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WHAT HAPPENED TO THE KNOWLEDGE ECONOMY? ICT, INTANGIBLE INVESTMENT, AND BRITAIN'S PRODUCTIVITY RECORD REVISITED

BY MAURO GIORGIO MARRANO

HM Treasury

JONATHAN HASKEL*

Imperial College Business School, CEPR, and IZA

AND

GAVIN WALLIS

HM Treasury and University College London

Despite the apparent importance of the "knowledge economy," U.K. macroeconomic performance appears unaffected: investment rates are flat, and productivity has slowed. We investigate whether measurement issues might account for this puzzle. The standard National Accounts treatment of most spending on "knowledge" or "intangible" assets is as intermediate consumption. Thus they do not count as either GDP or investment. We ask how treating such spending as investment affects some key macro variables, namely, market sector gross value added (MGVA), business investment, capital and labor shares, growth in labor and total factor productivity (TFP), and capital deepening. We find: (a) MGVA was understated by about 6 percent in 1970 and 13 percent in 2004; (b) instead of the business investment/MGVA ratio falling since 1970 it has been rising; (c) instead of the labor share being flat since 1970 it has been falling; (d) growth in labor productivity and capital deepening has been understated and growth in TFP overstated; and (e) TFP growth has not slowed since 1990 but has been accelerating.

1. INTRODUCTION

According to common debate, the "Knowledge Economy" is all around us. Think tanks and commentators argue that developed countries have no future in a globalized economy unless they specialize in knowledge-intensive activities. Whole goods and occupations, many based on ICT (Information and Communication Technology), that were almost unheard of even five years ago, proliferate

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*Correspondence to: Jonathan Haskel, Imperial College Business School, Tanaka Building, South Kensington Campus, London SW7 2AZ, UK (j.haskel@ic.ac.uk).

(think of iPods, SatNavs and Search Engine Programmers). Pressure groups extol both the virtues and contribution of the U.K. design and creative industries.

Where has all this shown up in U.K. economic performance? The ratio of nominal investment to nominal GDP has stayed more or less where it was since the 1950s, which is hard to square with the perception that firms are investing in knowledge assets in the teeth of a technological revolution. The share of profits in GDP has also remained quite stable, so if firms are investing more, this is not being reflected in additional profits. U.K. productivity performance over the 1990s remains a puzzle. According to existing studies U.K. productivity growth deteriorated after 1995.[1] This is in contrast to the U.S. experience, where there was a well-documented productivity acceleration associated with the ICT investment boom.[2] The U.K. also experienced an ICT investment boom in the late 1990s, so why the productivity slowdown?

Two possible answers could explain these puzzles. The first is that the investment in and/or the impact of the knowledge economy is in fact much less than popular discussion would suggest. The second is that the impact is hidden by measurement problems.

This paper examines the second view for the U.K., building on previous work by Oulton and Srinivasan (2003a), Basu *et al.* (2003) and Oulton and Srinivasan (2005).[3] Work by Oulton and Srinivasan (2003a, 2005) examined a number of measurement issues. They incorporated software into output; measured capital as capital services, not capital assets; built the capital data from a disaggregated level; and measured labor quality rather than just hours. Basu *et al.* (2003) specifically looked at whether ICT measurement could explain missing U.K. productivity growth in the 1990s. The productivity growth slowdown still remained in all these studies and the authors argued that it was likely due to unmeasured investment in organizational capital. We build on this work by using all these elements in our data but also adding intangible assets (where we think of spending on intangible assets as describing spending on a broad range of knowledge-type assets, such as R&D, software, organizational capital, etc; details below). Since one of our assets is organizational capital, given the previous work, it is of interest to see if incorporating this can change the picture of U.K. productivity performance in the late 1990s.

Whilst there have been some studies for the U.S. on the impact of intangibles on GDP, such as Corrado, Hulten, and Sichel (2005, 2006) and Nakamura (1999, 2001, 2003) there has not been anything for the U.K. We refer to Corrado, Hulten and Sichel as CHS from here onwards. In this paper we follow the central observation in these U.S. papers that in practice, spending on most knowledge assets is, in accounting terms, like spending on other intangible assets, such as software.

[1]O'Mahony and de Boer (2002), Oulton and Srinivasan (2003a) and Oulton and Srinivasan (2005).

[2]Oliner and Sichel (2000), Jorgenson and Stiroh (2000a, 2000b), Stiroh (2002) and Gordon (2003).

[3]The measurement problems addressed in this paper are not problems with the existing U.K. National Accounts, which continue to be compiled based on internationally agreed definitions. The focus of this paper relates to what the impact would be of extending the agreed definition of capital assets to include a broader range of intangible assets. As such, the output and productivity estimates should not be regarded as corrections to existing National Accounts rather as adjustments to National Accounts data for the wider definition of intangible capital we adopt.

Spending on *tangible* assets has a long measurement tradition; it is part of investment and therefore also part of GDP. However, spending on *intangible* assets, with a few exceptions, is treated as intermediate expenditure. In constructing GDP therefore, spending on R&D for example, is treated like spending on electricity, i.e. it is assumed not to be investment and so produces no asset at the end of the period. As an intermediate it does not appear in either investment or GDP data.[4] The upcoming revision to the System of National Accounts (SNA) will include a recommendation to capitalize R&D, but this is only one type of knowledge asset.

This paper tries to answer the following question: what are the consequences for a range of macroeconomic variables, including productivity, of treating spending on intangibles as investment rather than as intermediate expenditure? We do this as follows. First, following the approach of CHS, we assemble data on spending for a range of intangible assets. These are wider than the usual R&D and software and include design, spending on reputation, and human capital. Using these data we analyze the relative quantities of different types of expenditure and how they have changed over time. We believe this question of interest since we have little information on whether expenditure on software is more or less than expenditure on design, training, etc. and also on how such expenditure has changed over time.

Second, we look at the consequences for overall business investment and market sector gross value added, henceforth MGVA.[5] We believe this to be of interest since some have conjectured that ignoring intangibles explains why the traditionally-measured (i.e. focused on tangible capital) business nominal investment to MGVA ratio has remained so flat in the U.K. despite the perception that the underlying conditions for investment have been so favorable in recent years. We also think it of importance if the level of MGVA has been systematically understated.

Third, we look at the consequences for market sector labor productivity. Since the level of MGVA rises, the level of labor productivity rises. But labor productivity growth will only rise if the level of MGVA rises increasingly over the period; so the answer to this question is not as clear. The reason why labor productivity rises is that there is an extra input in the economy, namely an intangible capital stock, in addition to the tangible capital stock. Thus we think a question of interest is: how much has the change in the intangible capital stock contributed to productivity growth along with other inputs? The systematic method of answering this question is via growth accounting and so we extend previous U.K. growth accounting studies by including intangible capital. Note that not only has MGVA and input changed, but the factor shares will have changed as well, since the extra MGVA due to intangibles is matched on the income side by extra income to capital.

[4]Michael Mandel's (2006) *Business Week* article for example describes the treatment of Apple by national income accountants as "they count each iPod twice: when it arrives from China, and when it sells. That, in effect, reduces Apple—one of the world's greatest innovators—to a reseller of imported goods."

[5]Owing to the difficulty of measuring productivity and intangible spending in the government sector we focus on the market sector rather than the whole economy. Hence our estimates are based on market sector GVA rather than GDP.

It is worth pointing out that we present estimates of MGVA, labor productivity growth and growth accounting both with and without intangibles. Thus the reader uninterested in intangible assets can therefore obtain, we hope, some interesting data from the paper. In particular, all our estimates are consistent with the 2006 *Blue Book* and give data up to 2004.[6]

Our main findings are as follows. First, nominal business investment in intangible assets in 2004 is about equal to nominal business investment in tangibles (each is around 15 percent of MGVA). Of that intangible investment, around 50 percent of the total is on economic competencies (investment in reputation, human and organizational capital), 35 percent on innovative property (mainly scientific and non-scientific R&D and design), and 15 percent on computerized information (mainly software). Since 1970, nominal investment in intangibles has grown from about 6 percent of nominal MGVA to about 15 percent. Interestingly, the patterns of growth look remarkably like those in the U.S., although the U.K. has a bit less R&D investment and a bit more investment in design.

Second, accounting for intangibles makes a considerable difference to measured MGVA and the share of that output accounted for by investment and payments to capital and labor. The level of nominal MGVA rises by about 13 percent in 2004.[7] The share of nominal investment and payments to capital also rise.

Third, accounting for intangibles affects labor productivity growth (LPG) and total factor productivity growth (TFPG) in the market sector. Without intangibles, we confirm previous work that LPG and TFPG both slow down between 1990–95 and 1995–2000.[8] We also document a further slight slowdown in 2000–04 in LPG but a speeding up in TFPG. With intangibles, the picture changes interestingly. First, both LPG and TFPG accelerate between 1990–95 and 1995–2000, suggesting that the U.K. economy was building sufficient intangibles during that period such that their omission affected the productivity statistics in important ways. Second, even with intangibles, the post-2000 slowdown in LPG still remains.

There are of course a host of measurement problems in estimating investment in intangible assets. We have therefore assessed the robustness of our findings to different measurement methods and assumptions. In summary, our major findings (on the shares of nominal investment and wages and LPG and TFPG) are robust to changes in these measurement methods and assumptions.

The outline of the rest of this paper is as follows. In the next section, we set out how intangibles affect MGVA and growth. Section 3 describes the data used to try to measure the impact of treating intangible spending as investment (in our case the impact on business investment and market sector gross value added), and Section 4 outlines our growth accounting approach. Section 5 presents our growth accounting results and Section 6 concludes.

[6]The *Blue Book* is the annual publication of a balanced set of U.K. National Accounts.

[7]This is less than the share of intangible investment in MGVA because some intangible investment (some software, mineral exploration and copyright costs) is already included in MGVA (about 2 percent). It is slightly more than the figure in Giorgio Marrano and Haskel (2006), but that reported intangible investment as a proportion of GDP.

