ICT and GDP Growth in the United Kingdom: A Sectoral Analysis

A Report to

Cisco Systems

By

London Economics

February 2003

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Glossary

ALP	Average Labour Productivity
BEA	US Bureau of Economic Analysis
ICT	Information and Communication Technologies
GDP	Gross Domestic Product
NIPA	US National Income and Products Accounts
OECD	Organisation for Economic Cooperation and Development
ONS	Office of National Statistics
PPI	Producer Price Index
TFP	Total Factor Productivity

Executive Summary

Introduction and background

This study contributes to the recent debate about the contribution of Information and Communication Technology (ICT) to economic growth and the productivity performance of the United Kingdom. Like the US, the United Kingdom also experienced the enviable combination of higher growth and lower inflation towards the end of the 1990s coupled with rapidly increasing levels of ICT investment. However, US style gains in productivity growth failed to materialize, with labour productivity growth actually declining in the mid to late 1990s and Total Factor Productivity (TFP) growth also slowing after 1994. At issue is, therefore, whether ICT has had an impact on the UK's productivity performance at both the aggregate and industry level.

Cisco Systems commissioned a study from London Economics to:

- Analyse the contribution of ICT investment to the performance of the United Kingdom economy;
- Understand which sectors have benefited the most from ICT investment; and
- Assess the extent to which the productivity of non-ICT producing sectors has benefited from ICT investment.

Methodology

Our methodology is based on growth accounting techniques. Growth accounting essentially divides output growth into a number of constituent parts. Generally, two sources of growth in output can be identified: growth in inputs of production (broadly defined as capital and labour) and a residual term (the so-called TFP growth) due to some unmeasured technological progress. For the purpose of this study we decompose the growth of the capital input into two components: ICT and non-ICT capital. This allows us to estimate the contribution of ICT capital to output and labour productivity growth.

Data

This study uses data from twelve sectors of the UK, representing the entire economy over the period 1992-2000. The investment in ICT is measured in terms of investment in computer, software and telecommunication equipment. We use quality-adjusted price indices produced by the US

Bureau of Economic Analysis (BEA) to generate ICT investment in real terms, adjusted for exchange rate changes.

Results

The key findings of our study can be summarised in the following three sets of results as follows:

1. **ICT investment has made an important contribution to output growth in the UK over the period 1992-2000.**

    - These gains have involved the largest service sectors of the economy, such as Financial Intermediation (1.42 percentage points of the average growth of the sector, 5.2), Wholesale and Retail Trade (0.53 p.p. of 4.01), and the Manufacturing sector (0.49 p.p. of 1.13 percentage points). Due to the relative size of these sectors, these sectoral contributions explain the largest proportion of the contribution of ICT to output growth that has been observed at the aggregate economy level. When aggregated at the whole economy level, our results produce an economy wide contribution of 0.8 percentage point annually or 25% of total output growth (which was on average 3.23 percentage points per annum from 1992 to 2000).

    - Manufacturing is the sector that has (relatively) gained the most in terms of output growth from ICT (43% of output growth is due to ICT), followed by the large service sectors, such as Financial Intermediation (27%), Transport, Wholesale and Retail Trade (13%) and Other Services (9%). This suggests that the traditional sectors of the economy have benefited more from ICT investment than some of the most ICT-intensive service sectors.

2. **ICT investment has also made a sizeable contribution (through capital deepening) to labour productivity growth in the UK over the period 1992-2000.**

    - These contributions have involved the largest service sectors of the economy, such as Financial Intermediation (1.2 percentage points per annum), the Manufacturing sector (0.54 percentage point per annum) and Wholesale and Retail Trade (0.52 percentage point per annum). At the economy-wide level, ICT capital deepening made an average (absolute) contribution of 0.76 percentage point annually or 47% of the total labour productivity growth (which averaged 1.6 percentage points per annum from 1992 to 2000).

    - Our results indicate that the benefits of ICT investment on productivity are not confined only to ICT-*producing* sectors, but also extend to ICT-*using* sectors.

3. **The contribution of ICT to output growth and labour productivity increases over time in parallel with ICT investment.**

   - Comparing the early years of the 1990s with the later years, we observe that the contribution of ICT capital to both output and labour productivity growth increases over time in the majority of the sectors.

1 Introduction

Cisco Systems has commissioned a study from London Economics to assess the contribution of information and communication technology (ICT) investment to the performance of the United Kingdom economy, determine which sectors have benefited the most from ICT investment and evaluate the extent to which the productivity of ICT-*using* sectors has benefited from ICT investment.

This study adds to recent findings about the positive contribution of ICT to growth and productivity performance by focusing on the impact of ICT on the UK economy at a sectoral level using the most recent data.

The starting point is the recent surge in US GDP and productivity growth in the mid to late 1990s. This period coincided with major investment in and the diffusion of ICT. Rapid technological progress and falling prices in the semi-conductor industry drove down similarly prices of products using semi-conductor technology (computers, software and communications equipment). This spurred an investment boom in these technologies by firms and households substituting to relatively cheaper inputs. The tendency for the density and processing power of chips to double every 18 months (Moore's Law) - triggering innovations such as desktop computers, mobile telecommunications and the internet - has brought profound changes to lifestyles and business practices in recent years.

These advances in ICT have prompted significant debate about its contribution to the US growth and productivity revival of the 1990s, and the potential for permanently higher long-term GDP and productivity growth. Indeed, many argue the case for a more productive "new economy" with new rules and business customs arising from ICT investment. Others, more sceptical of the "new economy" vision maintain that increasing competition, business innovation (including, but not limited to ICT), and positive cyclical demand factors such as a soaring stock market and the shift by consumers to higher-value goods were the main causes of rising productivity growth during the mid to late 1990s. Such ICT sceptics note that productivity gains in the semi-conductor industry may have as much to do with Pentium's increased competition from Advanced Micro Devices as with the adoption of new technologies in the production process[1]. Similarly, rising productivity rates in the securities industry happened to coincide with a colossal stock market bubble, pointing to cyclical forces that should be discounted when examining the impact of ICT.

Compared to the US, the United Kingdom also experienced the enviable combination of higher growth and lower inflation towards the end of the 1990s coupled with rapidly increasing levels of ICT investment. However, US-style gains in average labour productivity (ALP) growth failed to

[1] See, for example, McKinsey Global Institute (2001).

materialize, with ALP growth actually declining in the mid to late 1990s. Total Factor Productivity (TFP) growth also slowed after 1994. There is then a need to assess the impact of ICT, if any, on the UK's productivity performance at both the aggregate and industry levels.

This study adds to and complements the findings of the recently published paper "ICT and Productivity Growth in the United Kingdom" by Nick Oulton of the Bank of England (2001). The Oulton study, that focused on a twenty year period ending in 1998, finds that a substantial contribution of ICT spending to UK GDP growth, and capital deepening at macro level, though the ICT contribution to labour productivity growth is less evident.

This study expands Oulton's work in two major ways:

- First, it extends the period covered by the analysis to 2000, adding two years characterised by heavy ICT spending; and
- Second, and more importantly, it adopts a detailed, sectoral approach whereas the Oulton study focused only the aggregate macroeconomic impact.

The benefits of such a detailed, sectoral approach are numerous. It will allow us to:

- Shed further light on how ICT investment has contributed to the performance of the UK economy;
- Assess which sectors have benefited the most from ICT investment;
- Quantify the extent to which ICT-*using* sectors' productivity has benefited from ICT investment; and
- Derive from the bottom up economy-wide estimates of the effects of ICT spending that are consistent with the underlying sectoral impacts.

Most of the research on the economic impact of ICT spending has focused so far on the United States. Besides the Oulton study for the UK, only a limited number of studies have examined the impact of ICT on other European economies[2]. But the present study is first European one that examines systematically the effects of ICT investment at a sectoral level.

This study is organised as follows. Section 2 provides the background to the study in terms of the links between ICT investment and economic performance and an overview of the results of previous US and UK studies. Section 3 describes the methodology that we use in the study. Section 4

[2] See, for example, Kegel et al. (2002), Audenis et al. (2002).

describes the construction and coverage of our data. Section 5 shows the results of our analysis. Finally, we offer some conclusions in Section 6.

2 Background

Before reviewing some of the key literature on the ICT debate, it is necessary to briefly set out three different ways of looking at the impact of ICT on growth:

- First, the role of ICT producers can be considered both in relation to their rising contribution to aggregate GDP and to the contribution of productivity gains within ICT production to TFP growth.

- Second, the role of increased accumulation of ICT as a capital input by ICT users should be assessed, particularly the effect of ICT-led capital deepening on average labour productivity growth.

- Third, the potential role of ICT as a special form of capital input should be examined, in particular whether ICT use influences aggregate TFP growth through externality and spill-over effects, an argument often cited by proponents of the "new economy" idea.

These differing perspectives on the role of ICT have shaped the debate and provide the framework used by much of the literature on ICT and GDP/productivity growth.

The study by Jorgenson and Stiroh (2000) is one of the most noted studies seeking to quantify the contribution of ICT to aggregate US GDP and productivity growth in the mid to late 1990s. Classifying information technology as encompassing computers, software and communications equipment, they adopt a growth accounting approach to measure the effects of ICT production and use[3].

The contribution of differing outputs and inputs is examined by the decomposition of variables such as investment into its various sub-components (e.g. investments in computers, software and communications equipment). Drawing on new information made available by the 1999 benchmark revision of the US National Income and Product Accounts (NIPA), the Jorgenson and Stiroh study uses aggregate data for the period 1959-1998 and focuses on the "new economy" period 1995-98.

This aggregate analysis yielded the following key results:

- ICT producers' outputs made a contribution to US output growth of more than 1 percentage point of the total average annual 4.73% growth in private domestic output for 1995-98.

[3] The framework adopted by Jorgenson and Stiroh (2000) assumes assuming competitive markets and constant returns to scale. Under these assumptions, the factor shares can be taken as a proxy for output elasticities.

- The contribution of ICT as a production input was of 0.94 percentage point, accounting for more than two-fifths of the total growth contribution of broadly defined capital.

- Average annual labour productivity (ALP) growth increased more than 1 percentage point during 1995-98 compared to 1990-95. Capital deepening and TFP growth contributed 0.49 percentage point and 0.63 percentage point respectively to this increase (overall ALP growth is lowered to 1% by an acceleration in hours worked causing a decline in labour quality growth).

- Aggregate TFP growth accelerated from an average of 0.36% per year for 1990-95 to 0.99% per year for 1995-98. A decomposition of this growth reveals that ICT producers account for 0.44 percentage point of the TFP growth observed over the period 1995-98[4]. This compares to 0.25 percentage point for 1990-1995. Non-ICT industry TFP growth also rises significantly to 0.55% for the period 1995-98 compared with 1990-95.

Following the analysis at the aggregate level, Jorgenson and Stiroh trace aggregate TFP growth to its sources at the industry level. The techniques used are similar to that at the aggregate level, utilising an industry level production model and a growth accounting equation. The key difference however, is that industry output is measured as gross output rather than value-added, with the production model including both final demand and intermediate goods. This allows for the correct allocation of aggregate TFP gains among industries, which is particularly useful when the productivity gains in one sector, namely computing are so driven by the gains in the sector of its major intermediate input – semi-conductors. Each industry's contribution to aggregate TFP growth for the period 1958-1996 is then calculated as the product of industry productivity growth and the appropriate industry "Domar" weight (Domar 1961 showed that aggregate TFP growth can be expressed as a weighted average of industry productivity growth).

