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

Data appendix (Annex A) and Annexes B-D

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Annex A The Bank of England industry dataset

A.1. Introduction

This annex describes the sources and methods used to construct the Bank of England industry dataset (BEID). In its current form, the dataset comprises annual data on 34 industries covering the whole economy over the period 1970-2000.

The starting point was a dataset on nominal gross output, value added, and domestic and imported intermediate input, and associated price indices, for 49 industries. This was prepared for us to our specification by a private sector economic consultancy, Cambridge Econometrics (CE). To this we added our own estimates of labour and capital input, finishing up with a KLEM-type dataset for 34 industries. The reduction from 49 to 34 industries was mainly necessitated by our desire to measure ICT capital services separately. The original 49 industries (which we refer to as CE 1-CE 49) and the final 34 industries, together with their definitions in terms of the United Kingdom's 1992 Standard Industrial Classification (SIC), are in Tables A.1 and A.2. Table A.3 gives the mapping between the 34 industries and the sectors they were aggregated to in Basu *et al* (2004).

As explained in the text, 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. In our case this means consistent with the 2002 *Blue Book* (Office for National Statistics (2002a)) and with the Input-Output Supply and Use Tables (I-O SUTs) for 1992-2000 (ONS (2002b)). The Supply and Use Tables give gross output, value added, profits, the wage bill and intermediate purchases (domestic plus imports), all in nominal terms, for 123 industries and products. So we can ensure that, for our 34 industries, these series match those of the I-O SUTs. Prior to 1992, detailed nominal consistency is harder to achieve, though we can ensure that it holds for broad sectors. For 1989-91 we used the I-O SUTs for those years, which are not fully consistent with the 2002 *Blue Book*, and various input output tables for earlier years, which are even less consistent. These earlier input-output tables were converted to a common SIC and price concept. This was possible since they all break down the economy into considerably more than 49 industries. They were also made consistent with the 2002 national accounts. Intervening years were then interpolated using national accounts totals as controls.(1)

In what follows, we first discuss our approach to measuring investment in ICT and then describe the measurement of output and of the inputs (labour, capital, and intermediate) in more detail.

A.2. The treatment of ICT

We employ US, not UK price indices for deflating investment in computers and software. We also apply a large adjustment to the official estimate of nominal software investment: we multiply it by three. Our reasons for these decisions are set out below: for more detail, see Oulton (2001) and (2002). Broadly, we argue that this gives a more realistic picture. In addition, it facilitates comparison with the United States, since it means that a very similar methodology is being employed for both countries.

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

The US computer price index

There is an official Producer Price Index (PPI) for computers in the United Kingdom (ONS code: PQEK), but in the past it fell much less rapidly than its US counterpart. It is common to describe the US index as hedonic, while the UK PPI was not hedonic until a methodological revision in 2003 which however only affected data for recent years. The suggestion is then that any substantial difference between the United States and other countries' indices arises from the use of hedonic methods.

A number of points can be made here. First, the hedonic technique has a firm basis in economic theory and has been employed in practice in United States official statistics for many years (see Triplett (1987) and (1990) and Moulton (2001)). Its application to US computer prices goes back to Chow (1967) and Cole *et al* (1986); the latter's work was extended by Oliner (1993) and by Berndt and Griliches (1993).[2]

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

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

Fourth, the UK *retail* price index for computers (which is published as part of the Harmonised Index of Consumer Prices) is also not hedonic, but has been falling at about the same rate as its US counterpart and much more rapidly than the corresponding UK PPI.

Fifth, in work commissioned by the ONS, Stoneman, Bosworth, Leech and McAusland constructed a hedonic index for UK computer prices for the years 1987 to 1992; their results are reported in

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(2) Nor are such studies confined to the United States. In a pioneering study of UK computer prices using hedonic methods, Stoneman found that over the period 1955-70, with quality held constant, his preferred price index fell at about 10% a year (see Stoneman, (1976), Chapter 3, Table 3.2, series (e)).

Stoneman and Toivanen (1997, Table A3). They found that their index fell by 19.1% a year over this period; by contrast the official PPI for computers (ONS code PQEK) fell by only 7.2% a year.

Three criticisms are often made of the application of US indices to the United Kingdom or other foreign countries:

- US producers possess monopoly power so that prices charged in the United States are not representative of prices charged in the United Kingdom.
- Adjusting for the exchange rate assumes that ICT products are priced in dollars with instantaneous pass-through into sterling, which may not be true.
- The US price indices are averages over different products, eg in computers they are averages over the prices of personal computers (PCs), notebooks, servers, etc. The mix of products may differ between countries.

The importance of the first point depends on whether we are concerned with the growth rates or the levels of prices. It is certainly possible that the level of prices may differ between countries because of market discrimination by suppliers who possess some monopoly power. And there is plenty of anecdotal evidence that ICT prices are higher in the United Kingdom. If market power is constant, then UK and US growth rates are unaffected. Even if the degree of monopoly power changes, the effect of this on the rate of growth of UK prices is likely to be swamped by the huge falls observed in US prices. Casual empiricism suggests that, if anything, the UK market for ICT has become more competitive in recent years relative to the United States. If so, UK prices will have fallen more rapidly than assumed here. Hence ICT stocks in the United Kingdom will have been growing more rapidly than on our estimates. This could affect the weight that ICT assets receive in calculating the growth of aggregate capital services.

The second and third points are valid in principle. How important they are in practice can only be resolved by direct research on prices. It is not obvious that such research would necessarily support a faster growth rate of United Kingdom prices than is assumed here.

Software investment in current prices

Software investment has three components:

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

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

Software investment was first incorporated into GDP in the United Kingdom in the 1998 National Accounts. Previously, all spending on software was treated as intermediate consumption (like business purchases of stationery). The procedure used by the ONS to derive a series for software investment was first to estimate a benchmark figure for 1995, based on a 1991 survey of sales of computer services companies, and then to carry this figure forwards and backwards using the growth rates of indicator series. For the earlier years, the growth of total billings by the computer services industry was used. Years after 1995 used the growth of the wage bill of full-time programmers, computer engineers and managers in the computer services industry.

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

There is also a striking discrepancy in the proportion of the sales of the computer services industry that are classified as investment in the two countries. In the BEA's 1996 input-output table, we find that 60% of total sales of products of industry 73A, 'Computer and data processing services, including own account software', was classified as final sales (mostly investment). The 1996 figure was based on the 1992 economic census which asked firms in this industry to distinguish between receipts from pre-packaged software, from custom software and receipts from other activities, the first two of these being investment. In the United Kingdom in the same year, investment apparently accounted for only 17.5% of total sales of the corresponding product group (input-output group 107, 'Computer and related activity').

The United Kingdom also appears to be out of line with other European countries. Lequiller (2001) has compared France with the United States. He finds that the ratio of software investment to IT equipment investment was about the same in the two countries in 1998 (his page 25 and Chart 5). He also finds that the ratio of software investment to intermediate consumption of IT services is substantially lower in France than in the United States (pages 26-27). This ratio is exceptionally high in the United States, but equally his Chart 6 shows that it is exceptionally low in the United Kingdom. In fact, the reported UK ratio is substantially lower than in France, the Netherlands, Italy and Germany. Lequiller argues that in Europe software investment is based on data from purchasers while in the United States it is based on data from sellers, with the latter method tending to produce higher results. This however cannot explain the low UK level since the 1995 benchmark figure was based on sales data.

Part of the difference in software levels may be due to a different treatment of own account software in the United States. This now constitutes about a third of all US software investment and is estimated from the wage bill (grossed up for other costs) of computer programmers employed throughout the economy (see Parker and Grimm (2000)). Own account software is likely to be important in the United Kingdom too. In 1995 only 27% of software engineers and computer programmers were employed in the computer services industry (see Oulton (2001), Annex B). Presumably, an important function of the other 73% was to write software.

Oulton (2001) employed US methods to estimate UK own account software and re-considered the survey on which the 1995 benchmark was based. The result is that 1995 software investment is estimated to be about 4.1 times the current official figure. Alternative, rougher multipliers are suggested by the two discrepancies noted above. A multiplier of 3.6 is arrived at by dividing the US ratio of computer investment to software investment, averaged over 1990-98 (=1.40), by the corresponding UK ratio (=0.39). A factor of 3.4 is suggested by the comparison of the UK and US input-output tables. In order to err on the conservative side, we choose a multiplier of 3. The growth rate of both nominal and real software investment is of course left unchanged by this adjustment.

Software price indices

In the United States, each of the three types of software has a different price index (see Parker and Grimm (2000)). In the case of pre-packaged software, an index using hedonic techniques exists. For own account software, there is no hedonic index and the growth of the price index for this component is linked to the growth of wages of computer programmers. This means that the price index is assuming zero productivity growth amongst programmers. For the remaining component, custom software, the Bureau of Labor Statistics uses a weighted average of the pre-packaged (25%) and own account (75%) indices. Nominal investment in each type of software is deflated by its own price index and then summed to get real software investment. The overall price index is derived as an implicit deflator: total nominal divided by total real investment. The assumption of zero productivity growth amongst computer programmers employed to write own account software is very implausible. So there is a case for saying that the index overstates inflation. But partly for reasons of compatibility, we decided to use it.

There is no official PPI for software in the United Kingdom. Expenditure on software is deflated by a combination of the index of earnings in the real estate, renting and business activity sector (with a 'guesstimated' adjustment for productivity) and RPIY.

Communications equipment prices

The market for communications equipment was till recently less integrated internationally than other ICT markets. The methodological difference between the UK and US official price indices is smaller. Hedonic methods only affect a small part of the US index (Grimm *et al* (2002)). And in practice the UK price moves in a similar fashion to the US one. For these reasons, we employ the UK price index (ONS code: PQGT) to deflate nominal investment in communications equipment.

Implications for the other variables in the dataset

Our approach to ICT has implications for the other variables in the dataset. Changing the prices used for measuring real investment in computers and software means that we must also adjust the prices used to measure UK output of these products. The 'times three' adjustment to nominal software investment raises nominal GDP as measured from the expenditure side. To maintain consistency we must make a corresponding adjustment to the income side of the accounts. These adjustments are described more fully below.

A.3. Output

Nominal output

The accounting identity relating gross output and value added in nominal terms is:

Gross output = Value added + Domestic intermediate input + Imported intermediate input

Also,

Value added = Gross operating surplus (profits) + Wage bill + Taxes on production

Value added is at basic prices. Taxes on production, which include items like business rates and vehicle licences, are usually a small proportion of the total. For 1989-2000, gross output, value added and its components come from the I-O SUTs. For some earlier years, they are derived from the periodic input-output tables, when available. For years prior to 1989 when no input-output table exists, they are derived by interpolation. Aggregate value added so derived is controlled to equal GDP at current basic prices (ONS code: ABML).[3] There is no corresponding control for aggregate gross output, which can only be carried back to 1989 using official data (ONS code: NQAF).

