure developed by Bell, Burriel-Llombart and Jones (2004). Their index of quality-adjusted labour input is a Törnqvist one that allows for changes in the composition of the labour force by age, sex and qualifications. The growth of labour quality is then measured as the growth of aggregate (quality-adjusted) labour input minus the growth of aggregate hours worked. It is the growth in qualifications that mainly accounts for the secular rise in quality that we observe.

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 US, 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 US (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 (Fraumeni, 1997). 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.

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 (2001, 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 US, 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. Based on a re-examination of the original 1991 survey on which the official series is based, we would also claim that the adjustment brings us closer to the truth (Oulton, 2001, Appendix C).

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 Oulton and Srinivasan (2005), 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.

For the whole economy, the ONS estimate of the growth of GDP per hour (excluding housing services) was 2.76% per annum over 1990-2000, while our estimate is 2.94% per annum. For the market economy, our estimate is 3.45% per annum. So both the adjustments we have made to the national accounts and the exclusion of the government sector raise the growth rate significantly.

3. A growth accounting analysis of the market sector

Table 2 shows the growth rate of labour productivity (output per hour) in the market sector and its components, following equation (2). The reallocation term is calculated by equation (6) above. Aggregate TFP growth is built up from the industry TFP growth rates by Domar aggregation: see equation (5).

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 2, 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 2, column 7). 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 2, column 6). However, like labour productivity growth, it fell in the second half of the 1990s. 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 twenty years. Growth was particularly rapid post 1995 (Table 2, column 2). Capital deepening results partly from an increase in the capital intensity of individual industries and partly from a shift towards or away from industries with a higher *level* of capital intensity: see equation (7) and charts 6.6-6.8 in Oulton and Srinivasan (2005). However, 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. 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, 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 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 3 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.

We now look more closely at the contributions of the 31 industries that make up the market sector. 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. Figure 2 shows the contribution of each industry to the *change* in labour productivity growth, comparing 1995-2000 with 1990-1995; Figure 3 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 aggregate TFP 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.

3.1 The role of ICT capital

We now turn to consider more specifically the role of ICT capital. Table 4 shows that ICT capital deepening accounted for a quarter of all physical capital deepening in the first of our decades, 1970-79. By the third decade, 1990-2000, the proportion of total capital deepening due to ICT capital deepening had doubled. In the last five years of the century, the proportion due to ICT was nearly two thirds.[3] 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 5 shows this decomposition. Over the three decades, ICT capital services per hour have grown at a remarkable 22.00% 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% (Figure 4).[4]

We can now evaluate the importance of ICT capital as a source of growth in the UK.[5] The results are shown in Table 3. ICT capital accounted for 13% of growth of output per hour in the market sector in 1970-79, 26% in 1979-90, and 28% in 1990-2000. In 1995-2000 the proportion rises to 46%. 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.

---

[3] Similar results for the whole economy were presented in Oulton (2001) and (2002).

[4] The income share is now about the same as in the US, though stocks of software and communications equipment per capita are lower in the UK (Oulton and Srinivasan, 2005).

[5] The proportion of labour productivity growth accounted for by ICT capital is the share of ICT capital in total capital deepening (Table 4) multiplied by the latter's share in accounting for labour productivity growth (Table 3).

Finally, it is important to note that ICT capital deepening was concentrated in a small number of industries in the 1990s (Figure 5). 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 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.

4. 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 up to 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 over 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 $\Delta_s X_{it} = X_{it} - X_{i,t-s}$) and ε_{it} is an error term. This equation uses value added rather than gross output, since the former is more reliably measured. Theory suggests that $0 < \beta_{ICT}, \beta_N, \beta_L < 1$, $\beta_{ICT} + \beta_N + \beta_L = 1$, 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:

$$\begin{aligned}\Delta_s \ln(V_{it} / H_{it}) = \alpha_i + \lambda_t + \gamma^{ICT} [\beta_{it}^{ICT} \Delta_s \ln(K_{it}^{ICT} / H_{it})] + \gamma^N [\beta_{it}^N \Delta_s \ln(K_{it}^N / H_{it})] \\ + \gamma^L [\beta_{it}^L \Delta_s \ln(L_{it} / H_{it})] + \gamma^H \Delta_s \ln H_{it} + \varepsilon_{it}\end{aligned} \tag{7}$$