Jorgenson and Stiroh find the following key results in this analysis:

- Annual industry productivity growth for the period 1958-96 was the highest in two high-tech industries, Industrial machinery (1.5%) and Equipment and Electronic Equipment (2.0%). These two industries also show high rates of ALP growth of 3.1% and 4.1% per year respectively. These industries showed rapid accumulation of capital and intermediate inputs that raised their ALP growth above economy-wide ALP growth.

[4] This is the lowest of three figures using different price-deflators with varying constant quality controls.

- Industry level analysis reveals low productivity growth in key non-ICT industries that have invested heavily in ICT with Finance, Insurance, and Real Estate and Services all showing falling contributions to aggregate TFP growth over the period 1958-1996.

The key factors behind the resurgence of high US GDP growth rates in the late 1990s are thus found to be accelerating TFP growth (driven by increased productivity (TFP) growth in ICT producing industries) and capital deepening in ICT-using industries. Computers are said to have played the most significant role, although the role of software and communications equipment is increasing. However, contrary to the "new economy" argument stressing spillovers arising from ICT use across industries, Jorgenson and Stiroh find no evidence of a corresponding increase in an ICT-led TFP growth in non-ICT industries, although they stress the need for further research in this area. Finally, the paper argues that there remain risks to permanently "raising the speed limit" – revising intermediate growth projections upwards – as permanently higher GDP growth rates rely on the continuation of a high pace of technological change, most notably in the semi-conductor industry.

The results from Jorgenson and Stiroh (2000) above are confirmed by other US growth accounting research, notably that of Oliner and Sichel (2000) who find an increase in ALP of 1.04 percentage points for the period 1996-99 compared to 1995-95. Decomposition of this figure shows a contribution from increased ICT capital use (capital deepening) of 0.45 percentage point and from increased efficiency in ICT production of 0.37 percentage point. Their conclusion is therefore that increasing use of ICT along with increased efficiency in ICT production accounts for about three quarters of the rise in US ALP in the late 1990s. Oliner and Sichel also trace the driving force behind these changes to rapid and accelerating technological progress in the semi-conductor industry.

It is important to note here that there exists another substantial body of economic literature focusing on firm or plant level impact of ICT investment. While it is impossible to infer economy-wide output and productivity impact estimates from such studies, they nevertheless convey the critical message that, without accompanying changes in organisation and management and production systems, the impact of ICT investment is limited (Brynjolfson and Hitt 2000). In other words, to reap the full benefits of ICT investment, firms need to fundamentally rethink and overhaul their organisation.

Following on from the research undertaken in the US, Oulton (2001) also uses growth accounting approach to assess the impact of ICT in the United Kingdom. More specifically, in light of official data revealing a fall in UK labour productivity growth in the late 1990s and evidence that the late 1990s rise in US labour productivity growth was driven by growth in the stock of ICT capital, the paper raises the question of whether a comparable ICT investment boom occurred in the UK and if so, why it didn't lead to US style improvements in labour productivity.

The methodology and scope of the Oulton study follows the approach taken in other growth accounting studies, notably Jorgenson and Stiroh (2000) discussed above and Davies et al (2000), although there are considerable differences in estimates.

A standard growth accounting equation is derived and rearranged to obtain an equation that decomposes ALP growth into capital deepening – here defined as the capital share times the growth of capital per unit of labour - plus TFP growth. The first stage of the analysis is the calculation - using official data from the Office of National Statistics (ONS) – of baseline estimates of the growth of GDP and TFP. At this stage no adjustments are made to official measures of ICT products and, whilst ICT is included implicitly in both the output and input sides of the growth accounting equation, its effects are not explicitly noted. Baseline output growth in the period 1989-99 is estimated at 1.98% per annum and TFP growth at 1.16% in the same period, down from 1.79% for the period 1979-89.

Following the baseline estimates, the Oulton study makes two principal changes to the official statistics: firstly, US price indices are used to deflate ICT outputs and inputs in place of price indices used by the ONS. Oulton argues that these indices – showing greater price declines – are more in tune with reality than the official deflators. Secondly, the official estimate of the nominal level of software investment is tripled. Previous measurements are criticised for being far too conservative, misclassifying much investment as intermediate consumption and failing to take account of software investment undertaken by computer programmers working outside the computer services industry (in 1995 only 27% of software engineers and programmers worked within computer services.) It is argued that this oversight of large-scale investment in own account software – software produced in house by company programmers – has caused the wide discrepancies between software investment figures from the US (averaging 140% of computer investment in the 1990s) and the UK (averaging 39%).

GDP and TFP growth at the aggregate level are then recalculated incorporating the new estimates for software and using the US price indices as deflators. These adjustments yield the following results.

- UK GDP growth has been understated by as much 0.33 percentage point per-annum between 1994-98.

- The ICT share of GDP output has risen from 0.6% in 1979 to 3.1% in 1998. Furthermore, ICT accounted for 21% of GDP growth for the period 1989-99. From 1994 to 1998, ICT added, on average, 0.57 percentage point a year to GDP growth.

- ICT capital grew at 21.49% per annum for the period 1989-98. Consequently, aggregate capital services grew at a rate of 4.76% a year, substantially faster than the baseline estimate of 3.13%.

- Over the period 1994-98, ICT accounted for 90% of all capital deepening which in turn accounted for 46% of labour productivity growth. Within overall capital deepening, the part contributed by ICT to labour productivity growth has risen from 15% for 1979-89 to 25% in 1989-98. For the period 1994-98 this contribution rises to 48%.

- Despite the increased contribution of ICT capital deepening, there remains a slowdown in the UK labour productivity growth rate after 1994. The paper attributes this overall slowdown to two main factors: 1) a fall of 1.02 percentage points per year in the contribution to ALP growth of non-ICT capital and 2) a slowdown in TFP, the reasons for this are currently still unclear.

The significance of Oulton's assumption concerning the importance of software investment to the estimation of the contribution of ICT to UK output growth is highlighted clearly by comparing his results to those of Schreyer (2000) who ignores software altogether. Using a similar growth accounting methodology, Schreyer estimates that ICT added 0.31 percentage point to UK output growth for the period 1990-96 versus Oulton's figure of 0.57 percentage point for 1994-98. Whilst the different time frames used hinder direct comparability, the divergence between the two figures highlights the important role software investment has played in raising UK GDP growth.

Finally, Oulton suggests that the contribution of ICT to GDP growth in the UK will most likely continue to increase in light of the fact that the ICT share in GDP is still only two thirds of that in the US.

However, contrary to the position of Jorgenson and Stiroh (2000) and Oliner and Sichel (2000), the Oulton study argues that the future contribution of ICT will be determined as much by economic forces than by technical progress in the semiconductor sector. For example, on the output side, if prices in the sector fall faster than volumes rise (i.e. the price elasticity of demand for ICT products is inelastic) the contribution of ICT to GDP growth will steadily diminish. Similarly with regards to inputs, the contribution of ICT capital to aggregate input growth will diminish if the ICT share of profits is diminishing. Eventually there may come a time when ICT demand will become inelastic and continuing price falls will diminish the contribution of ICT to growth.

In response to the emerging consensus – rooted in the growth accounting studies of Jorgenson and Stiroh (2000), Oliner and Sichel (2000) and Oulton (2001) – that the production and use of information technology has played an important role in causing higher aggregate US GDP and productivity growth in the 1990s, Stiroh (2001) attempts to move the debate in two directions. Firstly, it is argued that an econometric approach to the issue – examining the statistical correlations between ICT-use and productivity growth – will provide a valuable alternative to the growth accounting framework. Whilst the contribution of growth accounting is acknowledged, several weaknesses are also highlighted, notably the assumptions of constant returns to scale and competitive markets when estimating factor shares and the use of these factor shares as a proxy for output elasticities. Secondly, it attempts to shift the analysis to the industry sector level, arguing that the impact of ICT may vary considerably between sectors, preventing aggregate studies from explaining the true link between productivity, ICT use and business practices.

Focusing on an examination of ALP growth (ALP data is more readily available and detailed at the disaggregated level), the Stiroh paper uses the familiar Cobb-Douglas output production function and the related expression for ALP with capital input explicitly decomposed into ICT-related and non-ICT related portions. This equation is estimated econometrically to quantify the impact of ICT input growth on ALP growth.

The links between the productivity revival and ICT are then examined using "difference-in-difference" style tests comparing the productivity acceleration in ICT intensive and non-ICT intensive sectors, and production functions are estimated using the generalized method of moments (GMM) methodology. The following key results are attained.

- Industries having made the largest ICT investments in the early 1990s show the largest productivity gains in the late 1990s.

- Production function estimates suggest that the output elasticity of ICT capital is large i.e. ICT capital accumulation is important for output and productivity growth.

- Industry decomposition (using industry gross output productivity rather than value-added) reveals large and important ICT-related differences between industries. ICT producers and users account for virtually all of the 1990s US productivity aggregate labour productivity revival. Of a 1.36 percentage points rise in aggregate productivity growth the contributions of ICT producers, ICT users and non-ICT using industries were 0.16, 0.66 and 0.08 percentage point respectively, with material and hours reallocations accounting for the remainder.

- These observed ICT related productivity gains are viewed as real rather than cyclical. If cyclical forces were at work they would most likely be present and equal across all industries and show no correlation with ICT-intensity.

Thus, as the other studies reviewed earlier in this section, Stiroh (2001) finds strong and robust correlations between ICT-intensity and productivity growth acceleration. While the large majority of US thus conclude that ICT has made a positive contribution to US, output and productivity growth, there exist still some doubters, notably Gordon (2000), who claims that the productivity revival in the US was largely cyclical[5].

[5] In an econometric analysis using quarterly data comparing the period 1995-99 to 1972-95, Gordon (2000) decomposes ALP growth into cyclical and trend components, and concludes that of a total increase in productivity growth of 1.35 percentage points, an unsustainable cyclical effect contributed 0.54 percentage point and real acceleration in trend productivity growth contributed 0.81 percentage point.

3 Methodology

In this section we present the methodological framework for estimating the contribution of ICT spending to output growth. These contributions are estimated using the method of growth accounting, which essentially divides output growth into a number of constituent parts. Generally, two sources of growth in output can be identified: growth in production inputs (broadly defined as capital and labour) and a residual term (the so-called TFP growth) due to some unmeasured technological progress. Growth accounting does not explain growth, in the usual sense of the word. It is merely descriptive. But, it allows to focus on the relative importance of the various factors determining growth. Readers not interested in the technical aspects of the methodology may wish to proceed directly to Section 4 of the report.

General framework

The starting point of the growth accounting calculations is a production function that summarises the technological relationship between output produced and inputs used in the production process. Denoting sectors by s=1,…,S and time by t=1,…,T, suppose the value-added production function can be written as

Equation 3.1: $Y_{st} = A_{st} f_s(L_{st}, K_{st})$

where Y_{st} is real output, A_{st} is the level of Total Factor Productivity (TFP), L_{st} is a vector of labour input and K_{st} is a vector of capital input. Under certain assumptions, omitting the sector subscript for questions of tractability, output growth in period t relative to period t-1 can be written using the Tornqvist discrete approximation of the Divisia index, given by[6]

Equation 3.2: $\Delta \ln Y_t = \bar{s}_{K,t} \Delta \ln K_t + (1 - \bar{s}_{K,t}) \Delta \ln L_t + \Delta \ln A_t$

where $\bar{s}_{K,t}$ is the share of capital in value added averaged over adjacent time periods:

$\bar{s}_{K,t} = (s_{K,t} + s_{K,t-1})/2$.