Real output

Given that nominal gross output is the sum of nominal value added and nominal intermediate input, a Divisia index of real gross output in industry *i* is:

$$\hat{Y}_i = v_i\hat{V}_i + (1 - v_i)\hat{M}_i$$

whence

$$\hat{V}_i = [\hat{Y}_i - (1 - v_i)\hat{M}_i]/v_i \qquad \textbf{(A.1)}$$

Here Y_i is real gross output in industry *i*, V_i is real, double deflated, value added, M_i is real intermediate input, v_i is the share of nominal value added in nominal gross output, and a hat denotes a growth rate. This last equation serves as a definition of real value added.

Consistency of industry real output with official estimates of GDP growth

There are two ways in which real GDP may be measured, from output or from expenditure. From the output side, a Divisia index of GDP growth is:

$$\text{GDP growth} = \sum_{i=1}^{n} w_i\hat{V}_i \qquad \textbf{(A.2)}$$

Here w_i is the share of nominal value added in industry *i* in aggregate nominal value added (current price GDP), and there are *n* industries. Second, from the expenditure side:

$$\text{GDP growth} = \sum_{i=1}^{n} s_i\hat{E}_i \qquad \textbf{(A.3)}$$

(3) We exclude the services of housing from GDP since it does not derive from any industry. So the sum of value added across the 49 industries equals ABML minus housing services (ONS code: QTPS).

where E_i is final expenditure on the products of industry *i* and s_i is the share of final expenditure on *i* in current price GDP. We can readily show that these two measures of GDP growth are equal, in the absence of errors or omissions in the statistics.[(4)] But note that equality is only guaranteed in principle if value added is measured by double deflation, as in equation **(A.1)**.

In practice, of course the two estimates will differ. The ONS takes the view that for annual data the expenditure side estimate is the most reliable. In the published figures, there is no discrepancy between the two estimates (unlike in the US NIPAs) but this is because the output side estimate is adjusted to conform to the expenditure side one. The reason for preferring the expenditure side estimate is twofold. First, much of the hard-to-measure part of the economy is engaged in producing intermediate products (eg business services or wholesale banking) and these activities largely drop out of GDP on the expenditure side.[(5)] Second, in practice the ONS does not use double deflation to estimate real value added (except in electricity supply and agriculture); instead it uses real gross output as a proxy for real value added (in most cases, gross output deflated by an appropriate price index): see Office for National Statistics (1998), chapters 11 and 13, and Sharp (1998). The discrepancy between the output and expenditure side estimates is removed by adjusting output growth in the private service industries; output in the production sector (about a third of the economy) and in the government sector (about a fifth) is not adjusted.

We accept the argument that (within its assumptions) the best available estimate of GDP comes from the expenditure side. We therefore require our estimates of industry output to be consistent with the expenditure estimate of GDP. There are two ways in which this could be implemented. In the first method (method A), we assume that the ONS's measures of 'real value added' are in fact measures of *real gross output* and proceed in a number of steps:

Step 1. Use equation **(A.1)** to calculate double deflated real value added in the production sector and government sectors, treating the ONS's 'real value added' as in fact 'real gross output' and using data on intermediate input (see below).

Step 2. Recalculate GDP growth by means of equation **(A.2)**, using the *new* estimates of real value added for the production sector and government sectors, but the *original* real gross output estimates for the services sector, which we continue to treat as measures of real value added.

Step 3. Step 2 will produce a different result from the original one for GDP, so we adjust the growth rates of real value added in services so that GDP growth is the same as before. The rationale for this is that overall GDP growth is given from the expenditure side, so should not be changed.

Step 4. Given the new, adjusted, growth rates of real value added in services, we calculate new growth rates of real gross output in services from equation **(A.1)**.

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(4) This ignores the difference between market prices at which expenditure is usually measured and basic prices at which output is usually measured. But the argument can easily be extended to encompass this point.

(5) Not completely, since some enter into international trade.

This method assumes in effect that the only reason for any difference between the output and expenditure side estimates is that gross output is erroneously used in place of value added for measuring output in the production sector. In practice, we find that this method produces a very large adjustment to the growth of output in private services: 3.6% per annum over 1979-2000 with a high degree of year-to-year variation. This seems far higher than any plausible estimate of the difference between the growth rates of real value added and real gross output in private services. Hence we reject Method A in favour of the alternative, Method B.

Under Method B, we assume (with the ONS) that the ONS's output measures are the best available estimates of *real value added* (the opposite to Method A). We then use these together with data on intermediate input to derive real gross output for each industry. On average across the 49 industries, the standard deviations of the growth rates of both real gross output and of real value added under Method B are about half those found under Method A. In fact, the variability of growth under Method A is often implausibly high.

Enforcing consistency between the industry estimates and GDP
We aggregate output in the 49 industries to the whole-economy level, using Method B, and compare the result with the official measure. Our industry outputs do not include private housing (the actual and imputed rentals on dwellings), so in making the comparison we exclude housing from official GDP. Our indices are in basic prices, so we use GDP at basic prices (ONS code: ABMM), after excluding housing (ONS codes for housing: nominal, QTPS; real, GDQL). We back out non-housing GDP from a Fisher index of the two components of GDP, housing output and non-housing GDP. In practice, we find that there is a discrepancy between our aggregate measure of GDP growth and the official estimate. It may seem surprising that there is any discrepancy at all, given that our real output series derive from official ones. But our estimate of GDP is built up from 49 components only, while the official estimate derives from a much lower level of aggregation. Also we use a Fisher index while the official series is Laspeyres but with weights which are updated every five years or so; however, this seems to make little difference. To enforce consistency between the micro and macro views, we adjust the growth rate of real value added in each of the 49 CE industries by the amount of the discrepancy (measured in percentage points per annum).

Other adjustments to industry-level output
Two other adjustments were made to the industry estimates of real value added:

1. We add back the 'financial services adjustment' into nominal value added in banking.
2. ICT adjustments. These lead to higher nominal value added and profits in all industries and to higher real output growth in the Electronics and Computing services industries due to the use of US rather than UK price indices.

These adjustments all raise the estimated growth rate of GDP, particularly in 1995-2000.

Financial services adjustment The so-called 'financial services adjustment' (FSA) is a consequence of the treatment of the banking industry in the 1968 System of National Accounts (SNA). In the latter, profits and value added in all other industries are recorded gross of interest payments, which are regarded as a transfer payment. But if the banking industry is treated in the same way, then there is double-counting since a large part of bank profits arise from net interest receipts. Hence under the 1968 SNA, interest receipts are subtracted from bank profits and value added. But then the weight given to the banking industry in GDP is absurdly small or even conceivably negative. The 1993 SNA is an improvement conceptually since it recognises that banks perform a service of financial intermediation. So bank value added is higher and that of firms in the rest of the economy lower by the amount of this financial service (measured essentially as the difference between borrowing and lending rates times the value of loans). Intermediate consumption by non-bank firms is higher, and value added lower, by the amount of this purchased service. However, the reduction in non-bank value added does not completely offset the rise in bank value added, because banks also lend to final buyers (consumers, government and the foreign sector). This service is counted as final consumption and so raises GDP under the 1993 SNA.

Our approach is to add back in the FSA (ONS code: NSRV) to profits and value added in CE industry 40 without making any further adjustment. So we have moved half way between the 1968 and the 1993 SNAs. This gives the appropriate weight to the banking industry, but we should really make some downward adjustment to profits and value added elsewhere to be fully in accordance with the 1993 SNA. We have not done this, mainly because we do not have the necessary information to move all the way to the 1993 SNA. The ratio of NSRV to nominal GDP averaged 3.7% 1979-2000, so after allowing for final buyers, the effect on value added in other industries would probably be small, a downward adjustment averaging probably about 2%. Note that our approach only affects the weight applied to banking in calculating aggregate GDP, not banking output.

ICT adjustments We use US price indices (adjusted for exchange rate changes), rather than UK ones, to deflate the output of computers and software. We also argued that the level of software investment has been underestimated in the United Kingdom. This implies that the level of profits and value added has also been underestimated. In more detail, the ICT adjustments are as follows:

(1) The growth of real gross output in CE industries 20 (Electronics) and 43 (Computing services) is adjusted by using US rather than UK price indices for (respectively) computers and software. In the case of industry CE 20, only that part of output believed to consist of computers is adjusted (about 50%).[6]

(2) We argued that in the United Kingdom nominal software investment has been seriously underestimated, by a factor of three. There has been a corresponding overestimate of intermediate consumption of software services. In our investment and capital estimates (see below), we therefore multiply the nominal level of software investment by three. For consistency, we must make a corresponding adjustment to profits and value added in each industry, so that the output and expenditure estimates of nominal GDP remain equal. Profits and value added are therefore increased in all industries to reflect this 'times three' adjustment

[6] This was estimated as the ratio of gross output of input-output industry 69 to total gross output of input-output industries 69, 73, 74 and 75; values for 1969-91 were set equal to the value for 1992. The source was the I-O SUTs. Input-output row 69 is Division 30 of SIC92, input-output rows 73-75 make up Division 32 of SIC92. The aggregate of SIC92 Divisions 30 and 32 is CE industry 20.

to nominal software investment: ie, we add twice the original level of software investment to each industry's profits and value added.

We have calculated aggregate GDP both before and after the adjustments that we think are desirable and compared it with the ONS estimate of GDP growth. The GDP measures are as follows:

gdp49: Fisher index of real value added in the original 49 industries, weighted together using nominal value added.

gdp34: Fisher index of real value added in our ultimate list of 34 industries, weighted together using nominal value added. Real output is adjusted for ICT and aggregated up to 34 industry level. The nominal weight for banking adds back in the 'financial services adjustment'. The industry-level output series that make up *gdp34* are the ones used in our growth accounting calculations.

abmmxh: GDP at basic prices (ONS code: ABMM), excluding housing (ONS codes: nominal, QTPS; real, GDQL). *abmmxh* is calculated as if ABMM were a Fisher index of the two components, housing output and non-housing GDP.

Table A.4 and Chart A.1 below shows the effect on the aggregate GDP growth rate estimated from industry data of making these adjustments. The difference between *abmmxh* and *gdp49* measures the extent of the discrepancy between industry-level output and aggregate output. In general, *gdp49* grows less rapidly than the official estimate. The largest discrepancy occurs in 1990-95, when *gdp49* falls short by 0.8% per annum. Removing the financial services adjustment raises the growth rate by 0.14 percentage points above the official level in the 1980s and by 0.03 percentage points in the 1990s. The ICT adjustment also has a substantial effect: growth in the 1980s is raised by a further 0.27 percentage points and in the 1990s by a further 0.15 percentage points. The effect is most marked in 1995-2000: 0.29 percentage points.

A.4. Capital[7]

Capital input is measured by capital services from different types of assets, following Jorgenson (1989). We distinguish between non-ICT capital and ICT capital. For each of our 34 industries we estimate the capital services flowing from stocks of the following four non-ICT[8] assets:

1. Buildings
2. Equipment (excluding computers, part of software and communication equipment)
3. Vehicles
4. Intangibles (excluding rest of software)

and the following three ICT assets:

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(7) For a fuller discussion of the methods and the empirical issues, see Oulton and Srinivasan (2003).