[8]O'Mahony and de Boer (2002), Oulton and Srinivasan (2003a) and Oulton and Srinivasan (2005).

2. Model

We follow CHS in setting out the following model. Suppose there are three goods produced, a consumption good, with real output volume C_t and price P_t^C, a tangible investment good, I_t with price P_t^I, and an intangible investment good N_t with price P_t^N, where the t subscript denotes time.

2.1. *Intangibles Treated as Intermediates*

Suppose first that the intangible investment good is regarded as an intermediate. The tangible capital stock K_t is assumed to accumulate according to the perpetual inventory model

$$K_t = I_t + (1-\delta_K)K_{t-1} \tag{1}$$

with depreciation rate δ_K (assumed constant over time). Then we can write the production function for each sector and, assuming factors are paid their marginal product and the production function is homogenous of degree one, the money flows for each sector as follows:

(2) (a) Intangible sector: $N_t = F^N(L_{N,t}, K_{N,t}, t);\quad P_t^N N_t = P_t^L L_{N,t} + P_t^K K_{N,t}$

(b) Tangible sector: $I_t = F^I(L_{I,t}, K_{I,t}, N_{I,t}, t);\quad P_t^I I_t = P_t^L L_{I,t} + P_t^K K_{I,t} + P_t^N N_{I,t}$

(c) Consumption sector: $C_t = F^C(L_{C,t}, K_{C,t}, N_{C,t}, t);\quad P_t^C C_t = P_t^L L_{C,t} + P_t^K K_{C,t} + P_t^N N_{C,t}$

where the superscripts N, I, and C refer to the three sectors. So, for example, in equation (2a), the left-hand side production function in the intangible sector says that the output of intangibles is produced by labor in the sector and tangible capital in the sector. The right-hand side equation says that with factors paid their marginal products, the value of the intangibles produced equals the returns to labor and tangible capital used in that sector. Since intangibles are assumed to be intermediates, the production functions in equations (2b) and (2c) for the tangible and consumption sector show that the volume of intangible output is simply an input into the production of tangible and consumption goods (we omit other intermediates which similarly net out). Since they are intermediate inputs, intangibles do not appear in total output which can be written[9]

$$P_t^{Q'} Q_t' = P_t^C C_t + P_t^I I_t = P_t^L L_t + P_t^K K_t \tag{3}$$

[9]This equation shows the equality of GDP on the expenditure side (consumption plus investment) and income side (rewards to the non-intermediate factors labor and capital). On the production side, value added in the C, I and N sectors are, respectively, the value of consumption less payments to intangibles used in the consumption sector (the intermediate good), the value of investment less payments to intangibles in the investment sector, and the value of intangibles. Adding these up gives economy value added as the value of consumption plus investment, which with factors being paid their marginal product is equal to wages and capital payments in all three sectors.

where the prime ′ indicates the case where intangibles are treated as intermediate expenditure and $L = L_N + L_I + L_C$ and $K = K_N + K_I + K_C$.

2.2. *Intangibles Treated as Capital*

Now suppose that the intangible investment good is treated as capital. Then as well as the tangible capital accumulation, intangible capital stock, R_t also accumulates according to

(4) $$R_t = N_t + (1-\delta_R) R_{t-1}$$

where R depreciates at rate δ_R. The production function and money flows for each sector can be written

(5) (a) Intangible sector: $N_t = F^N(L_{N,t}, K_{N,t}, R_{N,t}, t)$; $P_t^N N_t = P_t^L L_{N,t} + P_t^K K_{N,t} + P_t^R R_{N,t}$

(b) Tangible sector: $I_t = F^I(L_{I,t}, K_{I,t}, R_{I,t}, t)$; $P_t^I I_t = P_t^L L_{I,t} + P_t^K K_{I,t} + P_t^R R_{I,t}$

(c) Consumption sector: $C_t = F^C(L_{C,t}, K_{C,t}, R_{C,t}, t)$; $P_t^C C_t = P_t^L L_{C,t} + P_t^K K_{C,t} + P_t^R R_{C,t}$

Note that in contrast to equation (2) the stock of intangible capital, R_t, rather than intangible output, appears as an input in the production functions, and the payments to that stock, $P_t^R R_t$, appears in the payment equations rather than payment for the entire used up intermediate output. The corresponding output identity now includes the value of output of the intangible good on the production side, $P_t^N N_t$, and the payments to the stock of intangibles, $P_t^R R_t$, on the income side

(6) $$P_t^Q Q_t = P_t^C C_t + P_t^I I_t + P_t^N N_t = P_t^L L_t + P_t^K K_t + P_t^R R_t$$

where the total output of the intangible good $N = N_N + N_I + N_C$ and the intangible stock is $R = R_N + R_I + R_C$.

Thus the following points are worth noting. First, output is increased under the second approach from $P_t^{Q'} Q_t'$ to $P_t^Q Q_t$. Second, the investment rate increases from $P_t^I I_t / P_t^{Q'} Q_t'$ to $(P_t^I I_t + P_t^N N_t)/P_t^Q Q_t$ and the labor share falls from $P_t^L L_t / P_t^{Q'} Q_t'$ to $P_t^L L_t / P_t^Q Q_t$, where the labor share is the proportion of total income paid to labor.

Finally, to understand the implications for TFPG, we may write a growth accounting relation from the production functions above:

(7) $$(a) \quad \Delta \ln TFP' = \Delta \ln Q_t' - s_t'^L \Delta \ln L_t - s_t'^K \Delta \ln K_t$$

$$(b) \quad \Delta \ln TFP = \Delta \ln Q_t - s_t^L \Delta \ln L_t - s_t^K \Delta \ln K_t - s_t^R \Delta \ln R_t$$

where equation (7a) shows the expression for TFPG = $\Delta \ln TFP$ in the case where intangibles are expensed and equation (7b) where they are capitalized and the shares of each factor are denoted with an s.[10] As the equations show, the effect of including intangibles on TFPG is ambiguous. Whilst the level of output has risen, the growth rate may or may not rise depending on the growth rate of real intangible investment. So the effect on $\Delta \ln Q$ is ambiguous. In addition, the capitalization of intangibles means that (the growth in) an additional input has to be included as a determinant of growth. Thus we have more capital assets accounting for $\Delta \ln Q$ so that TFPG may rise or fall. Note finally that the shares differ between equations (7a) and (7b) since both output and the payments to capital differ.

The extra output from now including intangible output (with value $P_t^N N_t$) is mirrored by the payments to the extra factor of production, namely the intangible capital stock. Since it is a part of capital, this increases the overall payments to capital.

Also, the production functions make clear that the intangible input is the volume of intangible spending in the first case and the (flow of services from the capital) stock of intangible capital in the second. This means that the income flows have been evaluated using the rental rates of labor, and tangible and intangible capital services.

3. Intangible Spending and the Investment and Labor Shares

Here we discuss our data on intangible spending, investment ,and the overall investment and labor shares. We follow CHS in identifying three main intangible asset classes.[11] Firstly, computerized information (mainly software); secondly, innovative property (mainly scientific and non-scientific R&D); and finally, firm competencies (company spending on reputation, and human and organizational capital).

3.1. *Spending on Intangible Assets*

Table 1 shows our choice of intangible assets, their data sources, the expenditure figures for 2004, the proportion of the expenditure assumed to be investment (following the assumptions of CHS), the percentage of total intangible investment, their deflators, and depreciation rates. In this section we will limit our attention to

[10]The shares are the payments to each factor as a share of total payments to all factors. Total payments add up to output, which of course consists of payments to two factors when intangibles are intermediates and payments to three factors when expensed; thus the shares are different between (7a) and (7b).

[11]CHS have an extensive discussion of why investment in these intangibles should be treated as capital. They also discuss what fraction of measured intangible expenditure should be regarded as investment and thereby capitalized. Finally, one might ask if the list of intangible categories is exhaustive. This is discussed in Giorgio Marrano and Haskel (2006). It does, for example, accord with the categories used by the U.K. Competition Authorities in calculating intangible assets for the purpose of competition analysis.

TABLE 1
INTANGIBLE ASSETS

	Type of intangible investment (1)	2004 Cross Section (2)	Time Series (3)	Total Spending £bn, 2004 (4)	Proportion of Spending Considered as Investment (5)	% of Total Intangible Investment, 2004 (6)	Deflator (7)	Depreciation Rate (8)
			Computerized information					
(1)	Computer software	ONS estimates	**2004–1970** ONS data	21.59	1	16.7	ONS deflators	0.33
(2)	Computerized databases	Included in our software estimates						
(3)	Total			21.59		17.7		
			Innovative property					
(4)	Scientific R&D	Current expenditure on R&D from BERD. R&D in computer industry subtracted	**2004–1981** BERD **1980–1970** Backcast using the growth rate in the Annual Abstract of Statistics	12.4	1	10.2	Implied market sector GVA deflator	0.2
(5)	Mineral exploration	National Accounts	**2004–1970** ONS data	0.4	1	0.3	Implied market sector GVA deflator	0.2
(6)	Copyright and license costs	National Accounts	**2004–1970** ONS data	2.4	1	2	Implied market sector GVA deflator	0.2
(7)	*Other product development, design and research*				1			
(8)	New product development costs in the financial industry	20% of all intermediate purchase by Financial Services industry, ONS data. Intermediate purchases reduced by purchases of advertising, software, consulting and design.	**2003–1992** 20% of intermediate consumption of the financial sector (SIC 65, 67 I-O 100,102). Source: Input–Output Analysis **1991–1970** Backcasted using the growth rate of the turnover of the sector "Banking, finance, insurance business services, leasing" from the *Blue Book* (after constructing a "consistent" time series with the *Blue Book* data)	6	1	4.9	Implied market sector GVA deflator	0.2

TABLE 1 (*continued*)