The assumptions underlying the result in Equation 3.2 include the critical one that all factors in the production process are paid their marginal products, the sums of which exhausts all returns from pursuing that activity[7]. In addition,

[6] The Tornqvist index is superlative one and is exact if the underlying production function is translog (see Diewert 1976).

[7] Technically speaking, we are making the economic assumptions of perfect competition and constant returns to scale. Under these assumptions the elasticity of each factor with respect to output is simply equal to its share in the value of output.

the use of value added to measure output involves the assumption that material input is separable from other inputs in the production function. This traditional growth accounting method, which has as its theoretical underpinning the neoclassical growth model, has been employed by many authors including Jorgenson et al. (1987), Oulton and O'Mahony (1994) and O'Mahony (1999). $\Delta \ln K_t$ and $\Delta \ln L_t$ are defined respectively as:

$$\Delta \ln K_t = \sum_k \overline{w}_{k,t} \Delta \ln K_{k,t}$$

$$\Delta \ln L_t = \sum_l \overline{v}_{l,t} \Delta \ln L_{l,t} .$$

Here $\overline{v}_{l,t}$ is the proportion of the sector wage bill accounted for the *l*th type of labour and $\overline{w}_{k,t}$ is the share of the sector profit attributable to the *k*th type of asset. These shares are averaged across adjacent periods and are defined analogously to $\overline{s}_{K,t}$. By definition, each of these sets of shares sums to unity:

$$\sum_{l=1}^{L} \overline{v}_{l,t} = \sum_{k=1}^{K} \overline{w}_{k,t} = 1.$$

Once we know all the elements of Equation 3.2, we are in a position to estimating the contribution of labour, capital and TFP to each sector's output growth. While $\Delta \ln Y_t$, $\Delta \ln L_t$ and $\overline{s}_{K,t}$ can be generally measured by using statistical information provided by the national statistics agencies, the growth of the capital input is usually estimated by using data on investment flows. $\Delta \ln A_t$ is unobservable and therefore is calculated as a residual term once all the other elements in the equation are known.

The most frequently used method to calculate the capital stock is the perpetual inventory method (PIM), according to which the capital stock, $S_{k,t}$, at time t is given by

Equation 3.3: $S_{k,t} = S_{k,t-1} + (1-\delta) I_{k,t} = \sum_{\tau=0}^{\infty} (1-\delta) I_{k,t-\tau}$

where I_t is real gross investment at time t and δ is the depreciation rate. Equation 3.3 has the familiar interpretation that the capital stock is the weighted sum of past investments, where the weights are derived from the relative efficiency profile of capital of different ages. Moreover, since $S_{k,t}$ is measured in base-year efficiency units, the appropriate price for valuing the capital stock is simply the investment price deflator.

$S_{k,t}$ represents the installed stock of capital, but the use of Equation 3.2 requires information on the flow of capital services from that stock over a given period. Following Oulton (2001), we assume that capital services of type *k* in period *t* are assumed to be proportional to the stock available at the beginning of the period:

Equation 3.4: $K_{k,t} = S_{k,t-1}$

where the constant of proportionality is normalised to unity. In order to construct the aggregate capital growth, as given by $\Delta \ln K_t$, we need also to derive the weights $w_{k,t}$ for each asset type. These weights simply represent the shares of each asset in total profits. In a competitive market, each asset would come with a rental price attached to it. The sum of all rentals would then equate aggregate nominal profits (Π) as follows:

Equation 3.5: $\Pi_{k,t} = \sum_k p_{k,t} K_{k,t}$

where $p_{k,t}$ is the rental price of asset *k*. The rationale for using rental prices, rather than asset prices, to aggregate different types of capital is marginal productivity. Under appropriate assumptions, the rental price measures the additional output resulting from an extra unit of capital. Rental prices are not normally observed, but they are related to asset prices that are observed. Indeed, asset prices must be known in order to calculate investment in constant prices.

Knowing the price of asset k, the corresponding rental price, $p_{k,t}$, can be estimated by using a rental price formula. In equilibrium, an investor is indifferent between two alternatives: earning a nominal rate of return, i_t, on a different investment or buying a unit of capital, collecting a rental fee, and then selling the depreciated asset in the next period. The equilibrium condition, therefore, is:

Equation 3.6: $(1 + i_t) a_{k,t-1} = p_{k,t} + (1 - \delta_k) a_{k,t}$

where $a_{k,t}$ is the asset price. This formulation of the rental price effectively includes asset-specific revaluation term. If an investor expects capital gains on his investment, he will be willing to accept a lower service price. Conversely, investors require high service rents for assets like computers with large capital losses. Adding an adjustment factor for corporate taxes and subsidies to investment to Equation 3.6 and rearranging we obtain

Equation 3.7: $p_{k,t} = T_{k,t} \left[i_t a_{k,t-1} + \delta_k a_{k,t} - (a_{k,t} - a_{k,t-1}) \right]$.

Here i_t is now the nominal after-tax rate of return, assumed to be equalised across all asset types, and $T_{k,t}$ is the adjustment factor for corporate taxes and subsidies to investment:

$$T_{k,t} = \frac{1 - u_t D_{k,t}}{1 - u_t}$$

where u_t is the corporate tax rate and $D_{k,t}$ is the present value of depreciation allowances per £ spent on asset k[8]. The weight to attach to each asset to construct the aggregate capital growth is therefore

$w_{k,t} = p_{k,t} K_{k,t} / \Pi_{k,t}$.

The assumption that the rate of return *i* is equalised across different types of assets is quite strong, especially in times of rapid change. If producers are over-optimistic about future profits from investment, then the realised rate of return will be less than the rate measured by the present method. On the other hand, for a period the realised rate of return might be higher for new types of assets, such as ICT assets, since insufficient time has elapsed for accumulation of such assets to drive the rate of return down to equality with rates obtainable on non-ICT assets. The first possibility means that TFP growth will be understated by the above method, the second that it will be overstated.

The measurement of capital services makes no explicit allowance for variations in capacity utilisation. Generally speaking, since TFP is calculated as a residual, measurement errors in any of the observable growth rates will affect the estimates of TFP. This gives a strong pro-cyclical pattern to TFP growth. In a recession firms can hoard some of the labour that possesses specific skills and capital may not be fully utilised. However, these factors are not completely ignored by our framework because the growth of capital services is weighted by the profit share which varies procyclically and the labour input is measured in hours, which also have a pro-cyclical behaviour.

Before concluding this section, it is useful to set out the relationship between labour productivity growth and TFP growth. This can be done by subtracting the growth of the labour input from both sides of Equation 3.2 to obtain:

Equation 3.8: $\Delta \ln(Y/L)_t = \bar{s}_{K,t} \Delta \ln(K/L)_t + \Delta \ln A_t$ **.**

This shows that the growth of labour productivity can be decomposed into 'capital deepening' first term of the right-hand side and TFP growth.

ICT contribution to output growth

It is important at this point to make explicit how we intend to use the described above general framework to estimate the contribution of ICT to output growth. The idea is to decompose the growth of capital services in Equation 3.2 into ICT and non-ICT capital and then apply the growth accounting method on a sectoral basis. This approach will allow us to:

- Estimate for each sector the contribution of ICT capital to output and labour productivity growth, say for example Manufacturing vs.

[8] This term is the present discounted value of after tax profits arising from the depreciation of the capital stock allowed by the tax regime.

Services;

- Assess to what extent productivity in the non-ICT producing sectors has benefited from ICT investment; and

- Examine the contribution of various sectors to the positive impact of ICT that, so far, has been detected for the whole UK economy.

The previous points can be answered by re-specifying Equation 3.2, which is defined for each sector, as follows:

Equation 3.9: $\Delta \ln Y_t = \bar{s}_{K,t}\left[\bar{\beta}_t \Delta \ln K_{k,t}^{ICT} + (1-\bar{\beta}_t)\Delta \ln K_{k,t}^{NICT}\right] + (1-\bar{s}_{K,t})\Delta \ln L_t + \Delta \ln A_t$

where $\Delta \ln K_{k,t}^{ICT}$ is an index of ICT capital growth, $\bar{\beta}_t$ is its corresponding share of total profits and $\Delta \ln K_{k,t}^{NICT}$ is an index of non-ICT capital growth. The contribution of ICT capital to output growth can be simply expressed as:

Equation 3.10: $\bar{s}_{K,t}\left[\bar{\beta}_t \Delta \ln K_{k,t}^{ICT}\right]$**.**

In the same way, the contribution of the ICT capital to labour productivity through capital deepening now becomes:

Equation 3.11: $\bar{s}_{K,t}\left[\bar{\beta}_t (\Delta \ln K_{k,t}^{ICT} - \Delta \ln L_t)\right]$

Finally, in order to aggregate the contributions of the sectors at the whole economy level we will use the following formula:

Equation 3.12: $\Delta \ln Y_t^{aggregate} = \sum_{s=1}^{S} \bar{\alpha}_{s,t} \Delta \ln Y_{s,t}$

where $\Delta \ln Y_{s,t}$ is the ICT contribution to output growth in each sector and $\bar{\alpha}_{s,t}$ is the sector's share in total value added, averaged over two adjacent periods.

4 Data Description

Data construction

We draw on data from different sources to construct the sector-level panel data required for our growth accounting exercise. The data on value added, gross operating surplus, labour compensation, ICT and non-ICT investment come from the Office of National Statistics (ONS) Detailed Supply and Use Tables, available on the ONS website for the period 1992-2000.

Following Oulton (2001), we focus on three types of ICT capital: computers, software and telecommunication equipment[9]. These industry data have been aggregated up to the two-digit level (11 level) except for Transport and Communication, where we have distinguished Transport from Post and Telecommunications.[10] Therefore, our analysis focuses on twelve sectors that together account for all the economic activity in the U.K.

The data on employment is obtained from several sources including the Annual Business Inquiry (ABI) for the period 1998-2000, the Annual Employment Survey (AES) for the period 1995-1998 and the Census of Employment for 1991 and 1993. These data are available from the ONS through the NOMIS website.

Data on average hours worked come from the Labour Force Survey, which is also available from the ONS on a quarterly basis over the period 1984-2002. We have taken average worked hours measured in the spring period (the only available data before 1998 on a sectoral basis) as a proxy for the yearly data.

To deflate nominal series we use a variety of price indices. We use an implicit value-added deflator produced by the ONS to deflate nominal value added. Since the ONS does not currently produce price indices for ICT goods adjusted for quality change, we have used the US Bureau of Economic Analysis's (BEA) price indices for computers, software[11] and telecommunications equipment, which use hedonic techniques to correct for

[9] Oulton (2001) reckons that, in the UK, the official series for software investment probably underestimate the true levels and therefore applies a multiplying factor of 3 to correct it. Given that this adjustment does not change the growth rate of software investment, it has no impact on our analysis of the contribution of ICT to growth in output and labour productivity.