(8) Buildings exclude residential dwellings. The 'traditional' asset classification follows that of the OECD's System of National Accounts, 1992 and is that followed by the ONS.

5. Computers
6. Software
7. Communication equipment

While the wealth measure of capital is more firmly established and the standard measure produced by the ONS, in the context of production theory the flow of capital services is the correct measure to use.[(9)] The measures for ICT, non-ICT and total fixed capital are calculated by weighting the growth of asset stocks in the respective categories by their rental prices. Rental prices are measured using the Hall-Jorgenson formula.

The method

The equations of our model for estimating capital services are as follows:

$$B_{it} = I_{it} + (1-\delta_i)\cdot B_{i,t-1}, \qquad i = 1,\ldots,m \tag{A.4}$$

$$A_{it} = (1-\delta_i/2)\cdot B_{it} \tag{A.5}$$

$$K_{it} = \bar{A}_{it} = \left[A_{i,t-1}\cdot A_{it}\right]^{1/2}, \qquad i = 1,\ldots,m \tag{A.6}$$

$$p_{it}^{K} = T_{it}\left[r_t\cdot p_{i,t-1}^{A} + \delta_i\cdot p_{it}^{A} - (p_{it}^{A} - p_{i,t-1}^{A})\right], \qquad i = 1,\ldots,m \tag{A.7}$$

$$\Pi_t = \sum\nolimits_{i=1}^{m} p_{it}^{K} K_{it} = \sum\nolimits_{i=1}^{m} T_{it}\cdot\left[r_t\cdot p_{i,t-1}^{A} + \delta_i\cdot p_{it}^{A} - (p_{it}^{A} - p_{i,t-1}^{A})\right]\cdot K_{it} \tag{A.8}$$

$$\begin{gathered}\ln\left[K_t/K_{t-1}\right] = \sum\nolimits_{i=1}^{m}\bar{w}_{it}\ln\left[K_{it}/K_{i,t-1}\right],\\ \bar{w}_{it} = (w_{it} + w_{i,t-1})/2,\;\; w_{it} = \frac{p_{it}^{K}K_{it}}{\sum\nolimits_{i=1}^{m} p_{it}^{K}K_{it}},\;\; i = 1,\ldots,m\end{gathered} \tag{A.9}$$

where:

m is the number of assets
A_{it} is the real stock of the *i*th type of asset at the *end* of period t
$\bar{A}_{it}$ is the real stock of the *i*th type of asset in the *middle* of period t
B_{it} is the real stock of the *i*th type of asset at the *end* of period t, if investment were assumed to be done at the end of the period, instead of being spread evenly through the period
K_{it} is real capital services from assets of type i during period t
I_{it} is real gross investment in assets of type i during period t
δ_i is the geometric rate of depreciation on assets of type i
r_t is the nominal post-tax rate of return on capital during period t
T_{it} is the tax-adjustment factor in the Hall-Jorgenson cost of capital formula
p_{it}^{K} is the rental price of new assets of type i, payable at the end of period t

[(9)] See Oulton and Srinivasan (2003, Section 1) for a discussion of the difference between the capital wealth and capital services measure.

p_{it}^{A} is the corresponding asset price at the end of period t

Π_t is profit (= nominal aggregate capital services) in period t

K_t is real total capital services during period t

Equations **(A.4)** and **(A.5)** describe the evolution of asset stocks. They can be shown to arise from the following accumulation equation:

$$A_{it} = (1-(\delta_i/2))\cdot I_{it} + (1-(\delta_i/2))\cdot(1-\delta_i)\cdot I_{i,t-1} + (1-(\delta_i/2))\cdot(1-\delta_i)^2\cdot I_{i,t-2} + \ldots \quad \textbf{(A.10)}$$

The factor $(1-\delta_i/2)$ arises as investment is assumed to be spread evenly throughout the unit period, so on average it attracts depreciation at a rate equal to half the per-period rate. This assumption affects the level, but not the growth rate, of the capital stock.[10]

Equation **(A.6)** states that capital services *during* period t derive from assets in place in the *middle* of period t. The capital stock in the middle of period t is estimated as the geometric mean of the stocks at the beginning and end of the period. Equation **(A.7)** defines the rental price of assets of type i. Equation **(A.8)** says that profit equals the sum over all assets of the rental price times the asset stock. Equation **(A.9)** defines the growth rate of capital services.

This model can be applied to both industry and whole-economy data. Given asset prices, investment, depreciation rates, the tax adjustment factors, and aggregate profits, we apply it to whole-economy data in order to estimate the nominal rate of return. We assume that this rate of return applies to each industry. The sources for the whole-economy estimates are described fully in Oulton and Srinivasan (2003). Armed with an estimate of the rate of return, we then apply the model to industry data to estimate capital services in each of our 34 industries. The alternative was to estimate the model for each industry separately, using industry profit to estimate a different rate of return in each industry. We rejected this alternative, as likely to lead to unrealistically volatile estimates. For reasons explained below, the aggregation in Equation **(A.9)** is done using a Fisher index, not a Törnqvist index.

Real asset stocks, by industry

Equations **(A.4)** and **(A.5)** are used to generate stocks of each asset, by industry. They require an 'initial stock' value, an assumed depreciation rate and real investment for each asset, by industry. Starting stocks for buildings, plant and vehicles for end-1947 were calculated using historical data as generated in Oulton (2001). Starting stocks for intangible assets were set equal to zero in end-1947; for computers in end-1959 and software and telecommunications equipment in 1964.

We distinguish separate depreciation rates across assets, but these rates are not assumed to vary across industries.[11] A constant geometric depreciation rate is assumed for each asset.[12] These annual depreciation rates are based on Fraumeni (1997) and are given in Table A.5.

(10) This assumption corresponds to the practice of the BEA: see U.S. Department of Commerce (1999, box on page M-5).

(11) The only exception is vehicles where the annual depreciation rate is 5.89% for rail transport (Industry 22), 6.11% for water transport (Industry 24) and 8.25% for air transport (Industry 25). The rest of the industries have a common rate of 25%.

Real investment in each asset, by industry, is calculated by dividing nominal investment by the price deflator for the asset.

Nominal investment in the ICT assets for 1992-2000 is extracted from Table 6 of the Input-Output Supply and Use Tables (ONS 2002b) and for 1989-91 from earlier Supply and Use Tables. The data is only provided for 36 purchasing industries. We exclude roads, and to match the classification in the rest of the dataset we had to merge Motor vehicles, sales and repairs (I-O SUTs Industry 19) and Wholesale trade (I-O SUTs Industry 20) thus leaving us with 34 industries. The relevant rows in the tables are 69 ('Office machinery & computers') for computers, [13] 107 ('Computer services') for software and 74 ('Transmitters for TV, radio and phone') for telecommunications equipment. For earlier years we take the 1989 industry proportions of the total and distribute the whole-economy figures for those years accordingly. The whole-economy nominal investment series for computers and telecommunications equipment are taken from Oulton (2001, Table B.2) and software from Oulton and Srinivasan (2003, Table C.2). Investment in I-O SUTs industries 'financial intermediation' and 'real estate, renting and business activities' was adjusted (in proportion to the industries' value added) to match industry definitions for Industries 28 and 29 in our dataset.

For reasons set out in Section A.2 above, we employ US price indices, converted to sterling terms, to deflate investment in computers and software in current prices. For communications equipment, we use the official UK investment deflator.[14]

Nominal investment and associated price deflators in buildings, plant and vehicles for the 34 industries were taken from an investment dataset supplied by the ONS (now available on their website). The data have been scaled so that the aggregate nominal investment in each asset is equal to the published total in the National Accounts 2002. Some industry specific deflators for buildings and plant were smoothed so that the rental price (equation (**A.7)**) remained positive.

For some industries (2, 10, 16, 22, 25), for some years, nominal investment in vehicles is negative and for one year for industry 22, buildings investment is negative. This is conceptually possible since investment is measured as acquisitions less disposals. It is then arithmetically possible for the accumulation equations **(A.4)** and **(A.5)** to generate a negative stock. This is conceptually impossible and would be a sign either that our depreciation assumption is wrong or that there is an error in the data. But in fact we found that the stocks were always positive, even when investment was negative. So we have not adjusted the investment data.

Intangibles assets in the United Kingdom consist mainly of software, mineral exploration and artistic originals. The software investment series available in the ONS investment dataset is the software component of intangibles investment. However, the software series extracted from the

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(12) See Oulton and Srinivasan (2003, Section 3) for a discussion on the relative merits of geometric and straight-line depreciation rates.
(13) Only a proportion of the investment data in row 69 is taken to be computers since the total for row 69 includes office equipment. For details on this proportion see Oulton (2001), Annex B, Section B.1.
(14) Communications equipment in the United Kingdom is Industry 32.2 (SIC92). In the United States (following the classification in Jorgenson, Ho and Stiroh (2004)) communications equipment is in Industry 366 (SIC87).

SUTs is total software comprising software in intangibles and software subsumed in plant. Oulton and Srinivasan (2003, Appendix C) have constructed series for the whole economy for each component of total software investment. Using the whole-economy proportions, we divide industry level total software investment into industry levels of software in intangibles and software in plant. Except for our Industry 2 (‘Oil and Gas’) and Industry 34 (‘Miscellaneous Services’) we have assumed that total intangibles investment in all industries equals the ‘software in intangibles’ investment. In other words, we assume that except for Industries 2 and 34, the only intangible investment an industry does is in software.

From the published whole-economy intangibles investment series we can subtract the aggregate of software in intangibles investment to get intangibles investment in the other components: mineral exploration and artistic originals. In the absence of more detailed information, this is split equally between industries 2 and 34, ie we assume that industry 2 does mineral exploration and industry 34 (which includes radio, television, motion picture and video activities, and museums) is the main repository of artistic originals. Since we treat software as a separate asset, this implies that in the calculations, intangibles is really ‘intangibles net of part of software’ or ‘rest of intangibles’ and because of our assumptions, is zero for all industries except 2 and 34.

The UK National Accounts do not distinguish computers, software and communications equipment separately — they are subsumed in the plant (ie ‘other machinery and equipment’) and intangibles categories. However, because we treat computers and communications as separate assets in the calculations, plant is really ‘plant net of computers, part of software and communications equipment’ or ‘rest of plant’.

In nominal terms, to calculate ‘rest of intangibles’ and ‘rest of plant’ is easy. Simply subtract the sub-components from the total. We use the Törnqvist formula to back out the real investment in the ‘rest’ for each industry. For years for which real investment in one of the components (computers, part of software or communications) is zero, the Törnqvist formula breaks down. In such cases, we have assumed that the real investment in rest of plant (or intangibles) is approximately equal to real investment in total plant (or intangibles) less real investment in the non-zero components. The price deflator for plant for each industry and intangibles (for industries 2,34) is recalculated as the ratio of nominal ‘rest’ to real ‘rest’.