	Type of intangible investment (1)	2004 Cross Section (2)	Time Series (3)	Total Spending £bn, 2004 (4)	Proportion of Spending Considered as Investment (5)	% of Total Intangible Investment, 2004 (6)	Deflator (7)	Depreciation Rate (8)
(9)	New architectural and engineering designs	Estimated as half of the total turnover of the architecture and design industry SIC 74.2, ABI data. Turnover reduced by purchases of advertising, software, consulting. Includes also turnover of "speciality design activities" SIC 74842 multiplied by 2 to consider also own account	**2004–1995** 50% of the turnover of the industry SIC 74.2, source ABI published data. **1994–1992** 50% of the turnover of the industry SIC 74.2, source Service Sector Review. **1991–1985** Backcasted using the growth rate of the turnover of architects and engineers as published in Business Monitor. **1984–1979** Backcasted above using the growth rate of turnover of SIC 74.2 **1979–1970** Backcasted using the growth rate of the turnover of the sector "Banking, finance, insurance business services, leasing" from the *Blue Book* (after constructing a "consistent" time series with the *Blue Book* data)	18	1	14.7	Implied market sector GVA deflator	0.2
(10)	R&D in social science and humanities	Estimated as twice industry revenues of social science and humanities R&D industry	**2004–1995** Two times the turnover of the SIC 73.2. Source: ABI **1994–1992** Two times the turnover of SIC 73.2. Source: Service Sector Review **1991–1986** Backcast using the growth rate of the turnover of "Research and Development services" as in Business Monitor. Assumption: The Business monitor survey although different captures the same trends of the sector. **1985–1981** Backcast using the growth rate of R&D BERD. Assumption: R&D Berd (mainly scientific) and R&D in human sciences grew at the same rate **1981–1970** Back cast using the growth rate of R&D as in the Annual Abstract of Statistics.	0.3	1	0.28	Implied market sector GVA deflator	0.2
(11)	Total			39.5		32.4		

				Economic competencies				
(12)	*Brand equity*							
(13)	Advertising expenditure	Total spending on advertising as reported by Advertising Association, less expenditure on classified ads	**2004–1970** Advertising Association data	14	0.6	6.9	Implied market sector GVA deflator	0.6
(14)	Market research	Twice revenues of the market and consumer research industry as reported in ABI	**2004–1995** Twice the turnover of industry 74.13 source ABI **1994–1992** Turnover of the sector from Service sector review **1991–1970** Backcast using Advertising Association growth rate of turnover. Assumption: the turnover of the market research industry grew at same rate as the one of the advertising industry	4.5	0.6	2.2	Implied market sector GVA deflator	0.6
(15)	*Total*			18.5	1	9.1		
(16)	*Firm-specific human capital*	NESS05, a similar survey of employer provided training, adjusted to consider private sector expenditure and all UK	**1970–2004** Backcast using trends in wage costs and the industrial structure of the workforce to extrapolate the results of the NESS05 survey	28.8	1	23.7	Implied market sector GVA deflator	0.4

TABLE 1 (*continued*)

	Type of intangible investment (1)	2004 Cross Section (2)	Time Series (3)	Total Spending £bn, 2004 (4)	Proportion of Spending Considered as Investment (5)	% of Total Intangible Investment, 2004 (6)	Deflator (7)	Depreciation Rate (8)
			Organizational structure					
(17)	Purchased	Data on revenues of managment consulting industry from Management Consulting Assocation (MCA). To obtain the private sector expenditure we applied the private sector/total expenditure of the MCA to the grossed up total of the industry (still provided by the MCA)	**2004–1992** MCA data for 2004 adjusted to cover just the private sector backcasted using growth rate of turnover of SIC 7414 excluding PR source: ABI from 1995–2004 and using Service Sector Review for 1992–94 **1991–1985** Backcasted using growth rate of turnover of category "management consultant" source Business Monitor **1984–1979** Backcasted using growth rate of the total business services as published in Business Monitor **1979–1970** Backcasted using data above using turnover of the sector "Banking, finance, insurance business services, leasing" from the *Blue Book* (after constructing a "consistent" time series with the *Blue Book* data)	7	0.8	4.6	Implied market sector GVA deflator	0.4
(18)	Own account	Estimated as 20% of value of executive time using ASHE data on wages in executive occupations, excluding software occupations	**2004–1975** Managers earnings 2004 backcasted using ASHE and NESPD (constructing a consistent time series) **1974–70** Backcast using highest average wage from STAN	15.3	1	12.5	Implied market sector GVA deflator	0.4
(19)	*Total*			22.3		17.1		
(20)	Total			69.6		49.9		
(21)	GRAND TOTAL			130.8		100		

Notes: Column (1) shows the type of intangible investment. Column (2) indicates the data sources used for the cross section estimates of intangible spending in 2004. Column (3) shows the data sources for the time series estimate. Column (4) shows the expenditure for each asset for 2004. Column (5) indicates the percentage of the expenditure assumed as investment. Column (6) shows for each intangible asset the percentage of total intangible investment it represents. Column (7) indicates the deflator used and Column (8) the depreciation rate.

ONS is the Office for National Statistics. BERD is Business Enterprise Research and Development. ABI is Annual Business Inquiry. ASHE is Annual Survey Hours and Earnings. STAN is the structural analysis database of the OECD. SIC is Standard Industrial Classification. NESS05 is the National Employer Skills Survey 2005.

the first six columns. The type of intangibles, column 1, and the data sources for the cross section, column 2, are extensively described in Giorgio Marrano and Haskel (2006).[12]

3.2. *Cross Section Results*

To give some idea of the scale of expenditures, column 4 sets out expenditure on each asset for 2004. This is then converted to investment using the fraction in column 5. Column 6 then shows the fractions of total intangible investment each row accounts for. The following points are worth noting. First, around 50 percent of total investment is on firm spending on reputation, human and organizational capital (economic competencies). About 35 percent is on innovative property and 15 percent on computerized information. Second, according to these numbers, investment in R&D is just one part of investment in knowledge assets. In fact, R&D investment is less than investment in software, for example.[13] Third, the biggest single figure is training investment.

3.3. *Time Series Results*

Figure 1 shows the time series for nominal intangible investment for the aggregated categories as a share of adjusted nominal MGVA. Figure 1b shows the time series for the U.S. from CHS (2006) while Figure 1a reproduces the estimates for the U.K. They are cumulative charts so that that top line shows the share of total intangible investment in intangible-adjusted MGVA.[14] The lowest line shows the share of brand equity and the line above that shows the share of brand equity plus the firm-specific resources. Thus the gap between the lines is the share of each category of investment.

A number of points are worth making. First, the total line shows the growing importance of nominal intangible investment in the economy, rising from around 6 percent of MGVA in the 1970s to 13 percent in 2004 (6 percent to 15 percent of unadjusted MGVA, which includes some software, i.e. as currently measured in the National Accounts). Second, all investment types have risen, with the exception of brand equity, which is more or less flat. The most marked increases are for computerized investment and firm-specific resources. These two groups show therefore the biggest increases in the share of overall intangible investment.

3.4. *Labor Share*

The labor share is calculated as the ratio between compensation of employees and the sum of labor compensation and capital compensation, the latter called operating surplus in the U.K. National Accounts (in turn, for the whole

[12]There are two minor changes with respect to Giorgio Marrano and Haskel (2006). All the data are now consistent with the 2006 National Accounts and in the asset "new architectural and engineering designs" we include also twice the turnover of the SIC 74842 "Speciality designs activities" (around £4bn in 2004).

[13]Although the two types of spending might have quite different potential spillovers.

[14]That is, the denominator is GVA in the market sector, adjusted for the presence of intangible investment.

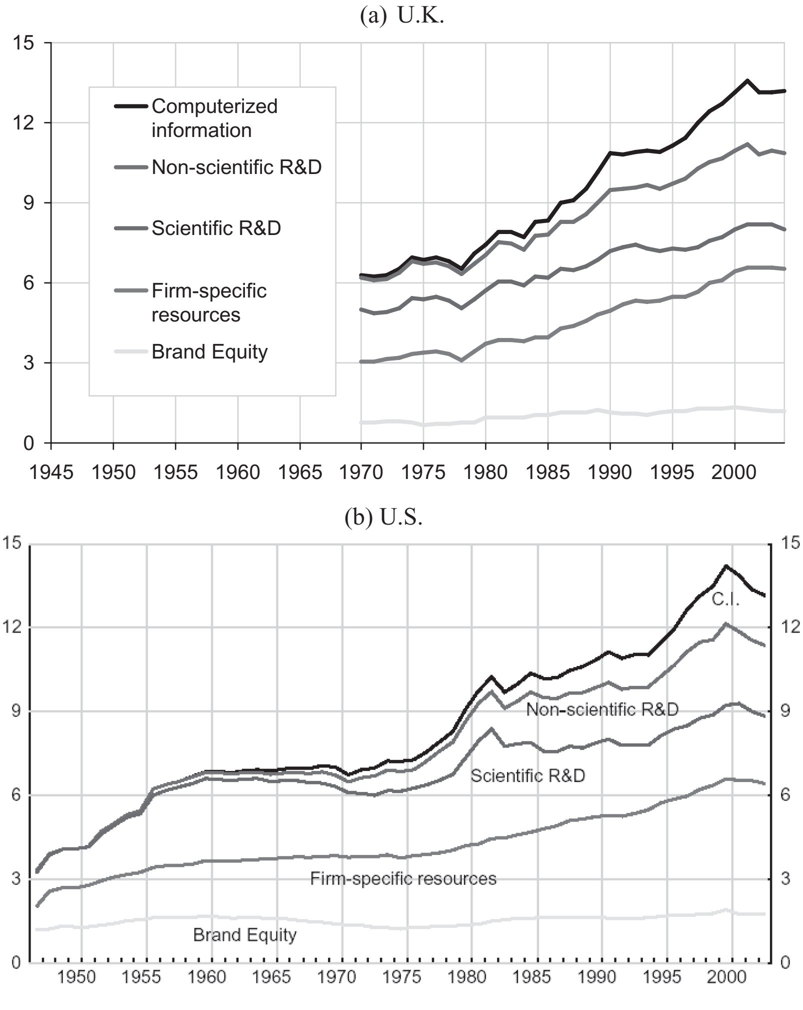

Figure 1. Intangible Investment (percentage of output)

Notes: The figures show the time series for intangible investment for the aggregated categories as a share of output. For the U.K. output is market sector GVA adjusted to include all intangibles. For the U.S. output is non-farm business output.