[10] Wee have not aggregated these two sectors because of marked differences in the ICT investment patterns shown by these two sectors.

[11] Software investment has three components: pre-packaged software, e.g. an office suite sold separately from the computer on which it is to be run; custom software, usually written by a software company specifically for sale to another company; and own account software, written in-house for a company's own use. In the US, each of these three types of software has a different price index (see Parker and Grimm 2000). We then use two alternative price indices in our estimates: the official UP price index for software ('low software' case) and the US pre-packaged software price index ('high software' case).

quality change[12]. For our analysis, we have adjusted these price indices for movements in the dollar-pound exchange rate. These hedonic price indices are the ones employed in the US National Income and Product account (NIPA). Non-ICT investment in constant prices has been generated by using a UK Producer Price Index (PPI), available from the ONS, adjusted to exclude the ICT components.

We use depreciation rates taken from Fraumeni (1997) for the ICT capital. These were also used by Jorgenson and Stiroh (2000) and Oulton (2001). For the Non-ICT capital we have used depreciation rates used in OECD (1991), obtained as weighted averages of depreciation rates for plant and machinery and buildings. Information on corporate tax rates and depreciation allowances has been supplied by the Inland Revenue.

To summarise, our panel data consists of twelve sectors, representing the entire UK economy over the period 1992-2000.

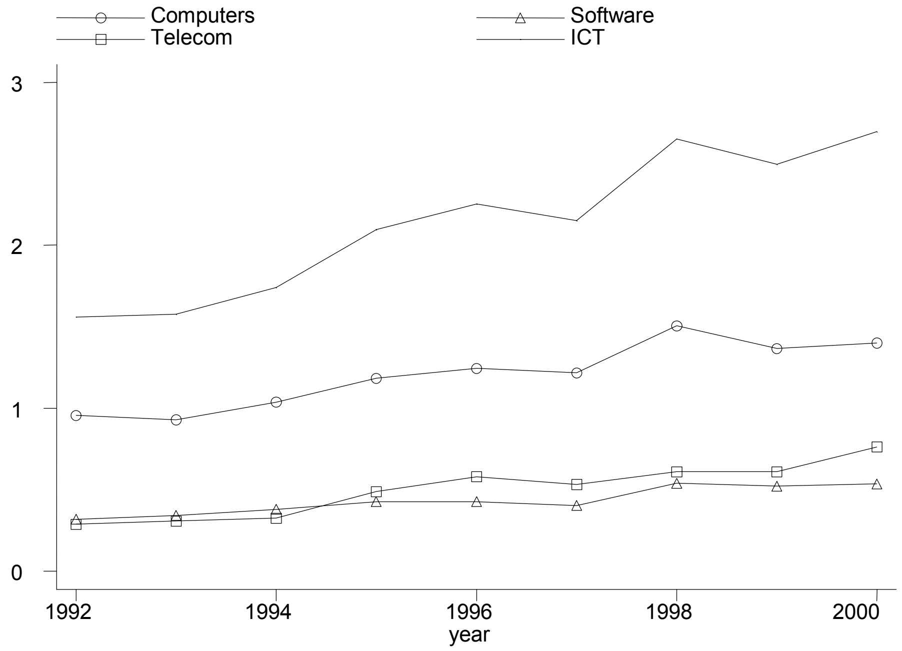
Descriptive statistics

Before moving to our growth accounting calculations, it is useful to examine some simple descriptive statistics on ICT investment in the UK. In Figure 4. we have plotted the aggregate investment in computers, software, telecommunication equipment and the sum of these three components (.i.e., total ICT investment) over the period 1992-2000. All the series are normalised on value added .

Total investment in ICT has steadily increased over time, from approximately 1.6% of total value added in 1992 to about 2.7% by the end of the period. Total investment in software has been substantially flat for the entire period, whilst there has been a moderate upward trend in investment in computers and telecom equipment.

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

Figure 4.1: Aggregate ICT investment as a per cent of value added, 1992-2000



NOTE: all series are in current prices.

We also provide a sectoral perspective on the above trends in aggregate ICT investment in Table 4.1. Post and Telecommunication is the sector that spent the highest fraction of valued added in ICT investment, approximately 19%, followed by Electricity, Gas and Water Supply (2.76%) and Financial Intermediation (2.75%).

Table 4.1: Average ICT and non-ICT investment as a per cent of value added by sector, 1992-2000

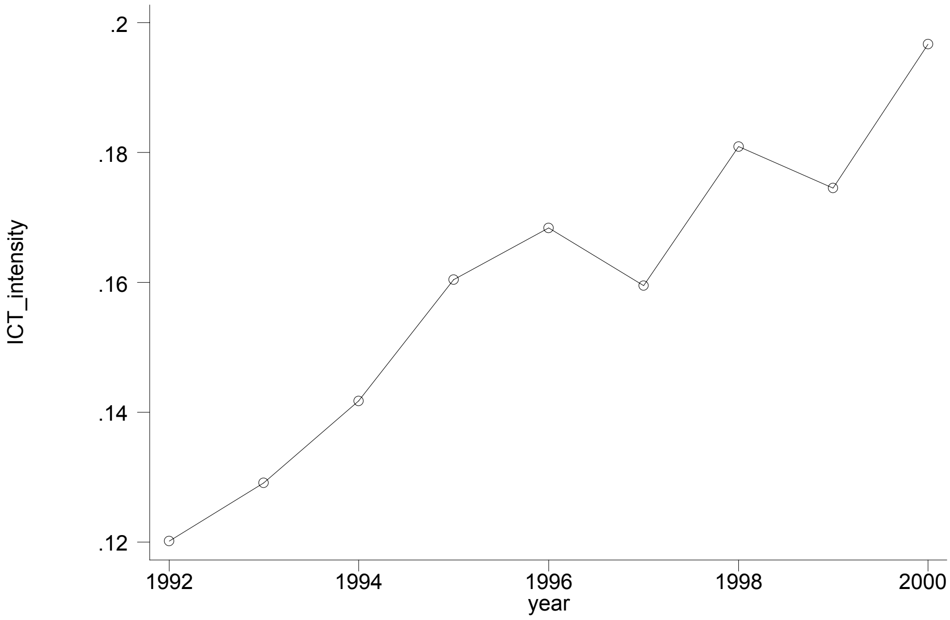
	Computers	Software	Telecom. Equip.	Total ICT	Non ICT
Agriculture, Forestry and Fishing	0.09	0.33	0.02	0.44	21.34
Construction	0.04	0.13	0.02	0.19	4.21
Education, Health and Social Work	0.32	0.37	0.04	0.73	6.56
Electricity, Gas and Water Supply	1.60	0.40	0.77	2.76	34.98
Financial Intermediation	1.91	0.69	0.15	2.75	9.28
Manufacturing	0.99	0.30	0.11	1.40	11.49
Mining and Quarrying	0.04	0.11	0.03	0.18	35.02
Other Services	0.91	0.47	0.55	1.94	27.56
Post and Telecommunication	5.40	0.77	12.63	18.81	43.33
Public Administration	1.36	0.38	0.17	1.91	11.83
Transport	0.91	0.40	0.02	1.32	21.89
Wholesale and Retail Trade	0.91	0.33	0.16	1.39	11.50

NOTE: all series are in current prices.

Looking at the trends in ICT investment in the various sectors, one notes that, as a percent of value added, the expenditure for ICT assets has been substantially constant over time for all sectors, except for Post and Telecommunications and Financial Intermediation. These sectoral trends for the above variables are plotted in Annex 2.

We have also assessed the trend in ICT investment relative to non-ICT investment for the whole economy in Figure 4.2 overleaf, where ICT intensity is defined as the ratio of ICT investment to non-ICT investment. Given that this ratio increases overtime, we can argue that ICT investment has grown faster than other more traditional types of investment.

Figure 4.2: Aggregate ICT investment intensity, 1992-2000

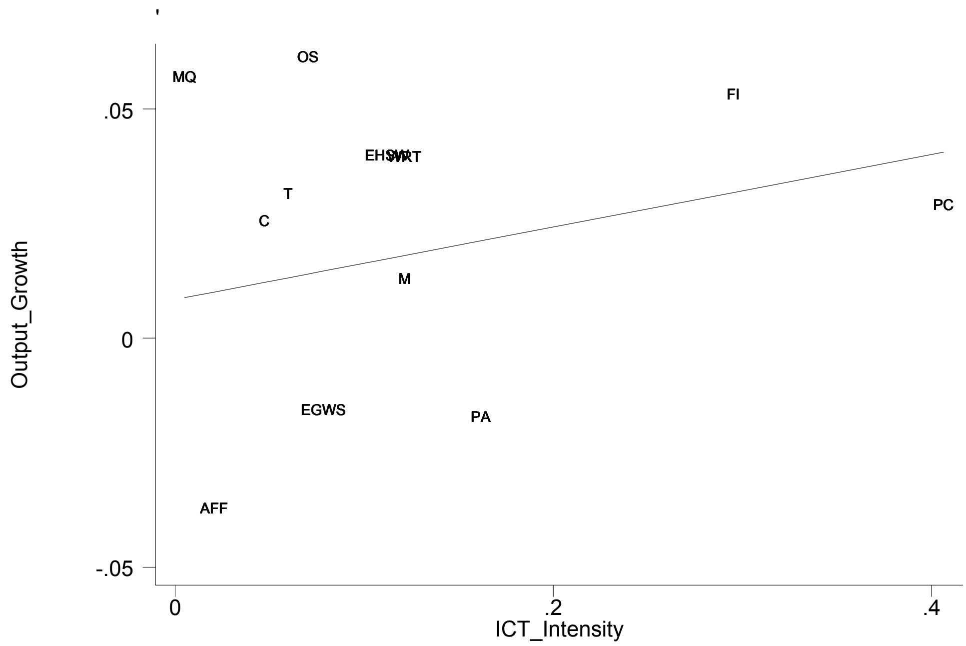


NOTE: all series are in current prices. ICT investment intensity = ratio of ICT investment to non-ICT investment.

Since our sectors are quite heterogeneous we also focus on the sectoral dynamics of ICT intensity. What we observe for the whole economy can either be a widespread phenomenon across all the sectors or, conversely, be only concentrated in a few sectors. Our findings suggest that ICT intensity has sharply increased for Post and Telecommunication, moderately for Financial Intermediation, Manufacturing and Other Services, and remained fairly stable for all the others. The detailed sectoral trends in ICT investment intensity are plotted in Annex 2.

Finally, we show the correlation between output growth and ICT investment intensity across sectors. This is illustrated in Figure 4.3, where we plot the relationship between (average) output growth and (average) ICT investment intensity. A quick look at the chart suggests that, in general, sectors with higher ICT investment intensity have experienced higher output growth.

Figure 4.3: Output growth and ICT investment intensity, 1992-2000



NOTE: AFF denotes Agriculture, Forestry and Fishing, C denotes Construction, EGWS denotes Electricity, Gas and Water Supply, EHSW denotes Education, Health and Social Work, FI denotes Financial Intermediation, M denotes Manufacturing, MQ denotes Mining and Quarrying, OS denotes Other Services, PA denotes Public Administration, PC denotes Post and Telecommunications, T denotes Transport, WRT denotes Wholesale and Retail Trade.