Thus using the real investment for each of the seven assets, starting values, and depreciation rates as given in Table A.5, we calculate real stocks for each asset by industry. Note that the depreciation rate of 13% per annum for plant in Table A.5 is applied to ‘rest of plant’ only. ICT assets like computers and software have higher depreciation rates.

Rental prices and shares, by asset, by industry
Rental prices for each asset in each industry are calculated via equation **(A.7)**. Asset prices are given with the nominal investment data (except for intangibles and plant where they are calculated as the ratio of nominal to real investment) and depreciation rates are as provided in Table A.5. Tax rates were kindly supplied by Rod Whittaker of HM Treasury and are assumed to be the same across industries. We assume in addition, that the tax rate on computers, software and telecoms is

the same as that for plant. As mentioned above, the nominal rate of return is calculated from whole-economy data and is thus assumed to be the same across all assets and all industries.

Using Equation **(A.8)** we multiply the rental prices by the real asset stocks for each asset in a particular industry, sum across assets and then divide the asset specific rental price times asset stock by the sum to obtain the rental price share of the asset. The rental prices shares, mostly for buildings and plant were quite volatile in the 74-80 period and have thus been smoothed.[(15)]

The shares of ICT capital and non-ICT capital in profits have been calculated by applying equation **(A.8)** to the assets in each category (eg computers, software and telecoms for ICT capital). These shares are then applied to the profits data to get the value of profits originating from that category.

We calculate Fisher indices of capital services for total, ICT, non-ICT and computers & software capital using the rental price shares and the real asset stocks for each industry (as in equation **(A.9)**). The reason we use Fisher for the aggregation is that for many industries telecoms stocks are zero and for some industries for some years computer and software stocks are zero. [(16)] These indices are converted into constant price series for capital services by setting the real capital service in the base year, 1995, equal to the nominal profits in that year.

A.5. Labour

Labour input is best measured by hours worked but it is necessary also to adjust for labour quality. The basic principle is to break out as many different types of labour as possible — distinguished eg by age, gender and qualifications — and to measure aggregate labour input as a weighted average of hours worked by each group. The weights should be the shares of each type of labour in the aggregate wage bill. This assumes that a version of marginal productivity theory holds: each type of labour is paid in proportion to its marginal product.[(17)] Ideally, we would like to construct a chain index of labour input for each industry. For each industry, we would need data on hours worked by age, gender and qualifications. Unfortunately, this is not possible for the United Kingdom at the level of industry disaggregation that we require.

We rely on the employer-based surveys for head counts of number of people employed by industry. We use the New Earnings Survey (NES), also employer-based, for hours per worker, by industry. An alternative source for hours worked and also for qualifications is the Labour Force Survey (LFS), which is a survey of households. From our point of view, this suffers from two major drawbacks: first, the LFS goes back only to 1984; second, the distribution of the labour force across industries revealed by this survey matches very poorly with that given by the employer-based surveys. The employer-based surveys are considered the more reliable in this respect. However, the LFS is generally considered to give the best estimate of aggregate employment and hours worked. The NES also provides data on age, gender and occupation and we have tried to use these data to provide estimates of quality change at the industry level. Unfortunately, we have found that

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(15) Some rental price shares for vehicles and plant for other years have also been smoothed.
(16) The Törnqvist formula in the growth rate calculations breaks down for those years when the asset stocks are zero.
(17) It is not necessary to assume that wages are *equal* to marginal products. But if they differ, the factor of proportionality must be the same for all types. This would be the case for example for a firm which is a price-taker in input markets and is in monopolistic competition in the product market.

the NES provides a poor basis for this purpose: when the results are aggregated up to the whole-economy level, we find them to be inconsistent with what we know from other sources (the LFS). So our indices in practice are just hours worked, ie an unweighted sum of hours worked by workers of different types. But we have made two aggregate level adjustments to the industry estimates. The first is to make the growth of aggregate hours consistent with the measure derived from the LFS (ONS code: YBUS). The second is to make use of an index of quality change constructed by colleagues in the Bank of England (Bell, Burriel-Llombart and Jones (2005)). Their index is for the whole economy and is a Törnqvist one encompassing the effects of changes in the composition of the labour force by age, gender and qualifications. We add their measure of the growth of labour quality to each industry's growth rate of labour input; we also present results without the aggregate quality adjustment.

In summary, the basic strategy is to measure total annual hours worked in each industry as the number of workers in the industry (the head count) times the annual hours per worker in this industry. The head count covers both employees and the self-employed. Total hours worked in each industry are then adjusted so that the growth of estimated total hours worked in the whole economy matches an independent estimate of this growth rate. We also apply a quality adjustment based on aggregate-level data to each industry's growth of labour input.

Sources for head counts

The most reliable measure of the number of *employees* at the industry level is provided by the regular employer-based surveys, formerly the Annual Employment Survey (AES), nowadays the Annual Business Inquiry (ABI). These provide head counts of the number of employees by industry for four categories of worker: male full time (FT), male part time (PT), female FT and female PT. The most detailed level of data is for Great Britain, ie the United Kingdom excluding Northern Ireland (which has 2.5% of the UK population). Data are available on a consistent industrial classification (the 1992 SIC) from 1978 to the present. The detailed data are quarterly, not seasonally adjusted, though some information is available monthly. In the first instance we extract these head counts of employees for the 49 CE industries. We obtain annual average employment levels as simple averages of the quarterly series.[18]

These surveys cover employees only and exclude the self-employed, who are a growing category. In 1971 11.1% of jobs held by males were self-employed; this proportion rose to 17.8% in 1997. The comparable figures for females were 5.1% in 1971 and 7.5% in 1997.[19] We estimate the self-employed as the difference between 'workforce jobs' (WFJ) and employees. This calculation can be done for each sex separately but unfortunately for a breakdown into only nine broad sectors. We assume that the self-employed proportion is the same for all industries in a given sector. The Labour Force Survey (LFS) is the only source for data on self-employment. Self-employment is measured in accordance with respondents' perceptions, which may differ from those of employers.

Sources for hours and quality

The AES/ABI surveys have no information on wages, hours, age or skills. But this deficiency can be made up to some extent by using the New Earnings Survey (NES). This is a compulsory survey,

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(18) These data are not published at this level of detail but are provided on request by the ONS.

(19) Source: Diskette labelled 'Historical supplement No. 5: Workforce data back series', published by the ONS.

also employer-based, covering 1% of all employees in Great Britain (about 250,000 employees), and based on a random draw of National Insurance numbers. This survey asks about each worker's pay packet and hours, the worker's age and his or her occupation. The survey does *not* ask about educational qualifications. The data in the NES are a snapshot of a particular week in April. We have data from the NES for the years 1975 to 1999. Nowadays the NES asks about actual weekly hours as well as usual weekly hours, but actual hours only go back to 1991. Hence we use usual weekly hours.[20]

We experimented with using the NES data on occupation as a proxy for qualifications and hence as a measure of labour quality. In principle, we can measure weekly wages and weekly hours for each of our 49 industries by age, gender and occupation. But at this level of detail the sample sizes are too small, so we drop age in the belief that changes in the age distribution are likely to have only a minor effect on labour quality. This leaves potentially (2 x 4 =) eight types of labour for each industry. We estimate the total weekly hours of each labour type as the average usual weekly hours of each group times the numbers in each group. The number in each group is the sample proportion of each group (from the NES) times the headcount of all workers, by gender, after grossing up for self-employment; the head counts derive from the AES/ABI, as just described.[21] The weight to be applied to each group is its share of the industry wage bill, which can be estimated from the NES. But we found that the results were quite different from those obtained from the LFS, for the years where they overlap.

We next experimented with using just two types of labour for each industry, males and females. As expected, this led to an index of quality which fell at a modest rate for most of our period, which simply reflects the fact that women earn less than men and the female share of total hours has been rising. But near the end of our period, in 1998 and 1999, this quality index rose sharply, by 0.96% and 1.91% respectively. This behaviour seems implausible and does not match the evidence from the LFS. As a result, we abandoned the NES as a source for quality change and decided to use the LFS to make an aggregate level adjustment for quality (see below).

Final method

For the reasons just discussed, we estimate simple, unweighted indices of hours worked for each industry. These are just unweighted sums over all labour types of hours worked in each industry. Prior to calculating these indices, we aggregated the industries from the original 49 to 34, to match our other data.

Usual weekly hours need to be converted to actual annual hours. We start by multiplying weekly hours by 52, but this overstates actual annual hours because it makes no allowance for eg sickness, maternity, and holidays. In fact the number of weeks worked per year likely has a downward trend due to the rise of paid holidays and the increase in the number of public holidays. Also, actual hours worked are affected by the business cycle. We have no reliable measures of these factors at

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(20) We are very grateful to Glenda Quintini who supplied us with the NES data, broken down into our 49 industries, for the years 1975-99. The big advantage of her data is that they enable consistency over such a long period in the occupational and industrial classification systems, a non-trivial task.

(21) The NES hours are averages over all workers, full time and part time. So the head count for each industry is the sum of full-time and part-time workers.

the industry level. We therefore apply an adjustment derived at the aggregate level to each industry (see below).

Implementing the method
The solution suggested for estimating labour input at the industry level was the following:

> *Step 1*. Start with employer-survey-based measures of numbers of employees by gender and industry (ie the head count data formerly gathered by the AES and nowadays by the ABI).
> *Step 2*. Add the self-employed (from the LFS), to yield what we call numbers employed.
> *Step 3*. Multiply numbers employed by usual weekly hours per worker. Usual weekly hours per worker, together with the wage bill, are available for each sex for 1976-99 from data supplied by Glenda Quintini. She derived these data from the NES (actual hours are only available from 1993).
> *Step 4*: Apply an aggregate adjustment to convert usual to actual hours (using the LFS-based series for total hours, YBUS).
> *Step 5*. Apply an aggregate adjustment for quality based on data from the LFS (the measure derived by Bell, Burriel-Llombart and Jones (2005)).

Steps 1-3 generate for each of the 34 industries a measure of labour input which is a simple sum of hours worked by males and females, initially for 1978-99. Our head count data from the AES/ABI go back to 1978, while our NES data go back to 1975. We backcast the head count series for 1969-77 using data for the growth rates of employees supplied by Cambridge Econometrics for these years. For the years 1969-74, we have no NES data on hours so we assume that usual hours grew at the same rate as employment.

For the year 2000, we have no NES-based data from Quintini so we assume that total usual weekly hours in each industry grew at the same rate as employment (employees plus self-employed), where employment is now from the AES survey.

Step 4: We calculate the growth of aggregate hours by aggregating up the simple industry-level indices of hours worked. We compare this with the growth of total weekly hours from the LFS (ONS code: YBUS). We then add the difference between the growth rates of YBUS and of our own estimate of aggregate hours to the growth of hours in each industry. Note that though YBUS is a measure of weekly hours, it is an average over people who actually worked and those who were absent for some reason (sickness, maternity, holidays, etc). So this procedure does capture differences between actual and usual hours.[(22)]

Insofar as the head count varies over the business cycle, then our labour input measures already make some allowance for business cycle factors. The YBUS adjustment is the main factor adding an element of variation in hours per worker over the cycle. So it is important to note that by construction it is *the same for all industries*.