The first chart (a) shows the time series for the U.K. while the second (b) shows the time series for the U.S. It is a cumulative graph so that that top line shows the share of total intangible investment in intangible-adjusted market sector GVA. The lowest line shows the share of brand equity and the line above that shows the share of brand equity plus the firm-specific resources. Thus the gap between the lines is the share of each category of investment. Brand Equity includes advertising and market research. Firm specific resources includes firm specific human capital and organizational structure. Scientific R&D includes scientific R&D and mineral exploration. Non-scientific R&D includes copyright and licences costs, new product development costs in the financial industry, new architectural and engineering design, and R&D in social science and humanities. Computerized information includes software.

Source: U.K. data our calculations. U.S. data CHS (2006).

economy, this adds up to nominal GDP, subject to some minor tax/subsidy and statistical adjustments). One problem in calculating this is the treatment of the income of the self-employed, whose income, termed "mixed income," might be considered a combination of labor and capital income. It is included, in the U.K. market sector data, with operating surplus. This boosts the capital share and thus potentially boosts the fraction of MGVA growth that is capital deepening.[15] We decided to split mixed income into labor and capital income. One way of doing this is to use the Labor Force Survey to estimate the pay of the self-employed by assuming they earn the same wage as equivalent (in terms of age, skills, etc.) employed workers. This method produces an estimate of self-employed labor income equal to 98 percent of mixed income. The other method is to simply calculate the capital–labor ratio from operating surplus after excluding mixed income and then apply this same ratio to the mixed income component. This method produces an estimate of self-employed labor income equal to on average around 65 percent of mixed income. We settled on the final option and as a consequence, the labor share is higher than in the case in which the mixed income is left in operating surplus.

Figure 2 shows the time series for the labor share in the both the U.K. and the U.S. excluding and including intangibles. Figure 2b shows the labor share from 1970 to 2003 for the U.S. and Figure 1b the series for the U.K. A number of points are worth noting. First, the levels of the labor shares are similar, with the 1970 level being about 68 percent excluding software and intangibles and 63 percent including them (the U.S. figures are 71 percent and 66 percent). Second, the overall trend in both countries is flat when excluding intangibles and falling when including them. If anything the trend is smoother in the U.S., reflecting the U.K. change from the peak in the mid 1970s (well known union push) and the trend downwards to the early 1980s.

3.5. *Investment Share*

Figure 3 shows nominal investment as a percentage of MGVA for the U.K. and U.S. including three cases: traditional National Accounts excluding software; including software (this is not shown in the U.S. graphs); and including all intangibles (where in the U.K. data the MGVA denominator excludes software, includes software, and includes all intangibles respectively). There are two major findings. First, in both countries, without intangibles, the nominal investment share is flat or a little bit decreasing and is a similar amount (around 15 percent). Second, once we include intangibles it increases in levels, to around 25 percent by the end of the period; the trend is upwards.

4. Growth Accounting

To implement the growth accounting set out in Section 2, we proceed as follows. First, we measure labor input L as employee hours. Second, we

[15]Indeed calculated on this basis the U.K. capital share is about 10 percentage points above the non-farm business U.S. capital share. None of the international comparisons of labor shares that we could find gave this kind of difference.

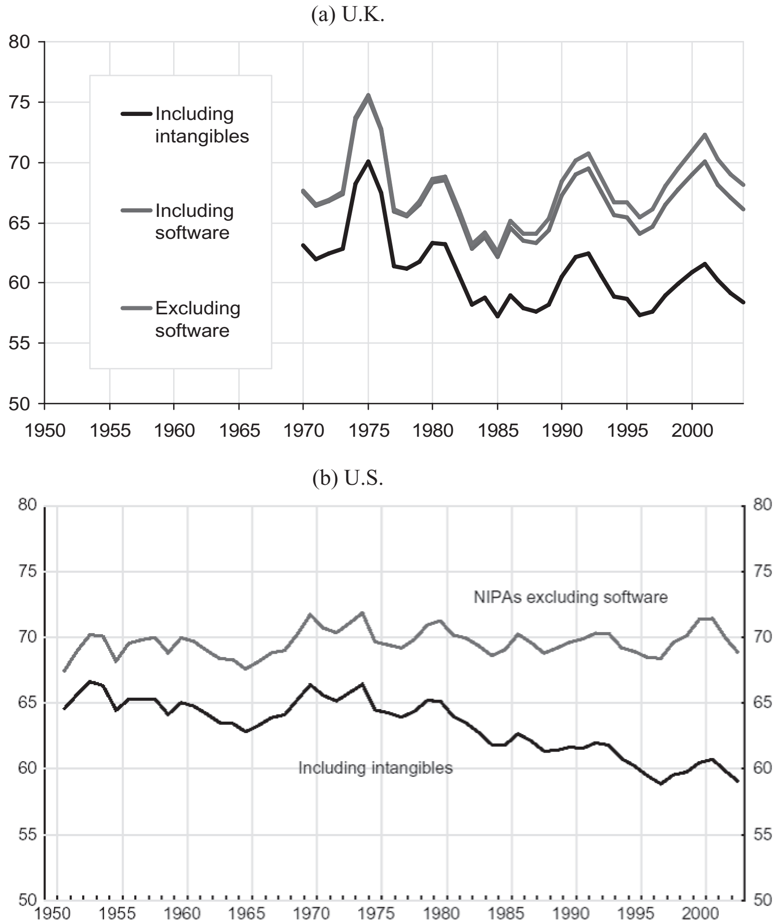

Figure 2. Labor Shares (percentage of output)

Notes: The figures show the time series for the labor share in the both the U.K. and the U.S. excluding and including intangibles. The first chart (a) shows the labor share from 1970 to 2004 for the U.K., while the second chart (b) shows the labor share from 1950 to 2003 for the U.S. For the U.K., output is market sector GVA adjusted to be consistent with the amount of intangibles included. For the U.S., output is non-farm business output.

Source: U.K. data our calculations. U.S. data CHS (2006).

express MGVA and capital in per employee hour terms. Third, in practice the quality of labor likely varies and so we distinguish between employee hours, L and quality adjusted employee hours, L^{QA}. Thus our growth accounting expressions are:

$$(8)\ (a)\quad \Delta \ln TFP'_t = \Delta \ln (Q'/L)_t - s'^L \Delta \ln \left(L^{QA}/L\right)_t - s'^K \Delta \ln (K/L)_t$$

$$(b)\quad \Delta \ln TFP_t = \Delta \ln (Q/L)_t - s^L \Delta \ln \left(L^{QA}/L\right)_t - s^K \Delta \ln (K/L)_t - s^R(t) \Delta \ln (R/L)_t.$$

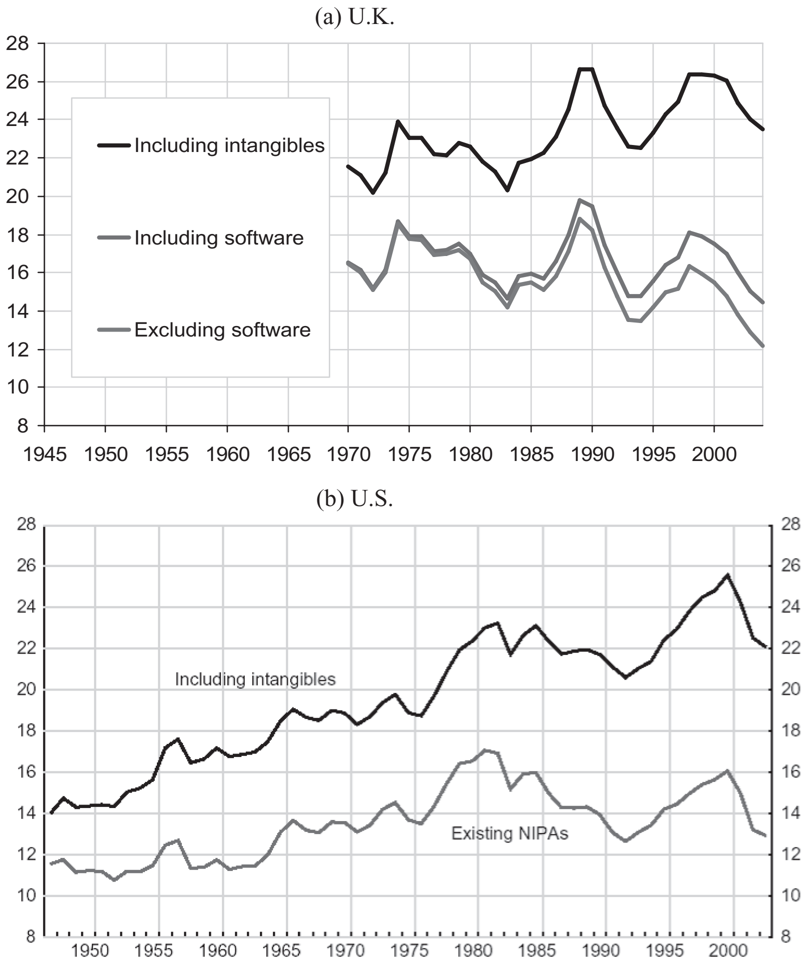

Figure 3. Nominal Investment Shares (percentage of output)

Notes: The figures show investment shares as a percentage of market sector GVA for the U.K. and non-farm business output for the U.S. in three cases: traditional National Accounts excluding software, including software (this is not shown in the U.S. graph), and including all intangibles. In each case the market sector GVA for the U.K. is the appropriate version for the amount of intangibles included.