ICT investment intensity = ratio of ICT investment to non-ICT investment

In the next section, we will assess more precisely the contribution of ICT investment to output and labour productivity growth over the period 1992-2000.

5 Results

The results of our analysis are presented in tables 5.1-5.9 as follows: tables 5.1 to 5.3 display our baseline estimates of the growth-determining factors, tables 5.4 to 5.6 show the ICT contribution to output growth through capital, and tables 5.7 to 5.9 report our estimates of the contribution of ICT to labour productivity growth. We now discuss each set of results in turn.

5.1 Baseline estimates

Table 5.1 reports our estimates of the contribution of TFP growth, labour and capital to output growth in each sector for the whole sample period, 1992-2000, without adjusting for ICT (baseline estimates)[13].

This table aims to give a broad picture of the growth-driving factors in the twelve sectors of the UK economy. As one would expect, the contribution of the growth-driving factors varies markedly across sectors. Moreover, only a few sectors post strong TFP growth over the period 1992-2000 while some sectors actually exhibit negative TFP growth over the period.

We start our review with the largest sectors of the UK economy, namely Financial Intermediation, Manufacturing and Wholesale and Retail Trade which together account for almost 60% of the economy. Two key facts are worth noting:

- Labour and capital account for a very high proportion of output growth in services – approximately 70% for Financial Intermediation and 70% for Retail and Wholesale Trade;

- In contrast, TFP growth explains virtually all the modest output growth for Manufacturing.

The main observation for the remaining 9 sectors is that, over the period 1992-2000, TFP growth is negative in a number of them, notably Agriculture, Forestry and Fishing, Public Administration and Post and Telecommunications. The latter three sectors post substantial declines in TFP with TFP falling annually by between 2 and 3.8 per cent.

Negative TFP growth is not an unusual finding and can be due to several causes such as:

- Real economic factors such as certain forms of inflexibility (for example, labour market inflexibilities that prevent companies from adjusting quickly to their desired level of workforce) and an excessively rapid growth of the inputs which may temporarily reduce

[13] These calculations are performed by using Equation 3.2.

the general efficiency of the company; and

- Measurement errors on both the output and input sides (see, for example, the discussion in Harbinger 1998).

For example, the negative TFP growth shown by the Post and Telecommunication sector may be due to an excessive growth of the capital services, perhaps fuelled by high profit expectations during the New Economy era. On the other hand, the negative TFP growth in the Public Administration sector may mainly reflect output measurement errors, as this is a sector where output is notoriously difficult to measure properly.

The other sectors in this group show mixed results, which sometimes may depend on sector-specific characteristics. For example, a remarkably high TFP growth in Mining and Quarrying may simply reflect the characteristics of the extraction industry, such as its volatile output and a very capital-intensive production process.

We also present estimates of TFP growth and labour contribution (columns 5 and 6) where we correct the labour input by (average) worked hours, but this does not dramatically alter the results[14]. The only sizeable changes are a small increase of the labour contribution for Financial Intermediation, from –1.55% to 1.76%, and a reduction of the labour contribution for Wholesale and Retail Trade.

Finally, we present the results of our growth accounting for two sub-periods of our sample in Table 5.2 (1992-1996) and Table 5.3 (1997-2000). Overall, the results are broadly consistent and qualitatively similar to those for the entire period.

The main facts to note are that:

- Compared to 1992-1996 TFP growth accounts for a smaller proportion of output growth in 1997-2000 for Financial Intermediation and Wholesale and Retail Trade;

- Manufacturing shows a markedly different trend. While TFP grew robustly (3.7% annually) over 1992-1996 and made a substantial contribution to output growth, it stopped growing over the 1997-2000 period, while manufacturing output declined;

- Public administration and Post and Telecommunications still post negative TFP growth, but the rate of decline is about 50% smaller over the period 1997-2000 than over the period 1992-1996;

[14] The contribution of capital remains unchanged because it is not affected by the correction and can therefore be read in column 4.

- Agriculture, Forestry and Fishing posts a very large annual decrease in TFP (7.8%) over 1997-2002, reflecting the large drop in output over this period that is not matched by similar reductions in inputs.

Table 5.1: Contributions to output growth, 1992-2000

		Baseline estimates			Labour input corrected		
Sector	**Output growth (%)**	**TFP growth**	**Labour contrib. (heads)**	**Capital contrib.**	**TFP growth (adjusted)**	**Labour contrib. (hours)**	**Labour share**
Agriculture, Forestry and Fishing	-4.87	-3.83	-0.87	-0.16	-3.66	-1.04	30.56
Construction	3.60	-0.56	2.02	2.14	-0.76	2.22	48.07
Electricity, Gas and Water Supply	-2.77	1.42	-3.62	-0.57	1.57	-3.77	33.74
Education, Health and Social Work	3.90	1.69	1.83	0.37	1.65	1.88	83.93
Financial Intermediation	5.20	1.45	1.55	2.20	1.24	1.76	40.44
Manufacturing	1.13	1.82	-0.51	-0.18	1.81	-0.50	68.50
Mining and Quarrying	6.66	7.74	-0.41	-0.66	7.72	-0.39	18.49
Other Services	6.38	2.66	2.15	1.57	3.42	1.39	53.37
Public Administration	-1.98	-2.01	-0.21	0.24	-2.06	-0.16	84.66
Post and Telecommunications	3.26	-2.01	1.59	3.68	-1.90	1.48	59.64
Transport	3.40	0.65	1.84	0.91	0.79	1.70	68.53
Wholesale and Retail Trade	4.01	1.30	1.27	1.44	1.76	0.81	61.09

NOTE: Private Households with Employed Persons, Product 123 of Supply and Use Tables, is not included in Other Services; all numbers are percentages. The computations of the average contributions of labour and TFP are performed excluding 1995 due to breaks in employment data (see Annex 1for details).

Table 5.2: Contributions to output growth, 1992-1996							
		Baseline estimates			Labour input corrected		
Sector	**Output growth (%)**	**TFP growth**	**Labour contrib. (heads)**	**Capital contrib.**	**TFP growth (adjusted)**	**Labour contrib. (hours)**	**Labour share**
Agriculture, Forestry and Fishing	1.37	1.08	0.20	0.09	0.83	0.45	28.01
Construction	3.48	1.96	-0.26	1.78	1.37	0.33	45.68
Electricity, Gas and Water Supply	-2.18	2.69	-4.46	-0.41	3.07	-4.85	36.03
Education, Health and Social Work	3.42	1.82	1.25	0.34	1.12	1.95	83.16
Financial Intermediation	3.74	1.55	0.57	1.62	0.86	1.25	38.70
Manufacturing	4.08	3.72	0.84	-0.48	3.43	1.13	67.97
Mining and Quarrying	10.45	11.66	-0.61	-0.60	11.56	-0.50	21.39
Other Services	5.79	1.15	3.48	1.17	2.44	2.18	51.64
Public Administration	-2.43	-2.94	0.17	0.34	-3.68	0.91	86.22
Post and Telecommunications	-0.02	-2.80	0.88	1.90	-4.00	2.08	61.31
Transport	3.97	1.37	1.85	0.75	0.02	3.19	68.97
Wholesale and Retail Trade	3.52	1.36	1.12	1.05	2.14	0.33	61.94

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services. The computations of the average contributions of labour and TFP are performed excluding 1995 due to breaks in employment data (see Annex 1for details).

Table 5.3: Contributions to output growth, 1997-2000

		Baseline estimates			Labour input corrected		
Sector	**Output growth (%)**	**TFP growth**	**Labour contrib. (heads)**	**Capital contrib.**	**TFP growth (adjusted)**	**Labour contrib. (hours)**	**Labour share**
Agriculture, Forestry and Fishing	-9.54	-7.79	-1.41	-0.34	-7.41	-1.79	32.47
Construction	3.69	-1.89	3.16	2.42	-1.89	3.16	49.86
Electricity, Gas and Water Supply	-3.21	0.68	-3.19	-0.69	0.72	-3.23	32.02
Education, Health and Social Work	4.26	1.74	2.13	0.39	2.03	1.84	84.50
Financial Intermediation	6.29	1.61	2.04	2.64	1.64	2.01	41.75
Manufacturing	-1.09	0.06	-1.19	0.04	0.20	-1.32	68.89
Mining and Quarrying	3.82	4.84	-0.31	-0.71	4.87	-0.34	16.32
Other Services	6.82	3.46	1.48	1.88	3.95	0.99	54.67
Public Administration	-1.64	-1.41	-0.40	0.16	-1.12	-0.69	83.50
Post and Telecommunications	5.72	-1.24	1.95	5.01	-0.47	1.18	58.38
Transport	2.97	0.11	1.84	1.02	1.00	0.95	68.19
Wholesale and Retail Trade	4.38	1.30	1.34	1.74	1.59	1.05	60.45

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services.

5.2 ICT contribution to output growth through capital

We now proceed towards estimating the ICT contribution to output growth through capital, as explained by Equation 3.10. Specifically, in this part of the analysis we decompose the growth of capital services into growth of capital services from ICT and non-ICT capital and assessed the contribution to output growth of both of them.

As explained earlier, we deflate the investment in ICT by using the constant quality price deflators produced by the BEA in the US that are adjusted for the dollar-pound exchange rate. These deflators are constructed by using hedonic methods and have the characteristics of producing a faster rate of fall in the price indices for ICT products (and hence, a higher growth rate of real investment for a given level of investment in current prices) than standard price indices[15]. We have conducted this exercise by using two alternative deflators for software investment: a 'low' deflator and a 'high' deflator. The low variant is the official US price index for software (again adjusted for the dollar-pound exchange rate), while the high variant is the US pre-packaged software price index (see footnote 11 for more information on US software price deflators). That is, for the high variant we assume it is appropriate to deflate all of the software investment by the price index for only one component of software.

Table 5.4 displays our estimates of the contribution of ICT to output growth for the period 1992-2000. In the columns labelled "low software" and "high software", we report the two sets of results, obtained by using the two different deflators for software mentioned above. Overall, our estimates show ICT has positively contributed to output growth in eleven out of the twelve sectors of the UK economy.

Our analysis of the results starts with a review of the sectors that have benefited the *most* from ICT capital, i.e. the sectors showing the highest absolute contribution to growth from ICT. Next, we identify the sectors where ICT capital explains the highest proportion of output growth, i.e. where ICT made the largest relative contribution. We now proceed to a detailed review of the results, focusing on the results obtained with the low software deflator.

Absolute impact of ICT capital

The first fact to note is that, over the period 1992-2000, the absolute contribution of ICT capital to output growth varies significantly across

[15] For a detailed discussion of the various characteristics of alternative price indices, see Oulton (2001) pp. 21-25.

sectors. It ranges from practically zero in Mining and Quarrying to 6.3 percentage points annually in the Post and Telecommunications sector. The latter sector, however, stands out as a major exception. While the absolute contribution of ICT capital was also large (1.4 percentage points annually) in the Financial Intermediation sector, it ranges of 0.3 to 0.6 percentage point per year in the case of six sectors (Electricity, Gas and Water Supply, Manufacturing, Other services, Public Administration, Transport and Wholesale and Retail Trade). These figures suggest that without investment in ICT, output growth in these six sectors would have been lower by 0.3 to 0.6 percentage point per year over the period 1992-2000

Finally, when comparing the absolute contribution of ICT to output growth over the two sub-periods of 1992-1996 and 1997-2000, one observes that in the vast majority of cases, the absolute contribution increases significantly in the second sub-period. In six sectors (Agriculture, Forestry, and Fishing, Construction, Electricity Gas and Water Supply, Education, Health and Social Work, Financial Intermediation, Manufacturing, Post and Telecommunications and Wholesale and Retail trade) the absolute contribution of ICT to output growth is more than 50% higher in the second sub-period than in the first sub-period. Only three sectors (Education, Health and Social Work, Mining and Quarrying and Transport) post a smaller contribution from ICT to output growth over 1997-2000 than over 1992-1996.