[(22)] The published series for YBUS goes back only to 1993. For the earlier years, we rely on an internal Bank estimate extending YBUS back to 1969. This in turn was based on O'Mahony (1999).

Step 5: The aggregate quality adjustment is made using the index of labour quality developed by Bell, Burriel-Llombart and Jones (2005). Their Törnqvist index of labour input uses five age groups, five education groups and two genders, ie 50 groups in all and runs from 1975-2000. It is based on qualifications and wages data from the LFS for 1985 onwards, and for the years 1975-84 on qualifications data from the General Household Survey. Quality growth is estimated as the growth of quality adjusted hours minus the growth of an unweighted index of hours. We set quality growth to zero for 1970-75.

Table A.6 shows average annual growth rates of the aggregate measures: labour input, hours, quality and the YBUS adjustment to aggregate hours; see Chart A.2 for the course of labour quality. The YBUS hours adjustment reduces the annual growth of labour input but only by 0.02 percentage points per annum, though this masks a some variation over the cycle: see Chart A.3. The adjustment has been predominantly positive in the 1980s and predominantly negative in the 1990s, particularly so in 1992.

A.6. Intermediate input

Nominal input

For each of our original 49 industries, we have the purchases of the products of each of the 49 industries from domestic sources and separately from imports. That is, for each year we have a 49 x 49 matrix of domestic purchases and a 49 x 49 matrix of purchases from imports.

The domestic/imports split was done using the input-output tables. For years when the I-O SUTs are not available but an input-output table exists, the latter was employed to produce estimates of intermediate input. The tables were first adjusted to conform to revised estimates of nominal GDP and nominal value added in broad sectors and aggregated up to the 49 industry level. For intervening years between input-output tables, interpolation was used.

Real input

For each product, we have a domestic price index and an import price index. These derive from the ONS's detailed Producer Price Indices. We use them to deflate purchases. For each industry, we construct a Fisher index of aggregate domestic intermediate input and a Fisher index of aggregate imported intermediate input. Then we construct a Fisher index of these two components to arrive finally at our index of real intermediate input. We use Fisher rather than Törnqvist indices since at this level of detail many of the cells in our purchases matrices are zeroes. A Törnqvist index cannot be calculated in these cases but no such problem arises for a Fisher index.

The resulting indices turned out to be implausibly volatile. For example, over the period 1979-2000, the average across the 49 industries of the standard deviation of the growth rate of intermediate input was 20.3% per annum. This was much higher than the average volatility of real value added. This excessive volatility seems to be due not to particularly high volatility of price inflation, nor to volatility of the individual components of the domestic and import use matrices, but rather to high volatility of the *total* of nominal purchases by each industry from year to year, at least for the period prior to 1992. Recall that prior to 1992 we do not have the I-O SUTs to rely on. So it is possible that the volatility of intermediate input is an artefact of the estimation process. We therefore decided to smooth the growth rates of the Fisher indices of intermediate input in the following, sequential way.

1. Outliers are clipped. If a growth rate exceeds +20% per annum, it is set equal to +20%. If it is less than -20% per annum, it is set equal to -20%.

2. If a growth rate is outside the bounds of the mean plus or minus 2 standard deviations (calculated for the period 1979-2000), then it is set equal to the mean.

3. A two-year, moving average of the growth rates is calculated.

Finally, we obtain indices of total intermediate input at the 34 industry level as Fisher indices of the indices at the 49 industry level.

A.7. Total factor productivity

We calculate TFP growth in each industry as the growth of real gross output minus the growth of a Törnqvist index of total input. Total input comprises capital, labour and intermediate. The shares of the three inputs are the payments made to each input as a proportion of nominal gross output (excluding taxes on production). These are taken from the I-O SUTs for the years 1992-2000. For earlier years the intermediate share derives from our annual series on gross output, intermediate input and value added. To derive the share of capital in 1969-91, we employ the 1992 share of profit in value added but adjusted so that industry profits sum to the national accounts total (this picks up any cyclical variability in the profit share at the aggregate level).

The share of ICT capital services in value added is derived as the share of ICT in total capital services times the share of capital in value added. The share of ICT in total capital services is estimated as the share of profits attributable to ICT in total profits, where profit attributable to each ICT asset is the rental price of that asset multiplied by the nominal value of the stock (see above).

The labour share in value added is derived as one minus the capital share. The labour and capital shares in value added are then converted to shares in gross output.

Table A.1
The original 49 industries (CE 1 - CE 49)

	Industry	*SIC92*
1	Agriculture	01,02,05
2	Coal	10
3	Oil & Gas etc	11,12
4	Other Mining	13,14
5	Food	15.1-15.8
6	Drink	15.9
7	Tobacco	16
8	Textiles	17
9	Clothing & Leather	18,19
10	Wood & Wood Products	20
11	Paper, Printing & Publishing	21,22
12	Manufactured Fuels	23
13	Pharmaceuticals	24.4
14	Chemicals nes	24 (ex 24.4)
15	Rubber & Plastics	25
16	Non-Metallic Mineral Products	26
17	Basic Metals	27
18	Metal Goods	28
19	Mechanical Engineering	29
20	Electronics	30,32
21	Electrical Engineering	31
22	Instruments	33
23	Motor Vehicles	34
24	Aerospace	35.3
25	Other Transport Equipment	35 (ex 35.3)
26	Manufacturing nes & Recycling	36, 37
27	Electricity	40.1
28	Gas Supply	40.2, 40.3
29	Water Supply	41
30	Construction	45
31	Retailing	52
32	Distribution nes	50,51
33	Hotels & Catering	55
34	Rail Transport	60.1
35	Other Land Transport	60.2, 60.3
36	Water Transport	61
37	Air Transport	62
38	Other Transport Services	63
39	Communications	64
40	Banking & Finance	65
41	Insurance	66
42	Professional Services	67,73,74.1-74.4
43	Computing Services	72
44	Other Business Services	70,71, 74.5-74.8
45	Public Administration & Defence	75
46	Education	80
47	Health & Social Work	85
48	Waste Treatment	90
49	Miscellaneous Services	91-99

Note SIC92 is the 1992 version of the United Kingdom's Standard Industrial Classification. It is identical to the European NACE system. Details on SIC92 industry codes can be found at http://www.statistics.gov.uk/methods_quality/sic/contents.asp.

Table A.2
The 34 industries used in the empirical analysis

	Industry	*SIC92*
1	Agriculture	01,02,05
2	Oil and gas	11,12
3	Coal & other mining	10,13,14
4	Manufactured fuel	23
5	Chemicals & pharmaceuticals	24
6	Non-metallic mineral products	26
7	Basic metals & metal goods	27,28
8	Mechanical engineering	29
9	Electrical engineering & electronics	30,31,32,33
10	Vehicles	34,35
11	Food, drink & tobacco	15,16
12	Textiles, clothing & leather	17,18,19
13	Paper, printing and publishing	21,22
14	Other manufacturing	20,25,36,37
15	Electricity supply	40.1
16	Gas supply	40.2,40.3
17	Water supply	41
18	Construction	45
19	Wholesale, vehicle sales & repairs	50,51
20	Retailing	52
21	Hotels & catering	55
22	Rail transport	60.1
23	Road transport	60.2,60.3
24	Water transport	61
25	Air transport	62
26	Other transport services	63
27	Communications	64
28	Finance	65, 66
29	Business Services	67, 70,71,72,73,74
30	Public administration and defence	75
31	Education	80
32	Health and social work	85
33	Waste treatment	90
34	Miscellaneous services	91-99

Note SIC92 is the 1992 version of the United Kingdom's Standard Industrial Classification. It is identical to the European NACE system. Details on SIC92 industry codes can be found at http://www.statistics.gov.uk/methods_quality/sic/contents.asp.

Table A.3
Mapping between 34 industries and sectors used in Basu *et al* (2004)

	Industry	*Private Non-farm Business*	*ICT Producing*	*Well Measured*	*Sectors in Basu* et al *(2004)*
1	Agriculture				
2	Oil and gas	✓		✓	Mining
3	Coal & other mining	✓		✓	Mining
4	Manufactured fuel	✓		✓	Manufacturing (non-durable)
5	Chemicals & pharmaceuticals	✓		✓	Manufacturing (non-durable)
6	Non-metallic mineral products	✓		✓	Manufacturing (non-durable)
7	Basic metals & metal goods	✓		✓	Manufacturing (non-durable)
8	Mechanical engineering	✓		✓	Manufacturing (durable)
9	Electrical engineering & electronics	✓	✓	✓	Manufacturing (durable)
10	Vehicles	✓		✓	Manufacturing (non-durable)
11	Food, drink & tobacco	✓		✓	Manufacturing (non-durable)
12	Textiles, clothing & leather	✓		✓	Manufacturing (non-durable)
13	Paper, printing and publishing	✓		✓	Manufacturing (non-durable)
14	Other manufacturing	✓		✓	Manufacturing (non-durable)
15	Electricity supply	✓		✓	Electric/Gas/Sanitary
16	Gas supply	✓		✓	Electric/Gas/Sanitary
17	Water supply	✓		✓	Electric/Gas/Sanitary
18	Construction	✓			Construction
19	Wholesale, vehicle sales & repairs	✓		✓	Wholesale Trade
20	Retailing	✓		✓	Retail Trade
21	Hotels & catering	✓		✓	Retail Trade
22	Rail transport	✓		✓	Transportation
23	Road transport	✓		✓	Transportation
24	Water transport	✓		✓	Transportation
25	Air transport	✓		✓	Transportation
26	Other transport services	✓		✓	Transportation
27	Communications	✓		✓	Communications
28	Finance	✓			Finance and Insurance
29	Business Services	✓			Business Services and Real Estate
30	Public administration and defence				
31	Education				
32	Health and social work				
33	Waste treatment	✓		✓	Electric/Gas/Sanitary
34	Miscellaneous services	✓			Other Services

Table A.4
Alternative measures of GDP growth, % per annum

	49 industries *gdp49*	*34 industries* *gdp34*	*Aggregate (ONS)* *abmmxh*
1969-1979	1.80	2.52	2.15
1979-1990	2.26	2.70	2.29
1990-2000	1.98	2.58	2.40
1990-1995	1.06	1.88	1.86
1995-2000	2.91	3.28	2.93

Notes See text.