Source: U.K. data our calculations. U.S. data CHS (2006).

A number of points are worth noting regarding equation (8). First, the shares are averages of shares over which the time difference is taken, so that (8) is a Tornquist index number. Second, the share of capital is defined as one minus the share of labor. This is accurate if there are constant returns to scale at the overall economy level, but is clearly an area where better measurement would be helpful. Third, since there are in practice many capital assets (for tangibles, plant, buildings, vehicles, and computer hardware; for intangibles, software, R&D, etc.) the $\Delta \ln K$ and $\Delta \ln R$ terms have to be constructed to incorporate these many types. This is done following Oulton and Srinivasan (2003a), who in turn follow Jorgenson and

Griliches (1967), by noting that the theoretically correct capital measure in a production function is the services that capital provides into output. In turn the services for each type of capital can be measured by the rental payments that a profit-maximizing firm would pay were it renting its capital. Since in practice firms rarely do this but buy the capital asset for a price p^A and then use it over its lifetime, the market-clearing rental payment for an asset B (where B can be tangible or intangible assets), p^B, can be derived as

$$(9) \qquad p_{it}^{B} = T_{it}\left[r_{it} \cdot p_{i,t-1}^{A} + \delta_{it} \cdot p_{it}^{A} - \left(p_{it}^{A} - p_{i,t-1}^{A}\right)\right], \quad B = K, R$$

where T is a tax adjustment and r is the rate of return on the asset.[16] This equation holds for each type of capital i. The relation between this and the $\Delta \ln K$ and $\Delta \ln R$ terms in (8) can be derived as follows. First, the overall level of profit in the economy, Π, is, by definition, the overall payments to capital, which is the sum of all rental payments to each capital type. This can be written as

$$(10) \qquad \Pi_t = \sum_{i=1}^{n} p_{it}^{K} K_{it} + \sum_{i=n+1}^{m} p_{it}^{R} R_{it}$$

where there are n tangible assets and $n + 1$ to m intangible assets. Second, the overall volume index of capital services can be shown to be a share-weighted average of all the asset-specific $\Delta \ln K$ and $\Delta \ln R$ terms:

$$(11) \qquad \Delta \ln K_t = \sum_{i=1}^{n} \left(p_{i,t}^{K} K_{it} / \Pi_t\right) \Delta \ln K_{it}$$

$$\Delta \ln R_t = \sum_{i=n+1}^{m} \left(p_{i,t}^{R} R_{it} / \Pi_t\right) \Delta \ln R_{it}$$

where the shares are the flow of rental payment for each asset as a share of total rental payments (Π).[17] As an empirical matter, we have to take a number of steps. First, we do not have information on time-varying depreciation rates and so set them constant over time. Second, we do not have information on asset-specific rates of return, r_i. In a competitive market, r_i will equalize across assets. If we assume this then we have two equations (9) and (10) in two unknowns, namely r and p^K which we can solve for. The economic intuition of this is that since we know the overall payment to capital, Π in the economy, from National Accounts, we can solve for the unobserved asset-specific rental prices that would ensure that all payments to capital assets added up to Π. Third, in line with the Tornquist method above, the weights in (11) are the time-averaged weights over which the difference is taken.

To summarize, we therefore implement growth accounting in the following steps. (i) Collect a time series of nominal investment in intangible and tangible assets, deflate to get real investment series, and build a real capital stock using the perpetual inventory method (see equations (1) and (4)). (ii) Recalculate MGVA to include intangibles (see equation (6)). (iii) Adjust the operating surplus Π for MGVA (see equation (6)). (iv) Build a Hall/Jorgenson capital services measures of

[16]The derivation of equation (10) is set out in Oulton and Srinivasan (2003a).

[17]By contrast the wealth stock, which is often presented as a measure of capital, is the share-weighted sum of capital stocks, where the shares are the asset prices.

TABLE 2
Tangible Assets

	Asset Type (1)	Time Series (2)	Deflator (3)	Depreciation Rate (4)
(1)	Computer hardware	National Accounts consistent investment series (see Wallis, 2009 for details)	ONS delflator (for 1983–70 backcasted using growth rates of NIESR's hardware deflator)	0.4 (National Accounts)
(2)	Buildings	National Accounts investment series. Consistent with 2006 *Blue Book*. Net stock estimates based on Wallis (2009)	National Accounts capital stock deflators	0.025 (BEA)
(3)	Plant and machinery	National Accounts investment series. Consistent with 2006 *Blue Book*. Net stock estimates based on Wallis (2009)	National Accounts capital stock deflators	0.13 (BEA)
(4)	Vehicles	National Accounts investment series. Consistent with 2006 *Blue Book*. Net stock estimates based on Wallis (2009)	National Accounts capital stock deflators	0.25 (BEA)

Notes: Column (1) shows the asset type. Column (2) indicates the data sources for the time series. Column (3) shows the deflator used and column (4) the depreciation rate.

BEA is Bureau of Economic Analysis. NIESR is National Institute of Economic and Social Research.

all capital inputs, ensuring the asset rental payments are consistent with the adjusted operating surplus (see equations (9) to (11)). (v) Build a quality adjusted labor index to measure L^{QA} (see equation (8)). (vi) Undertake growth accounting. The next sections describe how to do this.

4.1. *Time Series of Nominal Investment*

Investment in intangible assets is set out above. For tangible assets, we use the data based on Wallis (2009); see Table 2. Briefly, the dataset consists of a long back-history of constant price investment data classified by SIC92 industries. The asset breakdown of the investment series is: buildings, plant and machinery, and vehicles. In order to treat computers as a separate asset, computer investment is separated from investment in plant and machinery and the associated price deflators adjusted to account for this. The data are then aggregated to market sector levels.

4.2. *Deflation and Real Investment Series*

The choice of deflators, as CHS discuss, is a difficult one. One possibility is to develop a price index for the particular intangible according to the costs incurred in developing it, so that, for example, if most of the costs of R&D is payments to scientists, then the deflator might be the wage of scientists. As CHS show however, this implicitly assumes that scientists have no increase in productivity in the R&D process. A second possibility is to use the output deflator. This is sometimes justified in studies of, for example, R&D, where a physical unit has little meaning and so it is felt best to deflate by the price of the good which presumably embodies the knowledge that the R&D is generating. Triplett and Bosworth (2004) offer a similar justification for management consultants.

Our deflators are set out in more detail in Table 1. For computer hardware, we use data from the Office for National Statistics (ONS), the Bank of England and the National Institute of Economic and Social Research (NIESR). They are close to each other only in some years. ONS stops in 1984 and so we back-cast using NIESR data. We have explored U.S. deflators and the results are robust to this change. Software deflators are taken as follows. For own account we use wages of the relevant occupations and then a 2.5 percent productivity adjustment. Whilst this has the problem similar to the R&D deflator above, it is used by the ONS and so has the benefit of being consistent with their practices (which is useful in our context since at least part of the software is incorporated into the National Accounts; it is also consistent with the U.S. treatment of software). For purchased software we use the ONS purchased software deflator. For all other intangible assets we use an implicit deflator calculated from our nominal market sector output and real market sector output series.[18] Turning to the remaining tangible assets we use deflators for plant, vehicles, non-IT machinery, and buildings consistent with the U.K. National Accounts (see Wallis, 2009).

4.3. *Capital Stock*

A constant depreciation rate assumes geometric depreciation, the accuracy of which is of course open to question as well as requiring one to settle on a depreciation rate. Given the doubts and uncertainty over this, we settle here on applying conventional assumptions about tangible assets to the accumulation of intangible assets. Table 1 sets out our assumed rates. For intangible assets these are based on CHS (2006) assumptions. For tangible capital we use existing National Accounts deprecation rates. Our sensitivity analysis included varying the assumptions on the intangible asset side.

4.4. *Adjusting Operating Surplus of Market Sector*

The ONS publishes market sector operating surplus series back to 1992. We back-cast the series to 1970 using the gross operating surplus growth rates for the whole economy. As dwellings are not modeled as part of the productive capital stock, because they do not form part of the input into production, the part of operating surplus attributable to dwellings is subtracted. This part of operating surplus is measured by owner-occupied imputed rents and the depreciation of the stock of dwellings. To adjust the operating surplus for the intangibles we simply add nominal intangible investment. We build three versions of market sector gross operating surplus. The first version excludes software investment already present in the National Accounts. The second includes

[18]The output series are adjusted for the inclusion of intangibles.

this investment and adds also the revision to National Accounts software estimates presented in Chamberlin and Chesson (2006). The third includes all intangibles.

Concerning labor compensation, the ONS publishes market sector labor compensation series back to 1992. We back-cast the series using the growth rate of the OECD estimated wage bill.

4.5. *Recalculating MGVA to Include Intangibles*

The ONS publishes a time series back to 1992 of MGVA at current prices. We wish to remove private residential property from our data. So to be consistent with the treatment of operating surplus above, we subtract actual and imputed rental from housing from the MGVA data. We back-cast the series using the growth rate of the sum of the market sector labor compensation and operating surplus. To adjust for the intangibles we simply then add the nominal investment in intangibles (note not spending but investment) to nominal MGVA, ensuring that we do not double count any intangibles already included (such as some software and mineral exploration).

Regarding the real market sector growth rate, the ONS publishes time series that go back at least to 1970. We adjusted the real growth rate for intangibles devising an index of changes in real adjusted MGVA as a share-weighted change of real MGVA and real intangible investment, with the weights being the share of each expenditure category in overall GVA.

As for the gross operating surplus we build three versions of MGVA. The first version excludes software investment already present in the National Accounts. The second includes this investment and adds the planned revision to the software estimates. The third includes all intangibles.