The variables on the right hand side in square brackets now measure ICT, non-ICT and human 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 checked 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 in equation (7) when measured in log levels to be I(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). These results justify the use of first differences in equation (7).[6]

Table 6 shows the results of running the regression of equation (7) 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 5). These results were estimated by the least squares dummy variable (LSDV) method, ie OLS with fixed effects and time period

6 These results are reported in Oulton and Srinivasan (2005, Table 7.1).

dummies.[7] 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 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.[8]

Table 6 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 1979-1989. 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 higher. 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.[9]

---

[7] 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 6 we can strongly reject the null hypothesis that all the fixed effects are zero (ie that there is a common constant).

[8] 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.

[9] 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 US 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.

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 (7)). The results are in Table 7. 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.[10] 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 5 years.[11] 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.

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. But we found that the correlation between the estimated ICT coefficients and the true errors, where the latter were estimated by the mean across the 30 industries of the TFP growth rate, was actually negative (-0.35): details are in Oulton and Srinivasan (2005).

---

[10] 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.

[11] 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).

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.

5. 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, 2004). 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.[12] 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

$$pY = wL + p^K K_O \tag{8}$$

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

$$pY = wL_O + p_O^K K_O + p_C^K K_C \tag{9}$$

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 (9) assumes for 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:

$$p_C^A I_C = wL_C \tag{10}$$

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

$$p_Z Z = pY + p_C^A I_C \tag{11}$$

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.[13]

---

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

[13] 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.

Conventional aggregate profit is $pY - wL$, while true aggregate profit is $p_Z Z - wL$. Hence from (10) and (11) 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:

$$Y = \exp(\mu_Y t) f(K_O, L) \tag{12}$$

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

$$Y = \exp(\mu_Y t) g(K_O, K_C, L_O) \tag{13}$$

$$I_C = \exp(\mu_C t) h(L_C) \tag{14}$$

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:

$$p_C^K = (r + \delta_C - \pi_C) p_C^A \tag{15}$$

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

$$\dot{K}_C = I_C - \delta_C K_C \tag{16}$$

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 (8) and (12),

$$\mu_Y^{conv} = \hat{Y} - (wL / pY)\hat{L} - (p^K K_O / pY)\hat{K}_O \tag{17}$$

where hats denote growth rates (eg $\hat{K}_O = \dot{K}_O / K_O$). The true measure ($\mu_Y^{true}$) is, from (9) and (13),

$$\mu_Y^{true} = \hat{Y} - (wL_O / pY)\hat{L}_O - (p_O^K K_O / pY)\hat{K}_O - (p_C^K K_C / pY)\hat{K}_C \tag{18}$$

In the Appendix, we show that the error made by the conventional measure can be written:

$$\mu_Y^{conv} - \mu_Y^{true} = [s_C \hat{K}_C - i_C \hat{I}_C] - [s_C - i_C]\hat{K}_O + i_C \mu_C \tag{19}$$

where s_C is the income share of complementary capital, $s_C = p_C K_C / pY$, and i_C is the proportion of output devoted to complementary investment (in current prices), $i_C = p_C^A I_C / pY$. 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 $i_C \mu_C$ which is positive if $\mu_C > 0$. 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, ie conventionally-measured TFP growth will appear to decline.