Table A.5
Asset level depreciation rates and investment price deflators

	Asset	*Depreciation Rate (% per annum)*	*Investment Price Deflator*
1.	Other buildings and structures	2.5	UK: Industry specific
2.	Other machinery and equipment and cultivated assets ('plant')	13.0	UK: Industry specific
3.	Transport equipment ('vehicles')	25.0	UK: Industry specific
4.	Intangible fixed assets	13.0	UK: Industry specific [23]
5.	Computers	31.5	US: common for all industries[24]
6.	Software	31.5	US: common for all industries[25]
7.	Telecommunications equipment	11.0	UK: common for all industries (ONS code: PQGT)

(23) As explained in the text, for all industries, except Oil and gas (Industry 2) and Miscellaneous services (Industry 34), there is zero intangibles investment once software investment has been accounted for. For industries 1 and 3-33, the software deflator is used as the intangibles deflator. For the two industries that that have non-zero intangibles investment, net of software, we use industry specific deflators.
(24) Source: US Bureau of Economic Analysis, NIPA Tables, Table 7.6, translated into pounds using the sterling exchange rate (ONS code: AJFA).
(25) Source: US Bureau of Economic Analysis, NIPA Tables, Table 7.6, translated into pounds using the sterling exchange rate (ONS code: AJFA).

Table A.6
Mean growth rates of aggregate total hours, quality, and the YBUS adjustment to aggregate hours, % per annum

	Total hours (not quality-adjusted)	*Quality*	*Total hours (quality-adjusted)*	*YBUS adjustment*
1979-2000	0.11	0.84	0.96	-0.02
1979-1990	0.55	0.65	1.20	0.21
1990-2000	-0.36	1.05	0.69	-0.28
1990-1995	-1.55	1.33	-0.22	0.01
1995-2000	0.83	0.78	1.61	-0.56

Note Total hours (both quality-adjusted and not quality-adjusted) are after making the YBUS adjustment.

Chart A.1

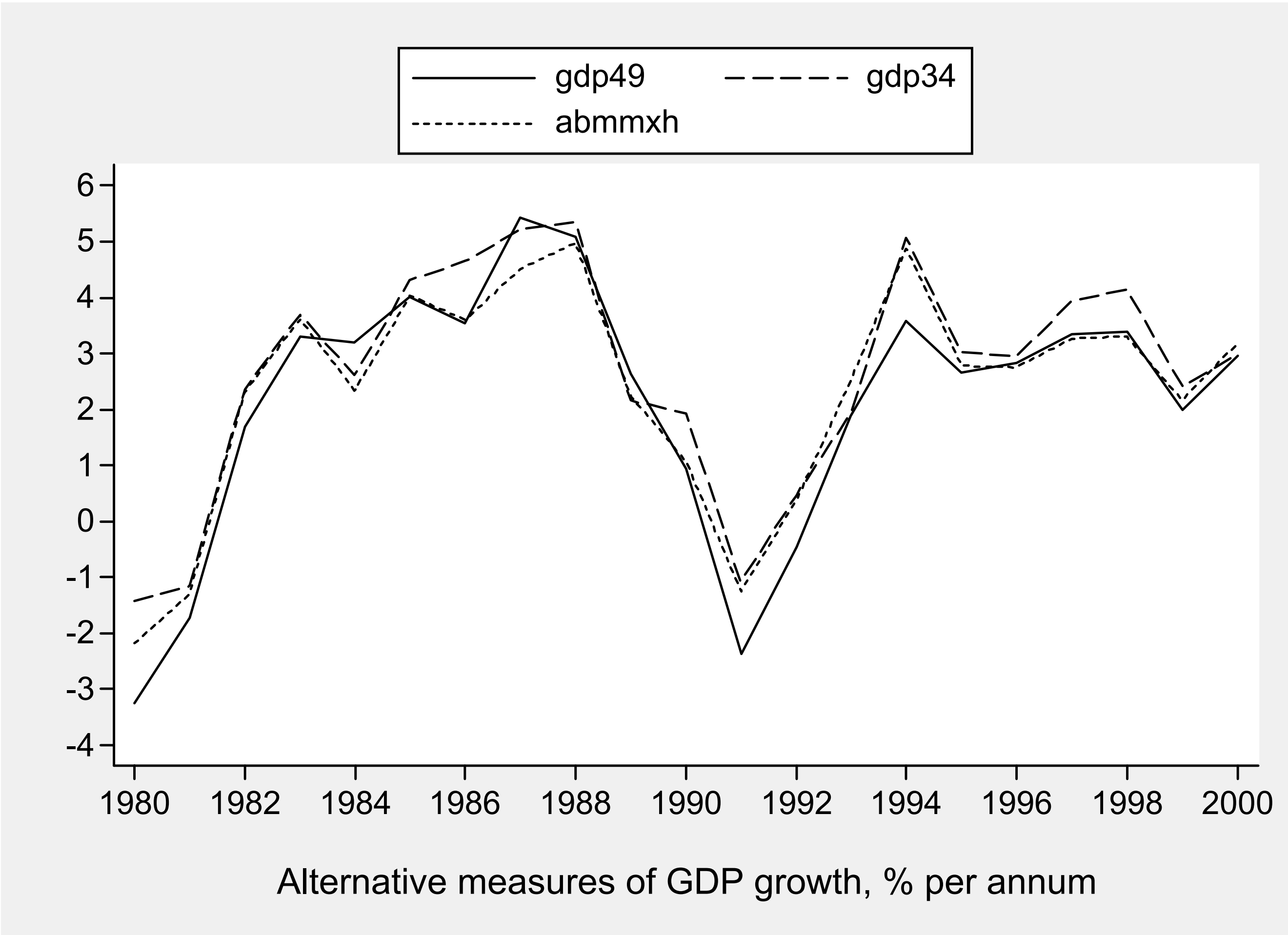


Chart A.2

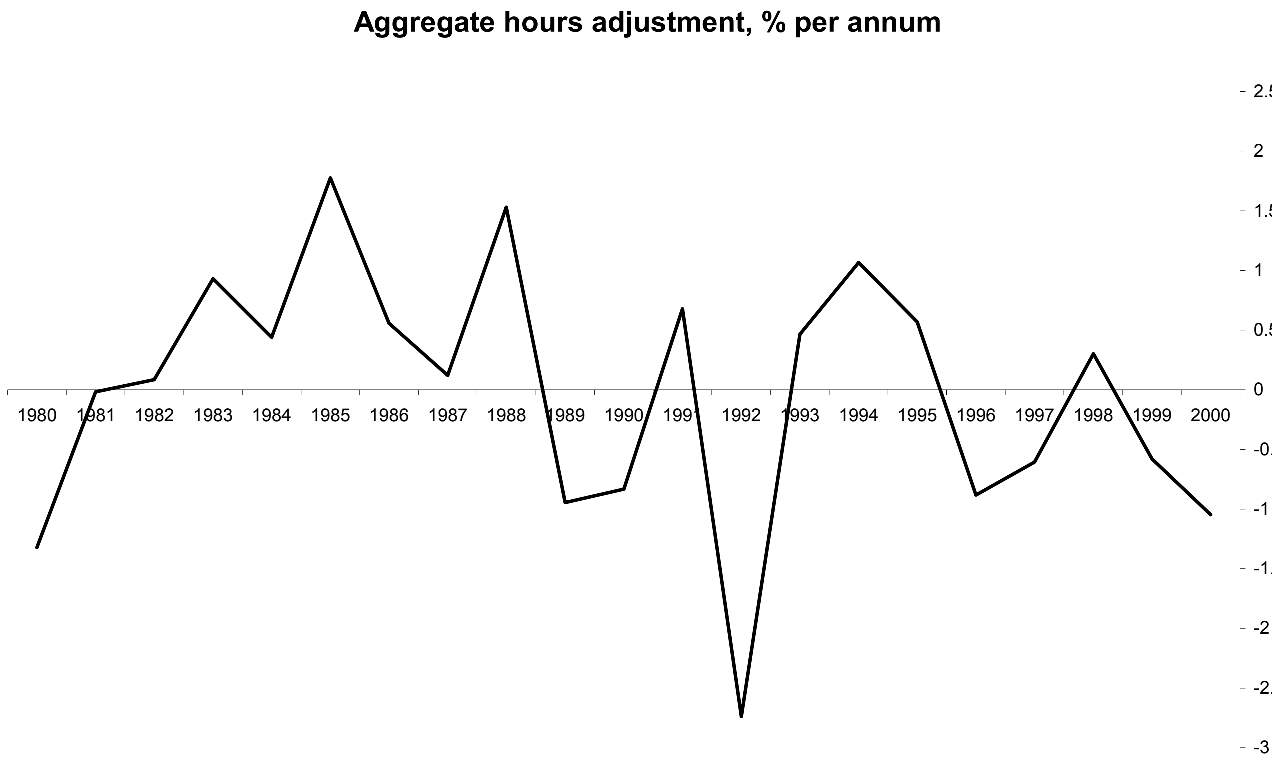
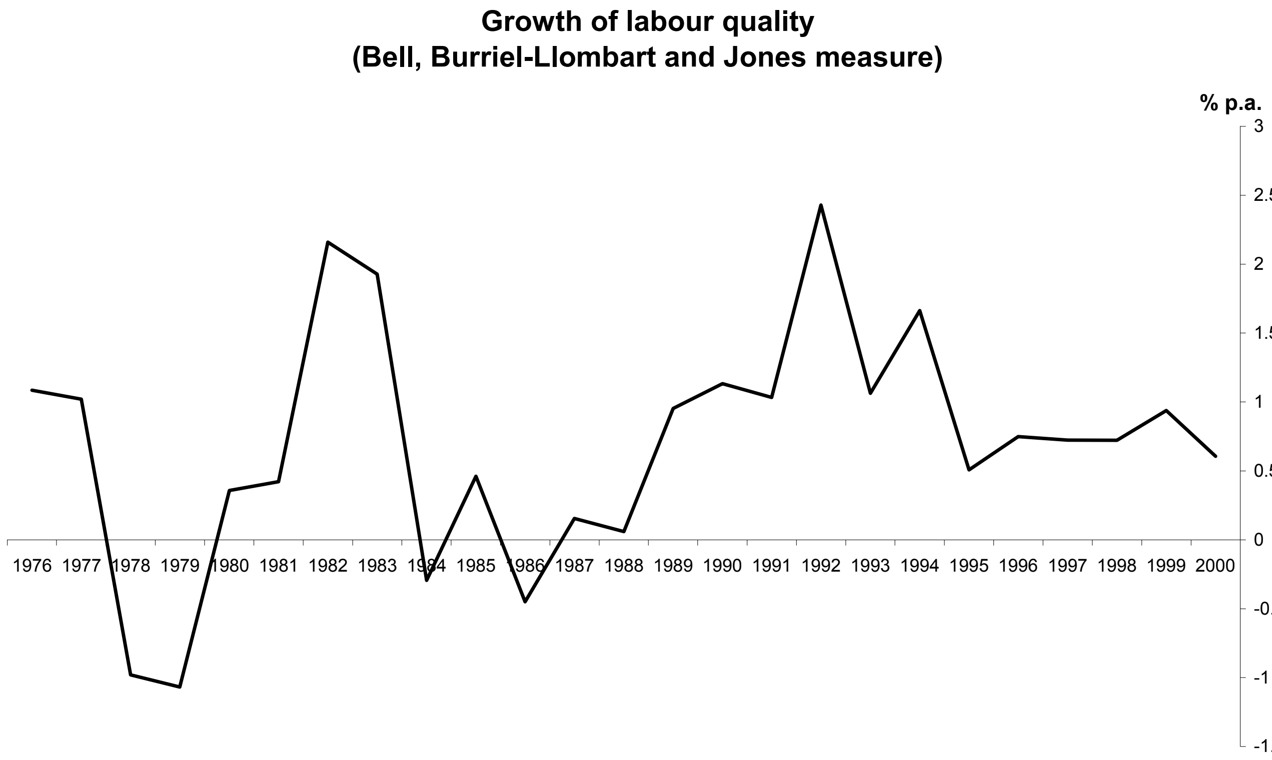


Chart A.3



Annex B The relationship between aggregate and industry-level labour productivity growth

B.1 Introduction

At the aggregate level, the growth of labour productivity can be expressed as the sum of two terms: (1) capital deepening, ie the growth rate of capital per hour worked times the share of capital in output and (2) the growth rate of aggregate TFP. The growth rate of aggregate TFP is a weighted sum of the TFP growth rates in each industry — Domar aggregation; the Domar weights are the ratios of gross output to aggregate value added (Domar (1961); Jorgenson *et al* (1987)). This suggests that it should be possible to derive an analogous decomposition of the capital deepening term. It turns out that aggregate capital deepening is a Domar aggregate of industry capital deepening plus a reallocation term. The latter measure the effect of shifts of labour towards more capital intensive sectors.