As ICT made a positive contribution to output growth in four largest sectors of the UK economy (Financial Intermediation, Manufacturing, Wholesale and Retail trade, and Education, Health and Social Work) which together account for 60%of total U.K. valued added, it is clear that the impact of ICT capital is being felt not only at the sectoral level but as well at the macroeconomic level. This point is addressed in greater detail later in Section 5.4

Relative contribution of ICT capital

The results in Table 5.4 are also useful to identify the sectors that have benefited most from ICT investment, i.e. the sectors where ICT explains the highest proportion of output growth. ICT contribution is the highest in the Manufacturing sector (43%), followed by Financial Intermediation (27%), Transport (15%), Wholesale and Retail Trade (13%) and Other Services (9%)[17]. These estimates thus suggest that the sectors of the so-called "old economy"[18] have benefited from ICT more than the service sectors.

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[16] The very high contribution of capital to output growth for Post and Telecommunications should also be read in conjunction with the negative TFP growth rate for this sector.

[17] These percentages refer to the "low software" case. The results for the "high software" case are qualitatively similar.

[18] Obviously, the manufacturing sector includes also elements of the new economy, i.e. the sectors involved in ICT manufacturing.

Moreover, while the relative contribution of ICT to output growth increases only marginally from the period 1992-1996 to the period 1997-2000 in the case of Financial Intermediation (from 26.2% to 27.8%), Transport, Wholesale and Retail Trade and Other Services post somewhat larger gains.

More importantly, the contribution of ICT to manufacturing output growth has become very significant in the second half of the nineties. Over the period 1992-1996, the growth in ICT capital accounted for only 0.3 percentage point of the average annual growth of 4.1 recorded by the Manufacturing sector over the period. But, over the period 1997-2000, without growth in ICT capital Manufacturing output would have fallen by 1.7% annually instead of the observed annual decline of 1.1%

Table 5.4 also highlights the fact that deflating the ICT capital with constant quality deflators produces an upward estimate of the capital growth (and a downward revision of TFP growth). This is can be noticed by comparing the figures in the column labelled "Total capital contribution" with those in column "Capital contribution (no adjustment)", reported from Table 5.1 for reference purposes. The set of results termed "high software" show, as expected, slightly larger figures for the ICT contribution.

Overall conclusions

The two general conclusions emerge from the results presented in Tables 5.4 to 5.6 are that, with very few exceptions:

- ICT has made a positive contribution to sectoral output growth in the U.K. over the period 1992-2000; and,

- The contribution was more important over the period 1997-2000 than 1992-1996.

Table 5.4: ICT and non ICT contribution to output growth through capital, 1992-2000

		Low software			High software				
Sector	**Output growth (%)**	**ICT contrib.**	**Non ICT contrib.**	**Total capital contr.**	**ICT contrib.**	**Non ICT contrib.**	**Total capital contrib.**	**Capital contrib. (no adj)**	**Value added share**
Agriculture, Forestry and Fishing	-4.87	0.07	-0.17	-0.10	0.09	-0.17	-0.08	-0.16	1.42
Construction	3.60	0.05	2.19	2.24	0.08	2.19	2.27	2.14	4.99
Electricity, Gas and Water Supply	-2.77	0.29	-0.50	-0.22	0.32	-0.50	-0.19	-0.57	2.17
Education, Health and Social Work	3.90	0.10	0.36	0.46	0.14	0.36	0.49	0.37	11.69
Financial Intermediation	5.20	1.42	1.71	3.13	1.49	1.71	3.20	2.20	25.48
Manufacturing	1.13	0.49	-0.25	0.24	0.51	-0.25	0.26	-0.18	19.88
Mining and Quarrying	6.66	-0.02	-0.65	-0.67	-0.01	-0.65	-0.66	-0.66	2.44
Other Services	6.38	0.57	1.39	1.97	0.61	1.39	2.00	1.57	4.05
Public Administration	-1.98	0.39	0.18	0.57	0.42	0.18	0.60	0.24	5.42
Post and Telecommunications	3.26	6.33	0.65	6.99	6.38	0.65	7.03	3.68	2.83
Transport	3.40	0.50	0.75	1.25	0.53	0.75	1.28	0.91	5.01
Wholesale and Retail Trade	4.01	0.53	1.32	1.85	0.56	1.32	1.87	1.44	14.63

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services. Also, the "ICT contrib." and the "Non ICT contrib." do not sum to output growth because the labour contribution and TFP growth are not reported in the table. These contributions can be read in Tables 5.1 – 5.3.

Table 5.5: ICT and non ICT contribution to output growth through capital, 1992-1996

		Low software			High software				
Sector	**Output growth (%)**	**ICT contrib.**	**Non ICT contrib.**	**Total capital contr.**	**ICT contrib.**	**Non ICT contrib.**	**Total capital contrib.**	**Capital contrib. (no adj)**	**Value added share**
Agriculture, Forestry and Fishing	1.37	0.06	0.09	0.14	0.08	0.09	0.17	0.09	1.72
Construction	3.48	0.03	1.83	1.86	0.06	1.83	1.89	1.78	4.97
Electricity, Gas and Water Supply	-2.18	0.21	-0.33	-0.12	0.23	-0.33	-0.09	-0.41	2.42
Education, Health and Social Work	3.42	0.13	0.32	0.43	0.17	0.32	0.47	0.34	11.55
Financial Intermediation	3.74	0.98	1.49	2.47	1.05	1.49	2.54	1.62	24.23
Manufacturing	4.08	0.34	-0.45	-0.11	0.36	-0.45	-0.09	-0.48	20.95
Mining and Quarrying	10.45	-0.03	-0.59	-0.62	-0.02	-0.59	-0.61	-0.60	2.55
Other Services	5.79	0.45	1.06	1.51	0.49	1.06	1.55	1.17	3.72
Public Administration	-2.43	0.46	0.26	0.72	0.49	0.26	0.75	0.34	6.00
Post and Telecommunications	-0.02	4.32	0.35	4.67	4.35	0.35	4.70	1.90	2.77
Transport	3.97	0.52	0.64	1.16	0.55	0.64	1.19	0.75	4.99
Wholesale and Retail Trade	3.52	0.38	1.00	1.39	0.41	1.00	1.41	1.05	14.13

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services. Also, the "ICT contrib." and the "Non ICT contrib." do not sum to output growth because the labour contribution and TFP growth are not reported in the table. These contributions can be read in Tables 5.1 – 5.3.

Table 5.6: ICT and non ICT contribution to output growth through capital, 1997-2000

		Low software			High software				
Sector	**Output growth (%)**	**ICT contrib.**	**Non ICT contrib.**	**Total capital contr.**	**ICT contrib.**	**Non ICT contrib.**	**Total capital contrib.**	**Capital contrib. (no adj)**	**Value added share**
Agriculture, Forestry and Fishing	-9.54	0.08	-0.36	-0.29	0.11	-0.36	-0.26	-0.34	1.19
Construction	3.69	0.07	2.45	2.53	0.10	2.45	2.55	2.42	5.00
Electricity, Gas and Water Supply	-3.21	0.35	-0.63	-0.29	0.38	-0.63	-0.25	-0.69	1.99
Education, Health and Social Work	4.26	0.09	0.38	0.48	0.12	0.38	0.51	0.39	11.79
Financial Intermediation	6.29	1.75	1.88	3.63	1.83	1.88	3.70	2.64	26.42
Manufacturing	-1.09	0.60	-0.10	0.50	0.63	-0.10	0.53	0.04	19.07
Mining and Quarrying	3.82	0.00	-0.70	-0.71	0.00	-0.70	-0.70	-0.71	2.36
Other Services	6.82	0.66	1.65	2.31	0.70	1.65	2.34	1.88	4.30
Public Administration	-1.64	0.33	0.12	0.45	0.36	0.12	0.48	0.16	4.99
Post and Telecommunications	5.72	7.84	0.88	8.72	7.90	0.88	8.78	5.01	2.88
Transport	2.97	0.49	0.83	1.32	0.52	0.83	1.35	1.02	5.02
Wholesale and Retail Trade	4.38	0.64	1.55	2.19	0.67	1.55	2.22	1.74	15.00

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services. Also, the "ICT contrib." and the "Non ICT contrib." do not sum to output growth because the labour contribution and TFP growth are not reported in the table. These contributions can be read in Tables 5.1 – 5.3.

5.3 ICT contribution to labour productivity growth through capital deepening

In the final set of result, we show the contribution of ICT to labour productivity growth through capital deepening. Recall that labour productivity growth is given by the sum of TFP growth and the growth in the capital-labour ratio times the capital share, as shown in Equation 3.11. In this section we simply decompose the growth of the capital-labour ratio in ICT and non-ICT capital and estimate the contribution of both.

Table 5.7 reports these estimates for the period 1992-2000. Overall, our results show that ICT capital boosted labour productivity growth in the largest sectors of the economy. Beginning with Financial Intermediation, the ICT contribution was 1.2 percentage points annually, accounting for more than 80% of labour productivity growth of the sector. The remaining 20% is explained by a positive contribution of TFP growth and a negative contribution of non-ICT capital. The ICT contribution was more than half a percentage point for Manufacturing (42% of total) and Wholesale and Retail Trade (18% of total). The contributions in the above three sectors are very important for the economy-wide labour productivity growth, because these sectors represent collectively 60% of the UK economy.

ICT made sizeable contributions to productivity growth in other sectors as well. In fact, ICT contributed to roughly half of a percentage point to labour productivity growth in Transport (43% of total) and Other Services (13% of total) and almost to one percentage point for Electricity, Gas and Water Supply (10% of total). Post and Telecommunications shows the highest (absolute) contribution of ICT, but most of it is wiped out by a negative TFP growth. Again, in order to draw any conclusion with regards to the aggregate economy-wide labour productivity growth, the relative size of the sector should also be taken into account.

Table 5.7 reveals also that ICT investment has made a positive contribution to labour productivity growth in non-ICT producing sectors, such as, Financial Intermediation, Wholesale and Retail Trade, Transport, Other Services and Electricity, Gas and Water Supply. These results are overall consistent with those reported by Stiroh (2001).

We also estimate the contribution of ICT and non-ICT capital deepening for the periods 1992-1996 and 1997-2000. The results are reported in Table 5.8 and Table 5.9 respectively. Comparing the early years of the 1990s with the later years of the period, the contribution of ICT to labour productivity growth increases over time for the majority of the sectors. The (absolute) contribution of ICT is higher in the second sup-period than in the first for seven sectors (Financial Intermediation, Manufacturing, Wholesale and Retail Trade, Other Services, Post and Telecommunications, Agriculture and Transport). The ICT contribution is stationary for Construction, while the ICT contribution is decreasing over time for Electricity, Gas and Water

Supply and the public sectors, namely Education, Health and Social Work and Public Administration.