The second term in square brackets on the right hand side of (19) is likely to be small since the ordinary capital stock grows slowly, so consider the first term. The expression $s_C \hat{K}_C$ is complementary capital deepening. By analogy we can call the term $i_C \hat{I}_C$ 'complementary investment deepening'; complementary investment deepening is the growth rate of complementary investment weighted by the ratio of complementary investment to output (in current prices). The size of the error then depends on the magnitude of capital deepening relative to investment deepening. In a boom, the error will fall algebraically (become more negative) so other things equal conventional 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, ie $\hat{I}_C > \hat{K}_C$. So it is possible for investment deepening to exceed capital deepening and for the gap between the two to be getting wider (see the Appendix for a formal proof).

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:

$$d\hat{K}_C / dt = \lambda(\hat{K}_C^* - \hat{K}_C) \qquad 0 < \lambda < 1 \tag{20}$$

where $\hat{K}_C^*$ is the desired growth rate. Then the growth rate rises asymptotically towards its new equilibrium level 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.[14]

To make this notion more precise, we employ equation (19). 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 four different cases: low and high growth and low and high depreciation rates. We assume that the complementary investment ratio is four times the observed ICT investment ratio (the latter averaged 0.026 in 1990-1995 and 0.039 in 1995-2000). The evidence cited above suggests that the resulting complementary investment ratios are not unreasonable. The low depreciation rate is that of machinery and equipment, the high one that for ICT assets. Table 8 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. 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.

5.1 Econometric evidence

We estimate equation (19) on panel data, after taking first differences and rearranging:

$$\Delta\mu_Y^{conv} = \Delta s_C \hat{K}_C - \Delta i_C \hat{I}_C - \Delta[s_C - i_C]\hat{K}_O + \Delta i_C \mu_C + \Delta\mu_Y^{true} \tag{21}$$

The time periods are taken to be 1990-1995 and 1995-2000, so the left hand side is the *change* in TFP growth, 1995-2000 over 1990-1995. We have no direct measures of complementary capital and investment so we need empirical proxies.[15] 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

$$\Delta\mu_{it} = \beta_0 + \beta_1 \Delta[s_{it}^{ICT} \hat{K}_{it}^{ICT}] + \beta_2 \Delta[i_{it}^{ICT} \hat{I}_{it}^{ICT}] + \varepsilon_{it} \tag{22}$$

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 9. Initially we omit the government sector (industries 30, 31 and 32), agriculture (industry 1)[16] and also rail transport (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

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

[15] For a recent attempt to measure intangible investment in the US (using a wider definition than here), see Corrado *et al.* (2004).

[16] For comparability with the results in Basu *et al.* (2004) which are for the non-farm business sector.

and has the expected sign, though the goodness of fit is poor.[17] 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).[18]

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 9) 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

[17] 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.

[18] The results in column (5) are very similar to those reported for the UK 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 for non-ICT capital.

and investment must grow at the same rate. So this suggests one reason for thinking that TFP growth must eventually recover.

6. Conclusions

This paper has used a new industry-level dataset to consider the role of ICT in explaining productivity growth in the UK, 1970-2000, though mainly concentrating on the period since 1979. Using the growth accounting methodology, we found that the accumulation of ICT capital has played an increasingly important, and in the second half of the 1990s the dominant, role in accounting for labour productivity growth in the market sector. ICT capital deepening accounted for 13% of the growth of output per hour in the market sector 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. We also found that the growth rates of both labour productivity and of TFP fell in the second half of the 1990s, by about one percentage point per annum.

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 misclassified 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.

Table 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	7.03
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. 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 2. Industries 1-29, 33 and 34 constitute the market sector.

a. Excluding housing services.

Table 2
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 3
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 2 and 4.

Table 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 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*

Table 6
Regressions to test growth accounting assumptions:
dependent variable is growth of real value added per hour (30 market sector industries)

	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 (7). Standard errors in parentheses. Method of estimation is OLS; constant, time dummies and fixed effects included but not reported. Wooldridge test calculated using the 'xtserial' command in Stata (Wooldridge, 2002; Drukker, 2003).
* significant at 5%; ** significant at 1%.

Table 7
Regressions to test growth accounting assumptions: dependent variable is growth of real value added per hour over one, two, three, four or five years (30 market sector industries)

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 (7). Standard errors in parentheses. Method of estimation is OLS; constant, time dummies and fixed effects included but not reported.
* significant at 5%; ** significant at 1%.