B.2 A decomposition of capital deepening

At the whole-economy level, the accounting relationship states that aggregate value added (GDP) equals the returns to labour and capital:

$$p_V V = wL + p_K K$$

where V is aggregate real value added (GDP), L is aggregate labour, K is aggregate capital, p_V is the aggregate price level (GDP deflator), p_K is the rental price of capital and w is the wage. For simplicity, we assume only one type of capital and one type of labour and that input prices are equalised by competition across industries.(26) Assuming many types of capital and labour would complicate the notation without adding much, provided that there was a common price for each type.

At the aggregate level, applying the usual growth accounting equation, the growth of aggregate labour productivity (ALP) is(27)

$$\hat{V} - \hat{L} = s_K(\hat{K} - \hat{L}) + \mu \qquad \textbf{(B.1)}$$

where μ is the Solow residual and s_K is the aggregate share of capital:

$$s_K = \frac{\sum_{i=1}^{n} p_K K_i}{p_V V}$$

Equation **(B.1)** can be taken as an implicit definition of the aggregate TFP growth rate. On the assumption that the price of a given input is the same in all industries, it can be shown that the Solow residual as defined by equation **(B.1)** can be related to sectoral TFP growth by Domar aggregation (Jorgenson *et al* (1987)):

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(26) See Jorgenson, Gollop and Fraumeni (1987) for the more general case where the price of a given input may differ across industries. Further extensions to allow for imperfect competition and variable utilisation of inputs are in Basu, Fernald and Shapiro (2001).

(27) This next equation assumes that input prices are equalised across industries.

$$\mu = \sum_{i=1}^{n} \left(\frac{p_i Y_i}{p_V V} \right) \cdot \mu_i = \sum_{i=1}^{n} d_i \cdot \mu_i \qquad \textbf{(B.2)}$$

where *n* is the number of industries, Y_i is gross output of industry *i*, p_i the corresponding price, μ_i is TFP growth in industry *i*, and $d_i \equiv p_i Y_i / p_V V$ are the Domar weights. In Section B.7, we refer to the measure implicitly defined by **(B.1)** as the Solow residual, the 'top-down' measure of TFP growth; the right-hand side of equation **(B.2)** gives the 'bottom-up' measure. We can compare the two measures to see how far reality deviates from the assumption that input prices are equalised across industries.

Assuming that the assumption holds, at least approximately, we can conclude that ALP growth is determined by two factors: (1) capital deepening, $s_K(\hat{K} - \hat{L})$, and (2) TFP growth μ.. It is then natural to ask whether a similar decomposition can be derived for the other element in ALP growth, aggregate capital deepening. The answer is yes. We first derive sectoral decompositions for capital and labour growth.

Capital growth:

$$\hat{K} = \sum_{i=1}^{n} \left(\frac{p_K K_i}{\sum_{i=1}^{n} p_K K_i} \right) \cdot \hat{K}_i = \sum_{i=1}^{n} \left(\frac{p_K K_i}{p_i Y_i} \right) \cdot \left(\frac{p_i Y_i}{p_V V} \right) \cdot \left(\frac{p_V V}{\sum_{i=1}^{n} p_K K_i} \right) \cdot \hat{K}_i$$

$$= \sum_{i=1}^{n} s_{iK} \cdot s_K^{-1} \cdot d_i \cdot \hat{K}_i$$

Labour growth:

$$\hat{L} = \sum_{i=1}^{n} \left(\frac{L_i}{L} \right) \cdot \hat{L}_i = \sum_{i=1}^{n} \left(\frac{w L_i}{p_i Y_i} \right) \cdot \left(\frac{p_i Y_i}{p_V V} \right) \cdot \left(\frac{p_V V}{w L} \right) \hat{L}_i$$

$$= \sum_{i=1}^{n} s_{iL} \cdot s_L^{-1} \cdot d_i \cdot \hat{L}_i$$

Therefore the contribution of the growth of capital intensity, capital deepening, is

$$s_K(\hat{K} - \hat{L}) = s_K \sum_{i=1}^{n} s_{iK} \cdot s_K^{-1} \cdot d_i \cdot \hat{K}_i - s_K \sum_{i=1}^{n} s_{iL} \cdot s_L^{-1} \cdot d_i \cdot \hat{L}_i$$

$$= \sum_{i=1}^{n} d_i \cdot s_{iK}(\hat{K}_i - \hat{L}_i) + \sum_{i=1}^{n} d_i \cdot (s_{iK} - s_{iL} \cdot s_K \cdot s_L^{-1}) \hat{L}_i$$

The second summation here is a reallocation effect: the effect of a shift in employment towards or away from industries with a high level of capital intensity. Note that if labour input is rising at the same rate λ in all industries, the reallocation effect is zero:

$$\lambda \sum_{i=1}^{n} d_i \cdot (s_{iK} - s_{iL} \cdot s_K \cdot s_L^{-1}) = 0$$

Hence we can rewrite the reallocation effect as:

$$\sum_{i=1}^{n} d_i \cdot s_{iL} \cdot \left(\frac{s_{iK}}{s_{iL}} - \frac{s_K}{s_L} \right) \cdot (\hat{L}_i - \hat{L})$$

The reallocation effect is positive if:

$$\frac{s_{iK}}{s_{iL}} > \frac{s_K}{s_L} \text{ or } \frac{K_i}{L_i} > \frac{K}{L}$$

That is, aggregate capital intensity is rising faster if labour input is growing more rapidly in more capital intensive industries. The reallocation term would be zero if the ratio of capital to labour were the same in every industry. And the reallocation effect can only be non-zero when labour input is growing more rapidly in some sectors than in others. Note too that the reallocation term is not necessarily zero even if capital intensity is rising at the same rate in all industries. To prove this, let the common growth rate of capital intensity be $\hat{k} = \hat{K}_i - \hat{L}_i$. Then the sectoral capital deepening term is:

$$\hat{k} \sum_{i=1}^{n} d_i s_{iK} = \hat{k} \sum_{i=1}^{n} \frac{p_i Y_i}{p_V V} \frac{p_K K_i}{p_i Y_i} = \hat{k} \sum_{i=1}^{n} \frac{p_K K_i}{p_V V} = s_K \hat{k}$$

But the reallocation term is unaffected.

B.3 Summary

The contribution of capital deepening is composed of two parts. The first is the weighted sum of the sectoral contributions, where the weights are the same Domar weights used to aggregate the sectoral TFP growth rates. The second part measures the reallocation of labour towards or away from more capital intensive sectors. In words,

Aggregate capital deepening = Domar-weighted sum of sectoral capital deepening + reallocation

The reallocation effect is positive if labour input is growing more rapidly in more capital intensive industries. The reallocation term would be zero if the capital-labour ratio were the same in every industry.

In summary, our decomposition of ALP growth is:

$$\hat{V} - \hat{L} = s_K (\hat{K} - \hat{L}) + \mu$$

$$= \sum_{i=1}^{n} d_i \cdot s_{iK} (\hat{K}_i - \hat{L}_i) + \sum_{i=1}^{n} d_i \cdot (s_{iK} - s_{iL} \cdot s_K \cdot s_L^{-1})(\hat{L}_i - \hat{L}) + \sum_{i=1}^{n} d_i \cdot \mu_i$$

where the first two summations on the right-hand side measure capital deepening and the third measures TFP growth.

Annex C Structural change and aggregate labour productivity growth

In Annex B, we showed how to decompose the growth of aggregate labour productivity on the input side. Here we derive a simple decomposition on the output side. This allows us to divide aggregate ALP growth into growth stemming from ALP growth in individual industries and growth stemming from the reallocation of labour across industries, or in other words from structural change.

Let the ratio of nominal value added in industry *i* to aggregate value added (nominal GDP) be:

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

where p_i^V is the price of value added in sector *i*. Let the ratio of hours worked in industry *i* to aggregate hours worked be:

$$r_i = L_i / L, \quad \sum_{i=1}^n r_i = 1$$

Define ALP in industry *i* as:

$$q_i = V_i / L_i$$

and at the aggregate level define it as:

$$q = V / L$$

where $L = \sum_{i=1}^n L_i$. The nominal levels of productivity in industry *i* and for the whole economy are $p_i^V q_i$ and $p^V q$ respectively, where p^V is the aggregate price of value added (the GDP deflator).

The growth of aggregate real value added can be derived as a Divisia index of value added growth in the individual industries:

$$\hat{V} = \sum_{i=1}^n s_i \hat{V}_i$$

The relationship between the growth of labour productivity at the aggregate and industry level can now be derived as follows.

$$\hat{q} = \hat{V} - \hat{L}$$

$$= \sum s_i \hat{V}_i - \sum r_i \hat{L}_i$$

$$= \sum s_i (\hat{V}_i - \hat{L}_i) + \sum (s_i - r_i) \hat{L}_i$$

$$= \sum s_i \hat{q}_i + \sum (s_i - r_i)(\hat{L}_i - \hat{L})$$

$$= \sum s_i \hat{q}_i + \sum r_i \left(\frac{p_i^V V_i / L_i}{\sum p_i^V V_i / \sum L_i} - 1 \right) (\hat{L}_i - \hat{L})$$

$$= \sum s_i \hat{q}_i + \sum r_i \left(\frac{p_i^V q_i}{p^V q} - 1 \right) (\hat{L}_i - \hat{L})$$

The first term measures the impact of productivity growth in the individual industries. The second term is the reallocation effect and measures the extent to which hours worked are shifting towards industries with a high *level* of labour productivity. The reallocation effect would be zero *either* if the productivity level (in value terms) is the same in all sectors *or* if the growth rate of hours worked is the same in all industries.