Comparing Table 5.8 with Table 5.9, one notes that the share of labour productivity growth explained by ICT increases over time in Financial Intermediation (from 48% to 99%), Manufacturing (from 15% to 81%), Wholesale and Retail Trade (from 12% to 22%) and Electricity, Gas and Water Supply (from 8% to 12%). For Agriculture, Forestry and Fishing and Public Administration, without the contribution of ICT, productivity growth would have fallen more than observed in both the sub-periods. For Post and Telecommunications and Transport, without the contribution of ICT, productivity growth would have fallen more than observed in the first period. The remaining sectors show mixed results.

The main general conclusions that emerge from tables 5.7 – 5.9 can therefore be summarised as follows:

- The increase in ICT capital has made a very important contribution to labour productivity growth of the UK economy over 1992-2000;

- The benefits of ICT investment on labour productivity growth are not confined to ICT-*producing* sectors, but extend also to ICT *using* sectors. These results show that an economy that invests more in ICT can grows faster, independently of the production of ICT; and

- The positive effects of ICT on labour productivity increase over time, in parallel with ICT intensity.

Table 5.7: Contributions of capital deepening and TFP to labour productivity growth. 1992-2000

		Low software			High software		
Sector	**Labour productivity growth (hours) (%)**	**ICT**	**Non ICT**	**TFP growth**	**ICT**	**Non ICT**	**TFP growth**
Agriculture, Forestry and Fishing	-4.01	0.09	1.71	-5.82	0.12	1.71	-5.84
Construction	-0.87	0.02	-0.04	-0.85	0.05	-0.04	-0.88
Electricity, Gas and Water Supply	8.99	0.90	6.36	1.73	0.93	6.36	1.70
Education, Health and Social Work	1.79	0.08	0.04	1.66	0.11	0.04	1.63
Financial Intermediation	1.48	1.20	-0.55	0.83	1.28	-0.55	0.75
Manufacturing	1.28	0.54	-0.02	0.76	0.57	-0.02	0.73
Mining and Quarrying	7.58	-0.01	0.11	7.48	0.00	0.10	7.47
Other Services	4.24	0.53	0.33	3.38	0.56	0.33	3.35
Public Administration	-1.83	0.39	0.19	-2.40	0.41	0.19	-2.43
Post and Telecommunications	1.56	6.25	0.18	-4.87	6.30	0.18	-4.92
Transport	1.02	0.44	-0.03	0.61	0.47	-0.03	0.59
Wholesale and Retail Trade	2.89	0.52	0.90	1.46	0.55	0.90	1.43

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services. These computations are performed excluding 1995 due to breaks in employment data (see Annex 1for details).

Table 5.8: Contributions of capital deepening and TFP to labour productivity growth. 1992-1996

		Low software			High software		
Sector	**Labour productivity growth (hours) (%)**	**ICT**	**Non ICT**	**TFP growth**	**ICT**	**Non ICT**	**TFP growth**
Agriculture, Forestry and Fishing	-3.55	0.05	-1.08	-2.52	0.07	-1.08	-2.54
Construction	2.74	0.02	1.27	1.45	0.05	1.27	1.42
Electricity, Gas and Water Supply	13.08	1.07	7.44	4.57	1.10	7.44	4.55
Education, Health and Social Work	1.20	0.12	-0.03	0.54	0.15	-0.03	0.50
Financial Intermediation	1.48	0.71	-0.40	1.17	0.77	-0.40	1.11
Manufacturing	2.24	0.33	-0.90	2.82	0.35	-0.90	2.79
Mining and Quarrying	11.36	-0.03	-1.31	12.70	-0.01	-1.31	12.69
Other Services	2.61	0.35	-0.86	3.11	0.39	-0.86	3.07
Public Administration	-3.80	0.42	0.14	-4.37	0.45	0.14	-4.39
Post and Telecommunications	-2.64	4.12	-0.52	-6.24	4.14	-0.52	-6.27
Transport	-0.08	0.40	-0.92	0.44	0.42	-0.92	0.41
Wholesale and Retail Trade	3.39	0.40	0.90	2.09	0.42	0.90	2.07

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services. These computations are performed excluding 1995 due to breaks in employment data (see Annex 1for details).

Table 5.9: Contributions of capital deepening and TFP to labour productivity growth. 1997-2000

		Low software			High software		
Sector	**Labour productivity growth (hours) (%)**	**ICT**	**Non ICT**	**TFP growth**	**ICT**	**Non ICT**	**TFP growth**
Agriculture, Forestry and Fishing	-4.24	0.12	3.11	-7.47	0.14	3.11	-7.50
Construction	-2.68	0.02	-0.70	-2.00	0.04	-0.70	-2.02
Electricity, Gas and Water Supply	6.95	0.82	5.82	0.31	0.85	5.82	0.28
Education, Health and Social Work	2.09	0.07	0.07	1.94	0.10	0.07	1.91
Financial Intermediation	1.47	1.45	-0.63	0.65	1.53	-0.63	0.58
Manufacturing	0.80	0.65	0.42	-0.27	0.67	0.42	-0.29
Mining and Quarrying	5.68	0.00	0.81	4.87	0.01	0.81	4.86
Other Services	5.06	0.62	0.92	3.52	0.65	0.92	3.49
Public Administration	-0.84	0.37	0.21	-1.41	0.40	0.21	-1.44
Post and Telecommunications	3.66	7.32	0.53	-4.18	7.37	0.53	-4.24
Transport	1.57	0.46	0.41	0.70	0.49	0.41	0.67
Wholesale and Retail Trade	2.63	0.59	0.91	1.14	0.62	0.91	1.11

NOTE: Private Households with Employed Persons, Product 123,is not included in Other Services.

5.4 Macroeconomic Impact of ICT investment

Finally, in order to assess the economy-wide impact of ICT investment on output growth and labour productivity, we have aggregated to the national economy level the contributions of ICT to output growth and labour productivity presented in previous tables. The results are displayed in Table 5.10 and Table 5.11 respectively.

The first fact to note is that that a substantial portion of output growth can be attributed to ICT capital. (Table 5.10) and the contribution of ICT has grown in the late nineties:

- Over the period 1992-2000, ICT accounted, on average, for more than 25% of output growth.

- Moreover, the contribution of ICT to output growth increased sharply between 1992-1996 and 1997-2000. Over the latter period ICT capital accounts for almost 31% of output growth, while over the earlier period ICT capital contributes only 17.2% of total output growth.

As we have already observed in the previous tables, the estimates of the contribution of ICT are marginally higher in the "high software" scenario.

Table 5.10: Aggregate contribution of ICT to output growth through capital

	Output growth	Low software	High software
1992-2000	3.23	0.81 *25.1%*	0.84 *26.1%*
1992-1996	3.31	0.57 17.2%	0.60 18.1%
1997-2000	3.17	0.98 *30.9%*	1.02 *32.2%*

For these calculations we have used Equation 3.12; all figures are percentages

The second key fact to note is that a very sizeable portion of observed labour productivity growth is due to ICT capital deepening (Table 5.11).

Over the period 1992-2000, the ICT capital contributed to approximately 47% of labour productivity growth in "low software" case and 50% in the "high software" case.

Again, the absolute impact of ICT on labour productivity is much higher in the late nineties than in the earlier years although the relative impact is smaller as labour productivity growth shows a marked acceleration in the late nineties.

Table 5.11: Aggregate contribution of ICT to labour productivity growth through capital deepening

	Labour productivity growth	Low software	High software
1992-2000	1.61	0.76 *47.2*	0.80 *49.7*
1992-1996	1.77	0.50 *28.2%*	0.54 *30.5%*
1997-2000	1.53	0.90 *58.8%*	0.94 *61.4%*

For these calculations we have used Equation 3.12; all numbers are percentages. These computations are performed excluding 1995 due to breaks in employment data (see Annex 1for details).

Finally we would like to stress that, while being built up from the detailed sectoral results presented earlier, our economy-wide estimates of the contribution of ICT to output and labour productivity growth in the UK are quantitatively consistent with those reported by Oulton (2001) for the UK and Jorgenson and Stiroh (2000) for the US even if the latter results are obtained directly from macroeconomic data[19].

[19] For example, the estimates reported by Oulton (2001) suggest that, in the low software case, the average (absolute) contribution of ICT to aggregate output growth over the period 1994-98 is about 0.6 percentage point; our results suggest an aggregate contribution of about 0.7 percentage point for the same period.

6 Conclusions and recommendations

In this report we have used growth accounting techniques to estimate the contribution of ICT to output growth and labour productivity growth for twelve sectors representing the entire UK economy. The period covered is 1992-2000.

Our study builds on recent work by Oulton (2001) for the UK that uses only macroeconomic data and extends it in several important directions.

- First, by taking a sectoral approach we are able to provide a sectoral perspective in the relationship between ICT and output and productivity growth.
- Second, as a result of focus on sectors of the economy, our study provides information on which sectors have gained the most from ICT investment, say, for example, Manufacturing vs. Services.
- Thirdly, our results shed some light on to the extent to which productivity of non-ICT producing sector has benefited from investments in ICT capital.
- Finally, by using the most recent data, our study is able to examine the impact of the ICT investment wave of the late nineties.

The key findings of our study can be summarised as follows:

- ICT investment has made an important contribution to output growth in the largest sectors of the economy, namely Financial Intermediation, Whole and Retail Trade as well as the Manufacturing sector. These sectoral contributions explain most the ICT contribution to output growth that has been observed at the aggregate economy level, due to the relative size of these sectors.

- Manufacturing is the sector that has gained the most in terms of output growth from ICT, followed by the large service sectors, such as Financial Intermediation, Transport, Wholesale and Retail Trade and Other Services. This suggests that the sectors of the "old economy" have received a greater benefit than the some of the more ICT-intensive service sectors.

- ICT has made a substantial positive contribution to labour productivity growth in the non-ICT producing sectors, such as the largest service sectors, as well as Manufacturing. At the economy-wide level, ICT capital deepening explains almost 50% of the annual average labour productivity growth of 1.6% from 1992 to 2000

- Comparing the early years of the 1990s with the later years of the sample, one observes that the contribution of ICT capital to both output and labour productivity growth increases over time in most of the sectors.

Looking ahead, we would recommend that, as additional data become available, the effects of ICT investment on productivity be further examined at both the macroeconomic level and the sectoral levels as some of the positive impact of ICT investment on labour productivity may materialise only with a certain lag, especially if complementary organisational changes are required at the plant/firm level before the benefits of ICT investment can be fully reaped. It is possible that, therefore, the estimates reported in the present study underestimate the true long-run impact of the recent ICT investment wave on productivity growth

As is well-known, the quality of the data necessary for such assessments is still in some cases far from perfect. Any additional research on the topic of the effects of ICT investment would clearly benefit from further data quality improvements along the lines of the work already underway at ONS.

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Annex 1 Measurement issues

In this Annex we explain in further detail the construction and the assumptions underpinning some of the key variables used in the growth accounting.

Baseline estimates

Real value added. Real value added is obtained by deflating nominal value added - available from the Supply and Use Tables - with an implicit value added deflator produced by the ONS and available from the ONS website.