Table 8
Change in error in conventional TFP measure, following on change in desired growth rate of complementary capital (percentage points per annum)

Increase in desired growth rate of complementary capital	δ_C = 13%	δ_C = 31.5%
From 3% to 5% p.a.	-0.23	-0.05
From 10 to 20% p.a.	-0.72	-0.10

Note Calculated from equation (19) 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 (20) with $\lambda = 1/3$. The growth of investment in the second period is calculated from a discrete version of equation (A4) in the Appendix. The ratio of complementary investment to output (i_C) was set to four times the ratio of ICT investment to GDP in the market sector; the latter was 0.026 in 1990-1995 and 0.039 in 1995-2000. This ratio also helps to determine s_C (see equation (A3) in the Appendix). 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 1990-1995 and 1995-2000 respectively. Finally, *r* is set to 6%.

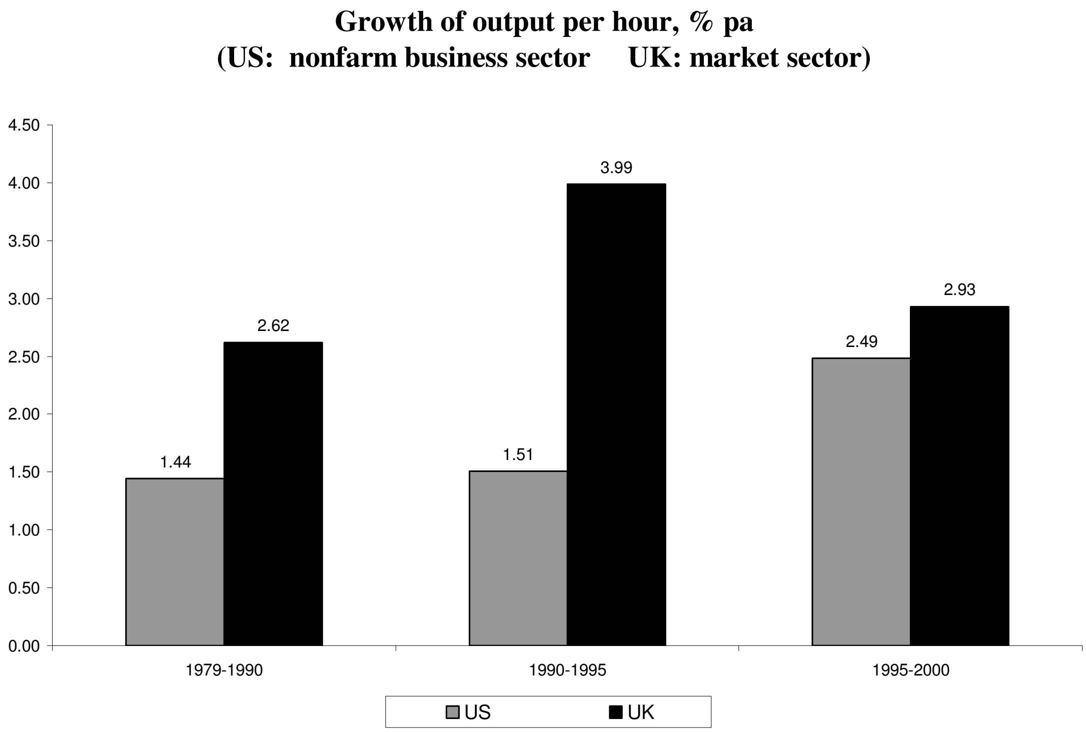
Table 9
TFP growth and the influence of ICT capital and investment deepening: cross-section regression tests of equation (27)