Annex D GDP growth from the output and expenditure sides

We can measure GDP from either the output or the expenditure side. That is to say, in nominal terms GDP is either a sum of value added in each industry or it is a sum of final expenditures net of imports (final outputs), and these two magnitudes are the same. We obviously want the growth rate of real GDP to be the same, whether we use the output or the expenditure approach. The purpose of this annex is to show that, in the absence of errors, omissions or inconsistencies, the two measures of growth will yield the same answer, provided that on the output side we measure GDP by double deflated value added. This result is well known, see eg the volume setting out SNA93, Commission of the European Communities *et al* (1993), where however no proof is given; hence for completeness one is given here.

D.1 Accounting relationships

We start by defining some accounting relationships at the industry level. For simplicity we assume a closed economy but the argument is easily extended to an open one. Value added in current prices in the *i*th industry is:

$$p_{iV}V_i = p_iY_i - \sum_{j=1}^{n} p_jX_{ij}, \qquad i = 1,...,n \qquad \textbf{(D.1)}$$

where Y_i is real gross output, X_{ij} is the real quantity of output supplied to industry *i* by industry *j*, and p_i is the price of industry *i*'s output. Here we have split up nominal value added conceptually into the product of the price of value added (p_{iV}) and the quantity (V_i).

A Divisia index of the growth of real value added is then given by:

$$\hat{V}_i = \left(\frac{p_iY_i}{p_{iV}V_i}\right)\hat{Y}_i - \sum_j \left(\frac{p_jX_{ij}}{p_{iV}V_i}\right)\hat{X}_{ij}, \quad i = 1,...,n \qquad \textbf{(D.2)}$$

Here a 'hat' denotes a growth rate or more precisely a logarithmic derivative with respect to time, eg $\hat{V}_i = d\log V_i / dt$. Equation **(D.2)** gives the double deflated growth rate of value added.

Gross output can be sold either to final demand (E_i) or for intermediate use:

$$Y_i = E_i + \sum_j X_{ji}, \qquad i = 1,...,n \qquad \textbf{(D.3)}$$

We define GDP from the output side, GDP(O), as aggregate nominal value added:

$$p_VV = \sum_{i=1}^{n} p_{iV}V_i \qquad \textbf{(D.4)}$$

where *V* is aggregate real value added and p_V is the price of aggregate value added (ie the price of GDP).

Turing to the expenditure side, GDP(E) in current prices is

$$p_E E = \sum_{i=1}^{n} p_i E_i \qquad \textbf{(D.5)}$$

where E is real GDP from the expenditure side and p_E is the corresponding price index. The first task is to check that GDP(O) equals GDP(E) in current prices.[(28)] Solving **(D.3)** for E_i, multiplying by p_i and summing:

$$\begin{aligned}\sum_i p_i E_i &= \sum_i p_i Y_i - \sum_i p_i \sum_j X_{ij} = \sum_i p_i Y_i - \sum_i \sum_j p_j X_{ij} \\ &= \sum_i \left[p_i Y_i - \sum_j p_j X_{ij} \right] = \sum_i p_{iV} V_i\end{aligned} \qquad \textbf{(D.6)}$$

Hence:

$$p_V V = p_E E \qquad \textbf{(D.7)}$$

D.2 The growth rate of real GDP

In continuous time, the growth of nominal value added $(p_V V)$ is the growth of the price of value added plus the growth of the quantity of value added: $\hat{p}_V + \hat{V}$, and this must equal the growth rate of the right-hand side of **(D.4)**. By totally differentiating **(D.4)** with respect to time, and collecting terms, we can define Divisia price and quantity indices of value added as:

$$\hat{p}_V = \sum_{i=1}^{n} s_i \hat{p}_{iV}$$

$$\hat{V} = \sum_{i=1}^{n} s_i \hat{V}_i$$

where the s_i are the (observable) shares of each industry in aggregate nominal value added:

$$s_i = \frac{p_{iV} V_i}{p_V V}$$

The growth rates of real GDP and of the price of GDP from the expenditure side are given by

$$\begin{aligned}\hat{p}_E &= \sum_{i=1}^{n} w_i \hat{p}_i \\ \hat{E} &= \sum_{i=1}^{n} w_i \hat{E}_i\end{aligned} \qquad \textbf{(D.8)}$$

where the w_i are the shares of each type of final output in the total:

(28) Typically, output is measured at basic prices and expenditure at purchasers' prices, but we are abstracting from taxes on expenditure here.

$$w_i = \frac{p_i E_i}{p_E E}$$

We now show that $\hat{E} = \hat{V}$ and consequently, from equation **(D.7)**, that $\hat{p}_E = \hat{p}_V$. First note that the growth of any component of final demand can be written (by differentiating **(D.3)** logarithmically with respect to time) as:

$$\hat{E}_i = \left(\frac{Y_i}{E_i}\right)\hat{Y}_i - \sum_j \left(\frac{X_{ji}}{E_i}\right)\hat{X}_{ji}, \qquad i = 1,\ldots,n \qquad \textbf{(D.9)}$$

Plugging this into the definition of the growth rate of GDP(E), equation **(D.8)**:

$$\hat{E} = \sum_i \left(\frac{p_i E_i}{p_E E}\right)\hat{E}_i = \sum_i \left(\frac{p_i E_i}{p_V V}\right)\hat{E}_i \qquad \text{(using (\textbf{D.7}))}$$

$$= \sum_i \left(\frac{p_i Y_i}{p_V V}\right)\hat{Y}_i - \left(\frac{1}{p_V V}\right)\sum_i p_i E_i \sum_j \left(\frac{X_{ji}}{E_i}\right)\hat{X}_{ji} \qquad \text{(using (\textbf{D.9}))}$$

$$= \sum_i \left(\frac{p_i Y_i}{p_V V}\right)\hat{Y}_i - \left(\frac{1}{p_V V}\right)\sum_i \sum_j p_i X_{ji}\hat{X}_{ji}$$

$$= \sum_i \left(\frac{p_i Y_i}{p_V V}\right)\hat{Y}_i - \left(\frac{1}{p_V V}\right)\sum_j \sum_i p_j X_{ij}\hat{X}_{ij} \qquad \text{(interchanging summation indices)}$$

$$= \sum_i \left(\frac{p_{iV} V_i}{p_V V}\right)\left(\frac{p_i Y_i}{p_{iV} V_i}\right)\hat{Y}_i - \left(\frac{1}{p_V V}\right)\sum_i \sum_j p_j X_{ij}\hat{X}_{ij} \qquad \text{(interchanging order of summation)}$$

$$= \sum_i \left(\frac{p_{iV} V_i}{p_V V}\right)\left(\frac{p_i Y_i}{p_{iV} V_i}\right)\hat{Y}_i - \sum_i \left(\frac{p_{iV} V_i}{p_V V}\right)\sum_j \left(\frac{p_j X_{ij}}{p_{iV} V_i}\right)\hat{X}_{ij}$$

$$= \sum_i \left(\frac{p_{iV} V_i}{p_V V}\right)\left[\left(\frac{p_i Y_i}{p_{iV} V_i}\right)\hat{Y}_i - \sum_j \left(\frac{p_j X_{ij}}{p_{iV} V_i}\right)\hat{X}_{ij}\right]$$

$$= \sum_i \left(\frac{p_{iV} V_i}{p_V V}\right)\hat{V}_i \qquad \text{(using (\textbf{D.2}))}$$

$$= \hat{V}$$

Hence also from **(D.7)**

$$\hat{p}_E = \hat{p}_V$$

We can therefore pick a common reference period in which we set $p_V = p_E = 1$. Hence in the reference period $V = E$, from **(D.7)**. But since the growth rates are equal, it follows that $p_V = p_E$ and $V = E$ in all periods, not just the reference period.

D.3 ONS methodology for measuring real GDP growth

In practice the ONS does not use double deflation to measure real value added at the industry level. Instead, they use the growth of real gross output as a proxy (this is similar to though not identical to single deflation of value added). They measure GDP growth as a weighted average of the growth of *real gross output* in the individual industries, using *nominal value added* as the weights. The ONS accept that real value added growth is the conceptually correct measure, but they employ real gross output as a proxy for practical reasons.(29) It is clear from equation **(D.2)** that real gross output and real value added do not in general grow at the same rate. In fact, they will only do so if real gross output is growing at the same rate as real intermediate input. So when real value added is proxied by real gross output, the growth of GDP(O) will not in general equal that of GDP(E) even in the absence of errors, omissions and inconsistencies in the statistics, at least not without some adjustment.

If there are systematic divergences between the growth rates of real gross output and real value added, does this bias the ONS's estimate of real GDP growth? The answer is no. The reason is that, on an annual basis, real GDP growth is estimated ultimately from the expenditure side (GDP(E)), not the output side (GDP(O)). In the short run, for quarterly growth rates, the output estimates are considered the most reliable indicators, but in the long run, the quarterly growth rate are benchmarked to the annual growth rates and the latter are based on the growth of GDP(E). So for annual growth rates, if the output estimate differs from the expenditure estimate, normally it is the output estimate that is adjusted (Office for National Statistics (1998)).(30)

The reasons for preferring GDP(E) over GDP(O) are clear. Aggregate consumption and aggregate investment constitute the great bulk of GDP. Nominal expenditure on these is reasonably well-measured at a fairly detailed level. And price indices exist to deflate most of the components. To estimate GDP(O) on an equally satisfactory basis, the ONS would in principle need to estimate double-deflated value added for each industry. For this they would require annual input-output tables and price indices for all outputs and inputs. A large proportion of output is in the 'hard to measure' areas like finance and business services. Here true price indices frequently do not exist. This does not matter so much for GDP(E) since most of the 'hard to measure' output is intermediate and is therefore excluded by definition from final expenditure.(31) But it will matter a lot for GDP(O).

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(29) Except in agriculture and electricity supply.

(30) The nominal *level* of GDP is influenced by evidence from both the output and the expenditure sides, since it is the end product of the balancing process used to derive the input-output supply and use tables.

(31) A small part appears in exports and imports.

Given the preference for GDP(E), the ONS therefore adjusts the growth rate of GDP(O) to conform with that of GDP(E). But the adjustment does not fall equally on all industries. In fact, neither the production sector nor the government sector is adjusted. So currently (though there are plans to change this) the whole of the adjustment falls on private services (Office for National Statistics (2000)). The size of the adjustment is not published.

We experimented with a number of different ways of deriving growth rates of real gross output and real value added, while accepting the ONS view that the expenditure side estimate is the most reliable measure of annual GDP growth. The main consideration was whether, by aggregating over our own measures of real value added growth at the industry level, we could get close to the official estimate of GDP growth. We found that we could not. We therefore decided to employ the ONS measures of industry level output growth as the best available estimate of real value added growth (even though they are measured as growth rates of real gross output). Our estimates of the growth of real gross output at the industry level are then derived by solving equation (**D.2)**.

A full resolution of these difficulties will require further research. Note that they affect not just our results but are relevant for anyone using UK industry data.

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