4.6. *Capital Services*

To do this we use method described above (equations (9), (10) and (11)). We smooth the rate of return and the capital gain term by taking a three-year moving average. All rates of return are positive, but for some years in the middle 1970s the building rental rates were negative. We set them equal to the nearest positive rate.

4.7. *Quality Adjusted Labor Index*

We use here the Bank of England index that adjusts hours for education, gender and age (see Bell *et al.*, 2005), kindly provided to us by Nick Oulton and Sally Srinivasan.

It might be felt that including both training spending by firms and the labor quality/composition adjustment double counts the contribution of skills. Conceptually, we wish to separate out the part of skills that are invested in by the firm (since that would be part of market sector intangible investment) and that part invested in by the state. Under Becker-type assumptions, investment by firms, which is only in firm-specific training, will not raise worker wages since workers cannot use these skills outside the firm. General training will raise worker wages.

Now, the adjustments in the labor quality/composition term multiply worker types by their wages relative to a base worker type. If firms are only funding firm-specific training, then since market wages are unaffected, such market wage adjustments will not double count labor quality.

One problem with this approach is if the effect of experience in the quality adjustment is in part due to the firm-specific training that older workers have received earlier in their career. If so, this would mean double counting for at least part of the experience effect.

5. Growth Accounting Results

5.1. *Overall*

In the results that follow we use the following conventions. Growth in capital services and labor quality are Tornquist indices as is growth in MGVA. The averages reported are 100 times the arithmetic averages of year-on-year Tornquist growth rates (e.g. 2000–04 is the average of 2000–01, 2001–02, 2002–03, and 2003–04). TFP growth is the residual and the capital and labor shares add to 1. Our growth accounting decompositions start in 1979 with our intangible capital dataset equal to zero in 1970. However, due to the period we are most interested in being the 1990s, and our data being of better quality from 1990 onwards, our analysis focus on 1990 onwards. This also allows us to ignore any initial conditions problems in association with the intangible capital stock.[19]

We undertook two main checks on the data. First, the ONS *Blue Book* 2006 does no growth accounting but does include some software in output. Thus we generated MGVA data excluding all software, including just software, and including all intangibles. We checked our data that included software against the ONS data and found the growth rates very close.[20] Second, Oulton and Srinivasan have undertaken a major industry-level study that includes software in both their output data and their capital services data (Oulton and Srinivasan, 2005). These results were up to 2000 and were consistent with the 2002 ONS *Blue Book*. The 2002 *Blue Book* data had limited coverage of software, so a major contribution of Oulton and Srinivasan (2005) was to add in software to both output and capital services. In recent unpublished worked, they use data to 2003, consistent with the 2005 ONS *Blue Book*, again incorporating software. A change here is that ONS have revised their employee-hours data to be consistent with the 2001 population census; Oulton and Srinivasan have revised their data accordingly. We use their labor hours and quality measure, that they kindly supplied us. This allows us to make a better comparison of our baseline results, without intangibles, with theirs.

5.2. *Growth Accounting Results, 1990–2004*

Table 3 shows the growth accounting results for 1990–2004. We look at this period to compare the results with Oulton and Srinivasan (2005) and to explore a

[19]The tangible capital stock is based on a very long run of investment data, back to the 1800s in some instances, so there are no initial conditions problems to deal with.

[20]The *Blue Book* 2006 includes somewhat less software than we do. For example, for 2004, our data is about £21bn while in the *Blue Book* 2006 is about £11bn.

TABLE 3
LPG Growth Accounting Results

Period	LPG	Capital Deepening	Human Capital Deepening	TFPG
	Excluding Software			
1990–95	2.93	1.40	0.83	0.70
1995–2000	2.72	1.82	0.44	0.46
2000–04	2.53	1.18	0.29	1.07
	Including Software			
Period	LPG	Capital Deepening	Human Capital Deepening	TFPG
1990–95	3.01	1.55	0.81	0.65
1995–2000	2.91	2.00	0.43	0.48
2000–04	2.64	1.35	0.28	1.00
	Including all Intangibles			
Period	LPG	Capital Deepening	Human Capital Deepening	TFPG
1990–95	3.09	1.90	0.73	0.46
1995–2000	3.23	2.27	0.38	0.57
2000–04	2.61	1.71	0.25	0.65

Notes: All data are average percentage growth rates per annum.

LPG is labour productivity per hour growth. Capital deepening is the share of capital times the growth rate of capital services per hour. Human capital deepening is the share of labor times the difference between quality adjusted and non-adjusted hours growth. TFPG is the growth rate in total factor productivity calculated as LPG minus capital deepening and human capital deepening.

major "fact" in the U.K., namely the 1995–2000 slowdown in both LPG and TFPG (in stark contrast to the U.S. speed up).

Table 3 has three panels. The top panel shows growth accounting results when we exclude software. The middle panel includes software and the bottom panel includes all intangibles. Each panel has three rows: the first row shows the period 1990–95, the second 1995–2000, and the third 2000–04. The columns show averages of the annual Tornquist growth rates for each period. The first column shows LPG (recall this is growth per hour in market sector labor productivity), the second capital deepening (the change in capital services per hour times the share in capital), the third human capital deepening (the change in quality-adjusted labor services per hour times the share of labor), and the fourth TFPG. TFPG is the first column less the sum of the second and the third. Before considering our results in detail, we wish to check that the numbers accord with other sources. As mentioned above, Oulton and Srinivasan (2005) is one benchmark for the comparison of the results. That paper published growth accounting results for the period 1970–2000 based on the Bank of England Industry dataset (BEID).[21] In turn, the BEID is based on the then current National Accounts with an adjustment for software.[22] More recently, Oulton and Srinivasan have revised and updated their data to 2003.

[21]The Bank of England Industry dataset is described in Oulton and Srinivasan (2003b).
[22]In addition to a few other adjustments such as to financial services output.

They kindly provided us with their updated quality-adjusted labor inputs and hours data, both of which we have used here.[23]

It is worth noting that there is a major difference between these results and the Oulton and Srinivasan (2005) results. In those data, there was a major fall in LPG between 1990–95 and 1995–2000 of 1.05 percentage points per annum (pppa). LPG in the two periods was 3.99 percent per annum (ppa) and 2.93 ppa, respectively. In our data this is much smaller (see the middle panel). This is because we use the BEID new set of hours data, which is in turn based on that from the ONS. The old hours data were very different, more negative in 1990–95 and more positive in 1995–2000. With these new hours data, based on the 2001 census of population, the slowdown is much less pronounced.

Turning to the other results, the main results are as follows. First, adding software increases LPG in every period. As set out above, the addition of software raises MGVA, so that the *level* of labor productivity rises, and this table shows that the *growth* of labor productivity rises too. Note that adding the rest of the intangibles further raises LPG, except in the very last period where it falls slightly relative to the last period in the middle panel. This suggests that the pace of intangibles expansion is less over that period.

Second, the addition of intangibles gives a different picture to the 1990s LPG slowdown mystery. Looking at the top panel, when software and other intangibles are excluded we see that LPG slowed down from 2.93 ppa to 2.72 ppa. Looking at the middle panel, where we include software, we see a similar slowdown, from 3.01 ppa to 2.91 ppa. However, the results in the final panel are most interesting: there we see a speed up, from 3.09 ppa to 3.23 ppa. If our measures of intangibles are correct, and they should indeed all (and fully) be capitalized, then one can conclude that the mid 1990s slowdown was a statistical illusion caused by not accounting for investment in intangibles. Clearly our estimates are subject to a wide range of assumptions but these data do suggest that measurement is likely to be a first-order issue in understanding the mid-1990s slowdown.

Third, consider capital deepening. Adding software increases capital deepening in every period (compare the top and middle panels). There are two possible explanations for this. Recall that capital deepening is the product of the capital share and growth rate of capital services. When including software the share of capital goes up and therefore, *ceteris paribus*, capital deepening rises. The growth rate of capital services per hour could, in theory, increase, remain the same, or decrease.[24] Table 4 shows the reason for the rise in capital deepening. The top panel

[23]We collected data for intangible spending and market sector GVA up to 2004. The Bank of England data on hours and labor quality goes up to 2003. Thus we interpolated these variables for one year by running a regression of them on two lags of themselves and current and lagged GDP. To check the data we compared the new hours data with an ONS market sector hours series and an ONS whole economy labor quality measure (kindly supplied by Peter Goodridge) (both start in 1999 and so we cannot use them for the full data period). Our single interpolated year matched the behavior of these ONS series well. Their updated data are unpublished, but turn out to be quite similar to the results here. The main difference is that our 1995–2000 LPG is a bit faster. Looking at their raw series, we find this difference arises from the fact that in the updated BEID dataset there is a dip in growth of labor productivity in 1998–99 whereas we do not have so much of a dip.

[24]Capital services growth is a rental cost weighted sum of individual capital services growth, where the rental prices are determined exogenously to exhaust overall payments to capital. Thus adding new capital assets changes the weights and so the growth of capital services might rise or fall.