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

Fig. 1



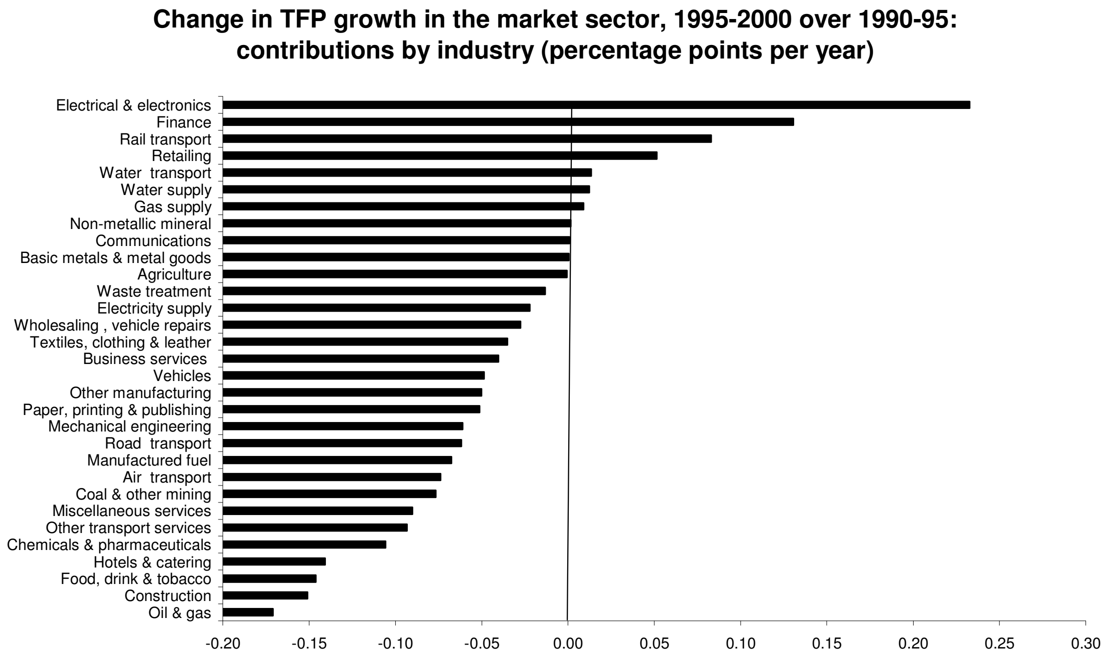
Source US: Bureau of Labor Statistics (downloaded from www.bls.gov)

UK: Bank of England Industry Dataset (see section 2)

Fig. 2

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 effect of shifts in the composition of output is excluded.

Fig. 3



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.