Employment. Sectoral employment data are consistently available from 1998 onwards from the ABI. Between 1995 and 1998 sectoral employment data were collected by the AES. There is a known difference in level between the AES and the ABI data in 1998 that has been dealt with by scaling the AES data over 1995-1997 using factors derived from the overlapping 1998 data sets. The AES is a relatively small survey covering approximately 130,000 businesses and is conducted on a yearly basis. Before 1995, employment data were collected for 1991 and 1993 through the Census of Employment. Due to these methodological differences and the absence of overlapping 1995 data we do not calculate the growth rate of employment for 1995. Employment for 1992 has been generated as a linear interpolation of 1991 and 1993, while employment for 1994 has been derived by using the forecasted labour productivity level for the year. This forecast is obtained by extrapolating forward the data for 1993 on the basis of the 1991-1993 average labour productivity growth rate.

Real capital stock. We construct the capital stock for the baseline estimates (where no distinction is made between ICT and non-ICT capital) by using data on total real investment by sector from the Detailed Supply and Use Table, Table 6. We first deflate nominal (total) investment by using a generic UK Producer Price Index (PPI) and then apply the perpetual inventory method (PIM) using a depreciation rate of 8.4% for Manufacturing, Transport and Post and Telecommunications (a weighted average of the depreciation rates for plant and machinery and buildings used in Machin and Van Reenen 1998 and OECD 1991) and 4% for the other sectors. For initial year stocks we used a real investment growth rate of 2.6% for the sectors with positive (average) investment growth and zero for the sectors with negative investment growth. For Manufacturing, we construct the initial stock by using an average net rate of return of 6.2%, available from *Profitability of UK companies 1st quarter 2002*, ONS. Inventories and land are excluded from the capital stock for all sectors.

ICT contribution

Real capital stocks. In our estimates of the ICT contribution we decompose the aggregate capital stock into two types of capital: ICT and non-ICT. The ICT capital is an index of computers, software and telecommunications equipment. We now describe how we construct each of these capital stocks in turn.

Computers. Nominal investment in computers, as measured by investment in "Office machinery and Computers" (IO group 69, SIC92 sub-class 30), is from Detailed Supply and Use Tables 1992-2000, Table 6. Although this class is not limited to computers, the non-computer component is minimal and decreasing over time. For example, data from *Product Sales and Trade* show that the computers share increased from 82% in 1993 to 95% in 2000.

Constant price series in computers were obtained using the US quality-adjusted price index, available from the BEA website. Capital stock measures where constructed using the PIM method and a depreciation rate of 30%, obtained as a weighted average of the depreciation rate for computers (31.5%) and office machinery (18%) available from Fraumeni (1997). Initial year stocks use an average presample growth rate of 36%, calculated on data reported by Oulton (2001), and spread across sectors using investment shares in 1992.

Software. Investment in 'Computer and related activity' (IO group 107, SIC92 sub-class 72) is from Detailed Supply and Use Tables 1992-2000, Table 6.

The construction of the software capital stock follows the methodology described above with a depreciation rate of 31.5% and an average presample growth rate of 23% in the 'low software case' and 38% in the 'high software case'.

Telecommunications Equipment. Investment in 'Television and radio transmitters and line for telephony and line telegraphs' (IO group 74, SIC92 sub-class 32.2) is from Detailed Supply and Use Tables 1992-2000, Table 6.

The construction of the Telecommunications Equipment capital stock again follows the methodology described above for computers and software with a depreciation rate of 11% and an average presample growth rate of 14%.

Non-ICT capital. Non-ICT capital was constructed along the lines of the total capital stock in the baseline estimates.

Rental prices. Rental prices for the different types of capital are calculated using the formulae in the text and information on asset prices, profits and tax/subsidy factors as follows.

The asset price of each asset type is entered as a price deflator. For the ICT assets, these indices are available from BEA. For the non-ICT capital, we adjusted the general UK PPI to exclude the ICT components.

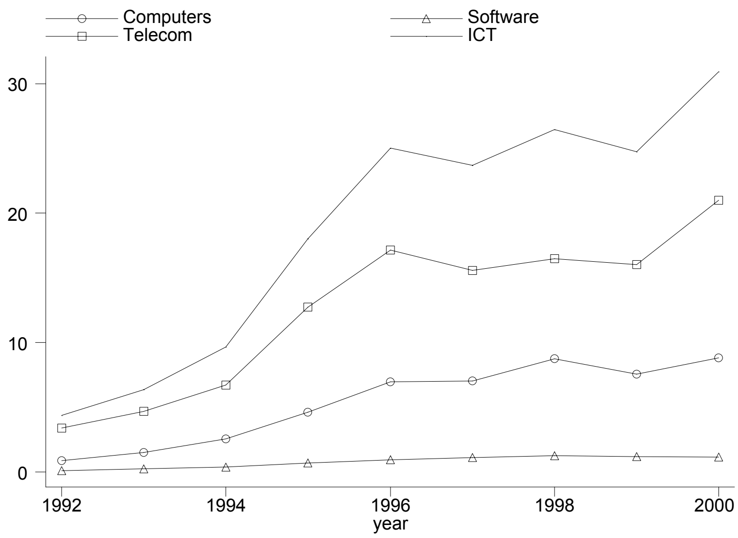
Nominal profits are simply measured as Gross Operating Surplus, available from the Supply and Use Tables.

The present value of depreciation allowances is constructed by using the methodology described in OECD 1991, pp. 234-235. Here we use a weighted average of depreciation allowances for machinery and building, financed through a combination of retained earnings, new equity and debt and ignoring personal tax rates.

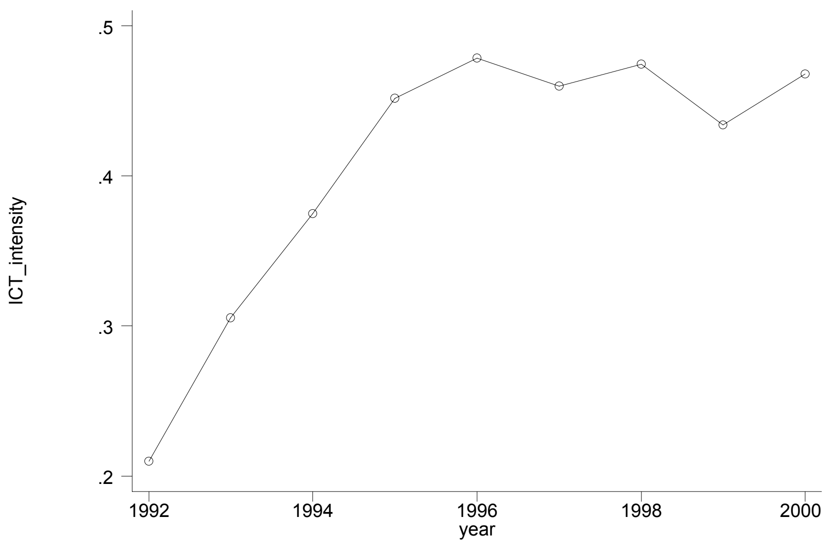
Annex 2 ICT investment and ICT intensity by sector

In this annex we plot the series of ICT investment and ICT intensity for each sector, as referred to in the main text.

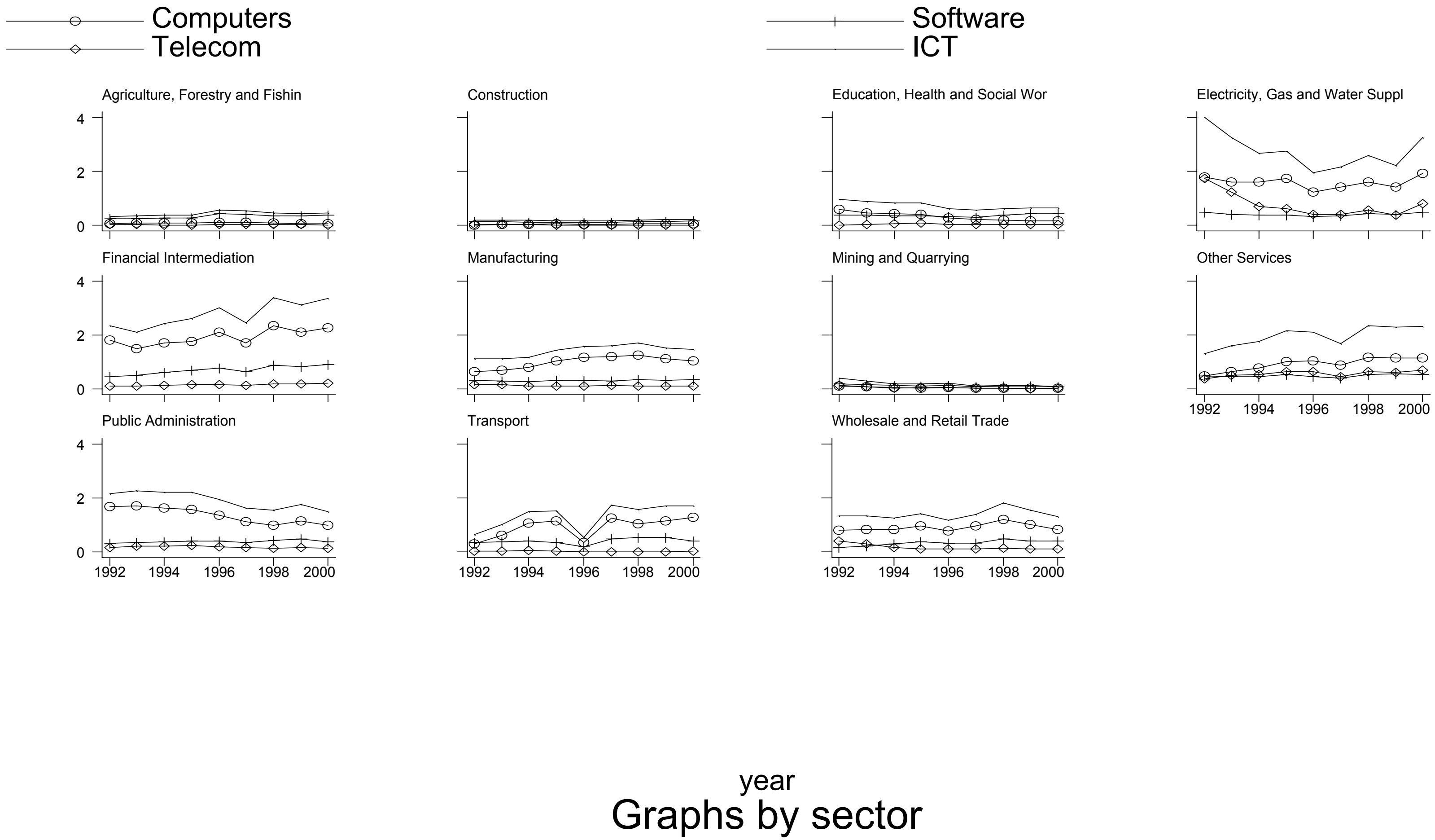
ICT investment in Post and Telecommunications, 1992-2000



ICT intensity in Post and Telecommunications, 1992-2000



ICT investment by sector, 1992-2000



ICT Investment Intensity by sector, 1992-2000