TABLE 4

Analysis of Capital Deepening

	Excluding Software											
	Capital Deepening: Average Annual Growth Rates, % Per Annum			Proportion of Total Capital Deepening, % Per Annum			Income Shares, % of Market Sector GVA			Capital Services Per Hour: Growth Rates, % Per Annum		
Period	ICT Capital (Hardware)	Non-ICT Capital	Total Capital	ICT Capital (Hardware)	Non-ICT Capital	Total Capital	ICT-Capital (Hardware)	Non-ICT Capital	Total Capital	ICT-Capital (Hardware)	Non-ICT Capital	Total Capital
1990–95	0.55	0.85	1.40	38.96	61.04	100	4.06	28.22	31.41	16.90	3.17	4.55
1995–2000	1.32	0.51	1.82	72.30	27.70	100	5.47	27.72	31.99	29.55	1.87	5.71
2000–04	0.69	0.49	1.18	58.31	41.69	100	5.89	24.66	30.10	15.51	1.95	4.03

	Including Software											
	Capital Deepening: Average Annual Growth Rates, % Per Annum			Proportion of Total Capital Deepening, % Per Annum			Income Shares, % Of Market Sector GVA			Capital Services Per Hour: Growth Rates, % Per Annum		
Period	ICT-Capital	Non-ICT Capital	Total Capital	ICT-Capital	Non-ICT Capital	Total Capital	ICT-Capital	Non-ICT Capital	Total Capital	ICT-Capital	Non-ICT Capital	Total Capital
1990–95	0.69	0.86	1.55	44.65	55.35	100	4.34	28.05	32.57	15.70	3.17	3.39
1995–2000	1.49	0.51	2.00	74.61	25.39	100	5.93	28.03	33.60	25.04	1.87	7.03
2000–04	0.86	0.49	1.35	63.66	36.34	100	6.43	25.32	32.12	13.23	1.96	4.22

	Including all Intangibles															
	Capital Deepening: Average Annual Growth Rates, % Per Annum				Proportion of Total Capital Deepening, % Per Annum				Income Shares, % of Market Sector GVA				Capital Services Per Hour: Growth Rates, % Per Annum			
Period	ICT	Non-ICT Tangible	Other Intangibles	Total	ICT	Non-ICT Tangible	Other Intangibles	Total	ICT	Non-ICT Tangible	Other Intangibles	Total	ICT	Non-ICT Tangible	Other Intangibles	Total
1990–95	0.65	0.90	0.36	1.90	33.97	47.24	18.80	100	4.06	28.22	7.59	39.43	15.69	3.20	5.45	4.90
1995–2000	1.38	0.51	0.39	2.27	60.54	22.48	16.98	100	5.47	27.72	8.75	41.05	25.00	1.89	4.75	5.54
2000–04	0.79	0.49	0.42	1.71	46.31	28.96	24.68	100	5.89	24.66	9.99	40.14	13.21	2.01	4.61	4.31

Notes: The top panel shows capital deepening without including software, the middle panel includes software, and the bottom panel includes all intangibles. The two right-hand panels divide capital deepening into the income shares and the growth of capital services per hour, dividing these terms in turn between the contributions of ICT and non-ICT. The capital deepening figures in the left-hand side are not quite the same as the income shares times the capital services because of averaging.

shows capital deepening without including software, the middle panel shows the inclusion of software, and the bottom panel shows the inclusion of all intangibles. The two right-hand panels divide up the capital deepening into the income shares and the growth of capital services per hour, dividing these terms in turn between the contributions of ICT and non-ICT. As Table 4 shows, if we look at the top and middle panel, the share of capital (column 9) and the capital services per hours (column 12) increases in the post-1995 periods when we include software.

Returning to Table 3, when we include all intangibles (see bottom panel) capital deepening increases further in every period by an amount of between 0.37 pppa and 0.28 pppa. Table 4 shows that the increase, as compared to the situation where software is not included, is mainly due to the share of capital increasing as the total capital services per hour growth rate stays roughly the same.

Fourth, regarding TFPG, the top panel shows the results already established in the literature, namely a fall in TFPG in the mid 1990s. Note an acceleration in 2000–04, which is a new result. The middle and lower panels show the effects of introducing software. Recall that, as the earlier theory section noted, the effect of the inclusions of extra investment can increase, decrease, or have no effect on TFPG. The middle panel shows that TFPG still slows down in the mid 1990s, but speeds up in 2000–04. The lower panel most interestingly shows that TFPG speeds up in the mid 1990s, and speeds up again 2000–04. Thus with these data at least, the 1990s TFPG puzzle is removed, namely there was a speed-up at that time which had been masked by the failure to adjust MGVA for intangible investment and is apparent even thought the new TFPG numbers include the extra knowledge input. There was then further speeding up in TFPG (and LPG) in the early part of this century.

To shed further light on this, consider similar data for the U.S. The post-2000 record for the U.S. is set out in Jorgenson *et al.* (2007). They document a *rise* in LPG from 2.70 ppa in 1995–2000 to 3.09 ppa in 2000–05, with rises in capital deepening (1.51 ppa to 1.56 ppa), labor quality (0.19 ppa to 0.36 ppa), and TFPG (1.00 ppa to 1.17 ppa). Our nearest comparison would be the middle panel, which includes software. We have falls in LPG, capital deepening, and human capital deepening, but a rise in TFPG. Thus the question raised by these data is not the behavior of TFPG, but rather what were the set of incentives that led the U.S. to raise its capital deepening that did not operate in the U.K.[25]

5.3. *The Role of ICT*

Before turning to the comparison with the U.S. we return to Table 4 to examine the role of ICT. The two left-hand side panels for the top and middle rows divide capital deepening into ICT and non-ICT, and into ICT, non-ICT tangible, and other intangibles for the bottom panel. This decomposition is first shown with the actual figures and then with the proportions. If we look at the left-hand side of

[25]It may seem surprising that the U.K. performance is so similar to the U.S. performance given all the discussion about superior U.S. economic performance since 2005. Two points are worth bearing in mind. First, Timmer *et al.* (2003, updated 2005) note that between 1995 and 2004, U.S. LPG has been 1.8 percent, EU 1.4 percent and U.K. 1.6 percent. So the U.K. has been doing somewhat better than the EU. Second, the EU was growing much faster than the U.S. before 1995 and now the opposite is the case. So much of the mystery is about the relative lack of acceleration rather than the relative growth rates.

the middle panel and look at the rows corresponding to the years 1990–95 and the years 1995–2000 we can see that the ICT capital deepening increased while the non-ICT decreased; in the middle panel in the period 1990–95 ICT capital deepening was 44.7 percent of total capital deepening while non-ICT was 55.4 percent. In the period 1995–2000 it is reversed: ICT accounts for 74.6 percent of capital deepening while non-ICT just 25.4 percent. In the most recent period up to 2004, ICT again accounts for the lion's share of capital deepening. Turning to the right-hand side panel we can see that both the share of ICT and the capital services per hour growth rate increased in the late 1990s, while for non-ICT the share remained the same and the capital services growth rate decreased. Finally, the fall in capital deepening in 2000–04 is entirely due to a fall in ICT hardware capital investment.

5.4. *Comparison with the U.S.*

In Table 5 we set out the comparison with the U.S. where the U.S. data are taken from CHS (2006). Note that our pre-1995 data starts in 1979 and our data finishes in 2003 as opposed to 2004 in earlier tables (to be consistent with CHS). As before, for the U.S. there are three panels. The top one excludes software, the middle panel includes software only, and the bottom panel all intangibles. For comparison we therefore show our versions which respectively exclude software, include software only, and include all intangibles.

The most direct comparison is for the years 1995–2003 and it is summarized in rightmost panel, with each contribution a percentage of LPG; LPG is shown in the top row. The key results are the following. First, looking at overall LPG for 1995–2003, we see that it is somewhat higher in the U.S. whether intangibles are included or not, but is similar. What is dissimilar is that U.S. LPG accelerated sharply after 1995, whereas U.K. productivity growth did not, although it was growing much faster during the pre-1995 period.

Second, turning to the contributions to LPG over the comparable period 1995–2003, we see that capital deepening is a higher share of LPG in the U.K. than in the U.S. It is about 64 percent (top right panel) in the U.K., while for the U.S. it is 35 percent. Note that in most international comparisons the European share of capital deepening in LPG is usually higher than the U.S. (as EU catches up to U.S. by installing capital). Note too that the contribution of capital deepening rises as more intangibles are included: 64 percent of LPG with no software, 67 percent with software, and 73 percent with all intangibles. In addition, comparison of rows 3 and 2 in the bottom panel shows about 75 percent (1.54/2.14) of U.K. capital deepening is due to tangible capital compared to just 50 percent (0.85/1.68) in the U.S.

Third, the contribution of human capital deepening in 1995–2003 is very similar in both countries, at about 14 percent of labor productivity (top right panel). Fourth, in all cases, the contribution of TFP is less as a share of LPG in the U.K. than in the U.S. Fifth, we can get some idea of the contribution of intangibles by looking at the bottom panel. Comparing row 3 and row 6 in the right panel we see that 53 percent of U.K. LPG is due to tangibles and 28 percent in the U.S. This shows a bigger contribution to LPG of intangibles in the U.S.

TABLE 5
Growth Accounting Comparison with the U.S.

	U.S.		U.K.			U.S.	U.K.
	1973–95 (1)	1995–2003 (2)	1979–95 (3)	1995–2003 (4)		1995–2003 (5)	1995–2003 (6)
Excluding Software						Excluding Software	
Labour productivity growth	1.36	2.78	2.55	2.59		2.78	2.59
Capital deepening	0.6	0.98	1.23	1.64	2/1	35	64
IT equipment	0.33	0.7	0.50	1.13	3/1	25	44
Other tangible capital	0.27	0.28	0.73	0.51	4/1	10	20
Human capital deepening	0.28	0.38	0.55	0.36	5/1	14	14
TFP growth	0.48	1.42	0.78	0.58	6/1	51	22
Including all Intangibles						Including all Intangibles	
Labour productivity growth (percent)	1.63	3.09	2.86	2.93		3.09	2.93
Capital deepening	0.97	1.68	1.66	2.14	2/1	54	73
Tangibles	0.55	0.85	1.21	1.54	3/1	28	53
IT equipment	0.3	0.6	0.46	1.02	4/1	19	35
Other	0.25	0.24	0.75	0.52	5/1	8	18
Intangibles	0.43	0.84	0.44	0.60	6/1	27	20
Software	0.12	0.27	0.12	0.18	7/1	9	6
Other (new CHS)	0.31	0.57	0.32	0.41	8/1	18	14
Human capital deepening	0.25	0.33	0.49	0.31	9/1	11	11
TFP growth	0.41	1.08	0.72	0.48	10/1	35	16

Notes: All data are average percentage growth rates per annum except for columns (5) and (6).