Fig. 4

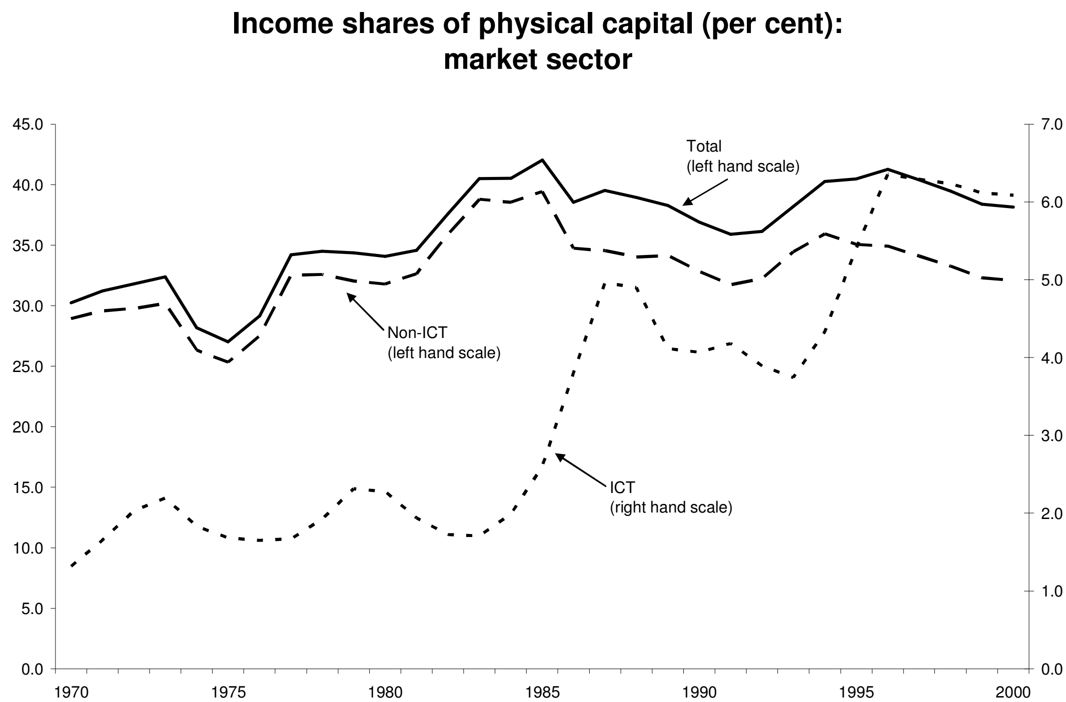
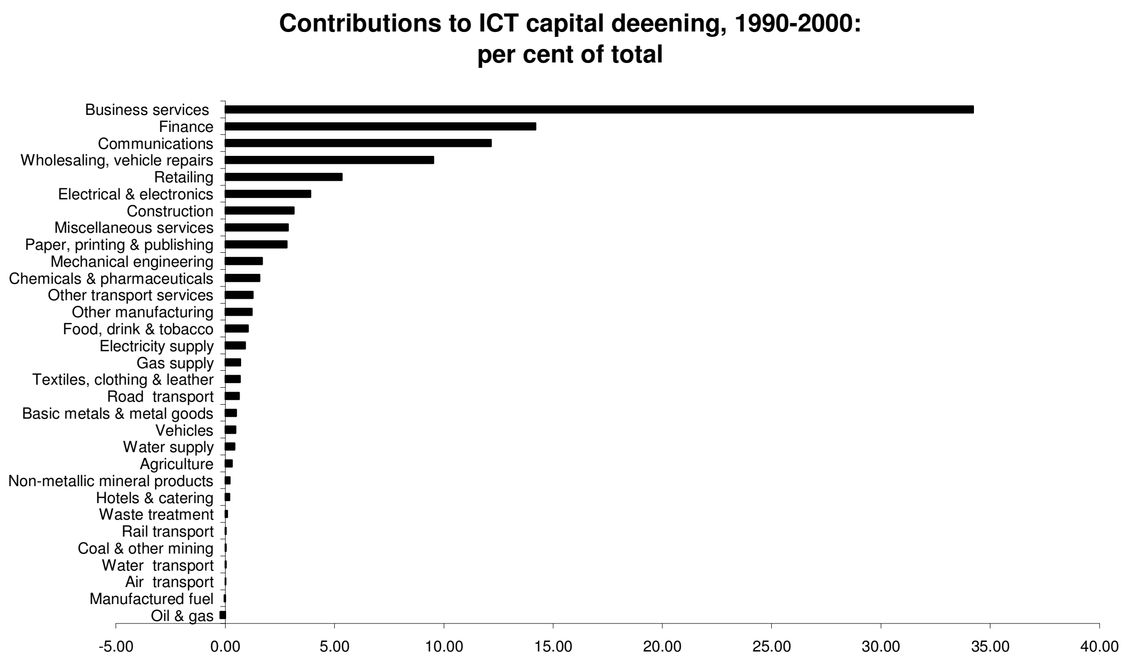

Income shares of physical capital (per cent):
market sector
Total
(left hand scale)
Non-ICT
(left hand scale)
ICT
(right hand scale)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1970
1975
1980
1985
1990
1995
2000

Fig. 5


Contributions to ICT capital deeening, 1990-2000:
per cent of total
Business services
Finance
Communications
Wholesaling, vehicle repairs
Retailing
Electrical & electronics
Construction
Miscellaneous services
Paper, printing & publishing
Mechanical engineering
Chemicals & pharmaceuticals
Other transport services
Other manufacturing
Food, drink & tobacco
Electricity supply
Gas supply
Textiles, clothing & leather
Road transport
Basic metals & metal goods
Vehicles
Water supply
Agriculture
Non-metallic mineral products
Hotels & catering
Waste treatment
Rail transport
Coal & other mining
Water transport
Air transport
Manufactured fuel
Oil & gas
-5.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00

Appendix

Derivation of equation (19)

From equations (17) and (18), the error made by the conventional measure is:

$$\mu_Y^{conv} - \mu_Y^{true} = \left(\frac{p_C^K K_C}{pY}\right)\hat{K}_C + \left(\frac{wL_O}{pY}\right)\hat{L}_O - \left(\frac{wL}{pY}\right)\hat{L} - \left(\frac{(p^K - p_O^K)K_O}{pY}\right)\hat{K}_O \qquad \text{(A1)}$$

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 (10) and (14),

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

Then substituting these relationships into (A1), we find that the error made by the conventional approach in measuring TFP growth in the production of ordinary output is:

$$\mu_Y^{conv} - \mu_Y^{true} = [s_C\hat{K}_C - vs_L\hat{I}_C] - [s_C - vs_L]\hat{K}_O + vs_L\mu_C \qquad \text{(A2)}$$

Now note that, from (10), $vs_L = wL_C / pY = p_C^A I_C / pY = i_C$, where as in the text i_C is the proportion of output devoted to investment in complementary capital (in current prices). We can then rewrite equation (A2) in more convenient form as:

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

which is equation (19).

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 (15) and (16), we find that

$$s_C = \left[\frac{r + \delta_C - \pi_C}{\hat{K}_C + \delta_C} \right] i_C . \tag{A3}$$

The relationship between the growth of investment and the growth of the corresponding stock

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 (16) 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:

$$\hat{I}_C = \frac{(d\hat{K}_C / dt)}{\hat{K}_C + \delta} + \hat{K}_C \tag{A4}$$

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*

References

Ahmad, N., Lequiller, F., Marianna, P., Pilat, D., Schreyer, P., 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 US but not the UK?', in M. Gertler and K. Rogoff, eds., *NBER Macroeconomics Annual 2003*, pp. 9-63, Cambridge, MA: The MIT Press.

Bell, V., Burriel-Llombart, P. and Jones, J. (2004). 'A quality-adjusted labour input series for the UK (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), pp. 83-108.

Brynjolffsson, E., Hitt, L. M., and Yang, S. (2002). 'Intangible assets: computers and organisational capital', *Brookings Papers on Economic Activity: Macroeconomics*, 1, pp. 137-99.

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

Corrado, C., Hulten, C., and Sichel, D. (2004). 'Measuring capital and technology: an expanded framework', forthcoming in C. Corrado, J. Haltiwanger and D. Sichel, 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), pp. 345-62.

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

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

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

Gordon, R. J. (2003). 'Exploding productivity growth: context, causes, and implications', *Brookings Papers on Economic Activity*, 2, pp. 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*, pp. 169-203, Cambridge University Press.

Groth, C. (2004). 'Capital adjustment costs in the UK', *Bank of England Working Paper*, forthcoming.

Helpman, E. and Trajtenberg, M. (1998). 'A time to sow and a time to reap: growth based on general purpose technologies', in E. Helpman, ed., *General Purpose Technologies and Economic Growth*, pp. 55-83, Cambridge, MA: The MIT Press.

Hulten, C. R. (2001). 'Total factor productivity: a short biography', in C. R. Hulten, E. R. Dean and M. J. Harper, eds., *New Directions in Productivity Analysis*, pp. 1-47, Chicago: The University of Chicago Press for the National Bureau of Economic Research.