U.K. data starts in 1979 and is for the market sector. U.S. data is for the non-farm business sector.

The top panel excludes software, the middle panel includes software only, and the bottom panel all intangibles. In the top panel the first row shows the growth rate of labor productivity per hour. The second row shows capital deepening defined as share of capital times the growth rate of capital services per hour. Capital deepening is split in IT equipment (hardware in this case) and other tangible capital. Row (5) shows human capital deepening. Row (6) indicates the growth rate of TFP calculated as row (1) minus row (2) minus row (5). The middle panel shows the same information as the top panel, the only difference is that IT equipment includes also software. In the bottom panel the first row shows the growth of labor productivity per hour as above. The second row shows capital deepening, which is split into tangibles (row 3) and intangible (row 6). Tangibles are in turn spilt into IT equipment and other (which includes also the intangibles already in the National Accounts) and intangibles is split into software and other intangibles. Row (9) shows human capital deepening and row (10) TFP growth defined as above. The most direct comparison is for the years 1995–2003 and is summarized in the rightmost panel, with columns (5) and (6) showing each contribution as percentage of total Labor productivity growth (LPG).

Source: U.K. data our calculations. U.S. data CHS (2006).

5.5. *Contributions of Each Intangible Asset*

In Table 6 we look at intangible capital deepening and how much each component accounts for. As above, the table shows the U.S. and U.K. comparison pre-1995 and post-1995, with the rightmost panel showing post-1995 fractions of intangible capital deepening accounted for by each intangible category. The main results are the following. First, if we look at the right panel in the U.S. there is a large contribution of R&D, while the U.K. has more of a contribution from non-scientific R&D. Indeed the share of overall contribution of scientific R&D is almost zero in the U.K. This is an interesting result that accords with popular discussion that U.K. design is "strong" whilst U.K. R&D lags behind the U.S.

Second, in the U.K. there is a bit more contribution of firm-specific capital. This confirms the finding on other datasets that firm specific training is higher in the U.K. relative to the U.S.

TABLE 6

Comparison of Intangible Capital Deepening Contibution of LPG with the U.S.

All intangibles	U.S. 1979–95 (1)	U.S. 1995–2003 (2)	U.K. 1979–95 (3)	U.K. 1995–2003 (4)		U.S. 1995–2003 (5)	U.K. 1995–2003 (6)
Intangible capital deepening	0.43	0.84	0.47	0.59			
Computerized information	0.12	0.27	0.12	0.18	2/1	32	31
Innovative property	0.13	0.22	0.16	0.14	3/1	26	24
Scientific	0.05	0.08	0.06	0.01	4/1	10	1
Non-scientific	0.08	0.14	0.09	0.14	5/1	17	24
Economic competencies	0.17	0.35	0.19	0.26	6/1	42	45
Brand equity	0.04	0.08	0.04	0.04	7/1	10	6
Firm-specific resources	0.13	0.27	0.15	0.23	8/1	32	39

Notes: All data are average percentage growth rates per annum except for columns (5) and (6).

U.K. labor productivity growth is for the market sector. U.S. labor productivity growth is for the non-farm business sector.

The table splits intangible capital deepening, defined as the share of intangible capital times the growth rate of intangible capital services per hour, into its components. Brand Equity includes advertising and market research. Firm specific resources includes firm specific human capital and organizational structure. Scientific innovative property includes scientific R&D and mineral exploration. Non-scientific innovation includes copyright and licences costs, new product development costs in the financial industry, new architectural and engineering design, and R&D in social science and humanities. Computerized information includes software. The most direct comparison is for the years 1995–2003 and is summarized in the rightmost panel, with each contribution shown as a percentage of total intangible capital deepening.

Source: U.K. data our calculations. U.S. data CHS (2006).

5.6. *Comparison of the Effects of Adding Intangibles in the U.S. and U.K.*

Finally, we ask the question: what difference does the inclusion of intangibles make in each country? To answer that, Table 7 shows the differences between LPG and its constituent parts with and without intangibles, for the U.S. and the U.K. The upper panel shows the difference when we include all intangibles against when we exclude all intangibles and include software. The lower panel shows the difference between when we include all intangibles against when we include just software.

The main results are that the sign of the difference is the same in all cases: when we include intangibles in both the U.S. and the U.K., LPG and capital deepening rises and TFP falls. Turning to the details, the upper panel shows the increase in LPG from including intangibles with respect to the case in which we exclude software; this is quite similar in both countries: 0.31 in the U.S. and 0.34 in the U.K. The increase in capital deepening is higher in the U.S., but this could be because capital deepening in the U.K. is already quite high. The decline in TFP is more in the U.S., but again this could be because U.S. TFP is higher than in the U.K. to begin with.

The lower panel shows that the increase in LPG is similar in both countries, the increase of capital deepening is slightly higher in the U.S., and, as above, the decrease in TFP is higher in the U.S. If we compare the LPG of each country in both panels we can see that a considerable part of the effect of intangibles is due to software. If we look at the U.K., for example, we see the increase in LPG from zero

TABLE 7

Comparison of Intangibles Impact with the U.S.

	U.S.	U.K.
	1995–2003	1995–2003
Differences Between Data Including All Intangibles and Data, Encluding Software		
	(1)	(2)
Labour productivity	0.31	0.34
Capital deepening	0.70	0.50
Human capital deepening	–0.05	–0.05
TFP growth	–0.34	–0.10
Differences Between Data Including All Intangibles and Data, Including Software		
Labour productivity	0.14	0.19
Capital deepening	0.42	0.32
Human capital deepening	–0.04	–0.04
TFP growth	–0.24	–0.08

Notes: All data are average percentage growth rates per annum.

The table shows the differences between labor productivity growth and its constituent parts with and without intangibles, for the U.S. and the U.K.

The upper panel shows the difference when we include all intangibles against when we exclude all intangibles (also software). The lower panel shows the difference between when we include all intangibles against when we include software. Labor productivity is per hour. Capital deepening is share of capital times the growth rate of capital services per hour. Human capital deepening is share of labor times the difference between quality adjusted and non-adjusted hours growth. TFPG is the growth rate in total factor productivity calculated as labor productivity growth minus capital deepening and human capital deepening.

Source: U.K. data our calculations. U.S. data CHS (2006).

intangibles to all intangibles is 0.31 but this increase is reduced to 0.14 when we account for software.

5.7. *Sensitivity of Results*

Given the range of assumptions that we have had to make, an obvious question is how robust our results are. In Giorgio Marrano *et al.* (2007) we present a wide range of robustness checks including, for example, assuming much higher depreciation rates or using a smaller conversion factor (i.e. treating a lower proportion of spending as investment). In summary, we found that the quantitative results are robust to large changes in the depreciation rate and conversion factors. The qualitative direction of the effects for LPG and TFPG is robust but the quantitative effect is somewhat reduced, the slowdown in LPG and TFPG is rather reduced. The robustness of our results suggests that, despite the associated measurement issues and number of assumptions needed, our results shed light on the U.K. productivity record and the importance of intangible investment in understanding recent productivity performance.

We also undertook some further robustness checks, including a growth accounting analysis for 1990–2000, which encompasses an entire business cycle (peak-to-peak). We found that the inclusion of the intangibles raises LPG from 2.83ppa to 3.16ppa, and decreases TFPG from 0.58ppa to 0.50ppa. That intangibles continue to have an important impact when looking at an entire business cycle shows that our results are not just driven by our choice of periods for growth accounting.

6. Conclusion

This paper has tried to understand better the impact of the "knowledge economy" on recent U.K. economic performance. The central question is one of measurement and follows the important papers by Oulton and Srinivasan (2003a), Basu *et al.* (2003) and Oulton and Srinivasan (2005). We explore the consequences for a range of macroeconomic variables of treating intangible spending as investment.

We do this by assembling investment data on a range of knowledge assets, such as scientific R&D, but also including software, design, non-scientific R&D, and spending by firms on reputation, and human and organizational capital. We look at the consequences for MGVA and business investment. We then look at the consequences for productivity by calculating the new implied LPG and TFPG.

Our main findings are as follows. First, our data on investment in intangible assets look remarkably like those in the U.S. Nominal intangible investment in 2004 was about equal to nominal tangible investment spending, each around 15 percent of MGVA. Around 50 percent of total intangible investment is on economic competencies, 35 percent on innovative property, and 15 percent on computerized information. Since 1970, nominal investment has grown from about 6 percent of nominal MGVA to about 15 percent. Second, accounting for intangibles raises MGVA (by about 6 percent in 1970 and 13 percent in 2004) and also the shares of nominal investment and capital. Third, accounting for intangibles also affects LPG and TFPG. Without intangibles, we confirm previous work that LPG and TFPG both slow down between 1990–95 and 1995–2000. We also document a further slight slowdown in LPG in 2000–04, but a speedup in TFPG. With intangibles, the picture changes interestingly. First, both LPG and TFPG speed up between 1990–95 and 1995–2000. Second, even with intangibles, the post 2000 LPG slowdown still remains but TFPG speeds up.

We compare our estimates to the U.S. study by CHS (2006). Like them, from 1995 to 2003, including intangibles raises LPG and lowers TFPG but there are some interesting differences. First, in the U.K. more of LPG is capital deepening and more of that capital deepening is tangible capital deepening. Second, there are slightly different contributions from different intangible types: R&D makes more of a contribution to capital deepening in the U.S., but design and training make more of a contribution in the U.K.

Clearly much future work could be done to improve the estimates presented in this paper. Our robustness checks indicate a number of areas where more work might particularly inform our estimates. Perhaps the biggest is that whilst we think that company organizational capital is quantitatively important we do not have a very good measure of it, either own account spending or bought in knowledge, for example from consultants. Nor do we have very good deflators for many intangible assets at the moment. However, it is worth noting that our main results are robust to varying a number of these measures. All this suggests that the view of macro performance changes quite substantially with different measurement and so these questions are worth pursuing.

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