Jorgenson, D. W. (1989). 'Capital as a factor of production', in D.W. Jorgenson and R. Landau (eds.), *Technology and capital formation*, pp. 1-35, 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*, 34, pp. 249-83, reprinted in D.W. Jorgenson, *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 C. Corrado, J. Haltiwanger and C.R. Hulten (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, pp. 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,* vol. 1, pp. 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, pp. 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.

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, pp. 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), pp. 38-43.

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

Oulton, N. (2001). 'ICT and productivity growth in the UK'. *Bank of England Working Paper no. 140*, available at www.bankofengland.co.uk/workingpapers/wp140.pdf.

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

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/workingpapers/wp192.pdf.

Oulton, N. and Srinivasan, S. (2005). 'Productivity growth in UK industries, 1970-2000: structural change and the role of ICT ', Bank of England Working Paper no. 259, available at www.bankofengland.co.uk/workingpapers/wp259.pdf.

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), pp. 1559-76.

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

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.

CENTRE FOR ECONOMIC PERFORMANCE
Recent Discussion Papers

680	Stephen Machin Olivier Marie	Crime and Police Resources: the Street Crime Initiative
679	Alan Manning Barbara Petrongolo	The Part-Time Pay Penalty
678	Andrew Clark Fabien Postel-Vinay	Job Security and Job Protection
677	Eran Yashiv	Evaluating the Performance of the Search and Matching Model
676	Alex Bryson Rafael Gomez Tobias Kretschmer	Catching a Wave: the Adoption of Voice and High Commitment Workplace Practices in Britain: 1984-1998
675	Nick Bloom Mark Schankerman John Van Reenen	Identifying Technology Spillovers and Product Market Rivalry
674	Lorraine Dearden Howard Reed John Van Reenen	The Impact of Training on Productivity and Wages: Evidence from British Panel Data
673	Giulia Faggio Stephen Nickell	Inactivity Among Prime Age Men in the UK
672	Chiara Criscuolo Ralf Martin	Multinationals and US Productivity Leadership: Evidence from Great Britain
671	Roberto Torrini	Profit Share and Returns on Capital Stock in Italy: the Role of Privatisations Behind the Rise of the 1990s
670	Silvia Ardagna Francesco Caselli Timothy Lane	Fiscal Discipline and the Cost of Public Debt Service: Some Estimates for OECD Countries
669	Alejandro Cuñat Marco Maffezzoli	Can Comparative Advantage Explain the Growth of US Trade?

668	Francesco Caselli Silvana Tenreyro	Is Poland the Next Spain?
667	Francesco Caselli	Accounting for Cross-Country Income Differences
666	Gianluca Benigno Pierpaolo Benigno	Designing Target Rules for International Monetary Policy Cooperation
665	Olmo Silva	Entrepreneurship: Can the Jack-of-All-Trades Attitude be Acquired?
664	Maarten Goos	Sinking the Blues: the Impact of Shop Closing Hours on Labor and Product Markets
663	Christopher A. Pissarides Giovanna Vallanti	Productivity Growth and Employment: Theory and Panel Estimates
662	Philip R. Lane Gian Maria Milesi-Ferretti	Financial Globalization and Exchange Rates
661	Alex Bryson Lorenzo Cappellari Claudio Lucifora	Do Job Security Guarantees Work?
660	David Marsden Richard Belfield	Unions, Performance-Related Pay and Procedural Justice: the Case of Classroom Teachers
659	Rachel Griffith Rupert Harrison John Van Reenen	How Special is the Special Relationship? Using the Impact of R&D Spillovers on UK Firms As a Test of Technology Sourcing
658	Douglas Kruse Richard B. Freeman Joseph Blasi Robert Buchele Adria Scharf Loren Rodgers Chris Mackin	Motivating Employee Owners in ESOP Firms: Human Resource Policies and Company Performance
657	Christopher Crowe	Inflation, Inequality and Social Conflict

The Centre for Economic Performance Publications Unit
Tel 020 7955 7673 Fax 020 7955 7595 Email info@cep.lse.ac.uk
Web site http://cep.lse.ac.uk