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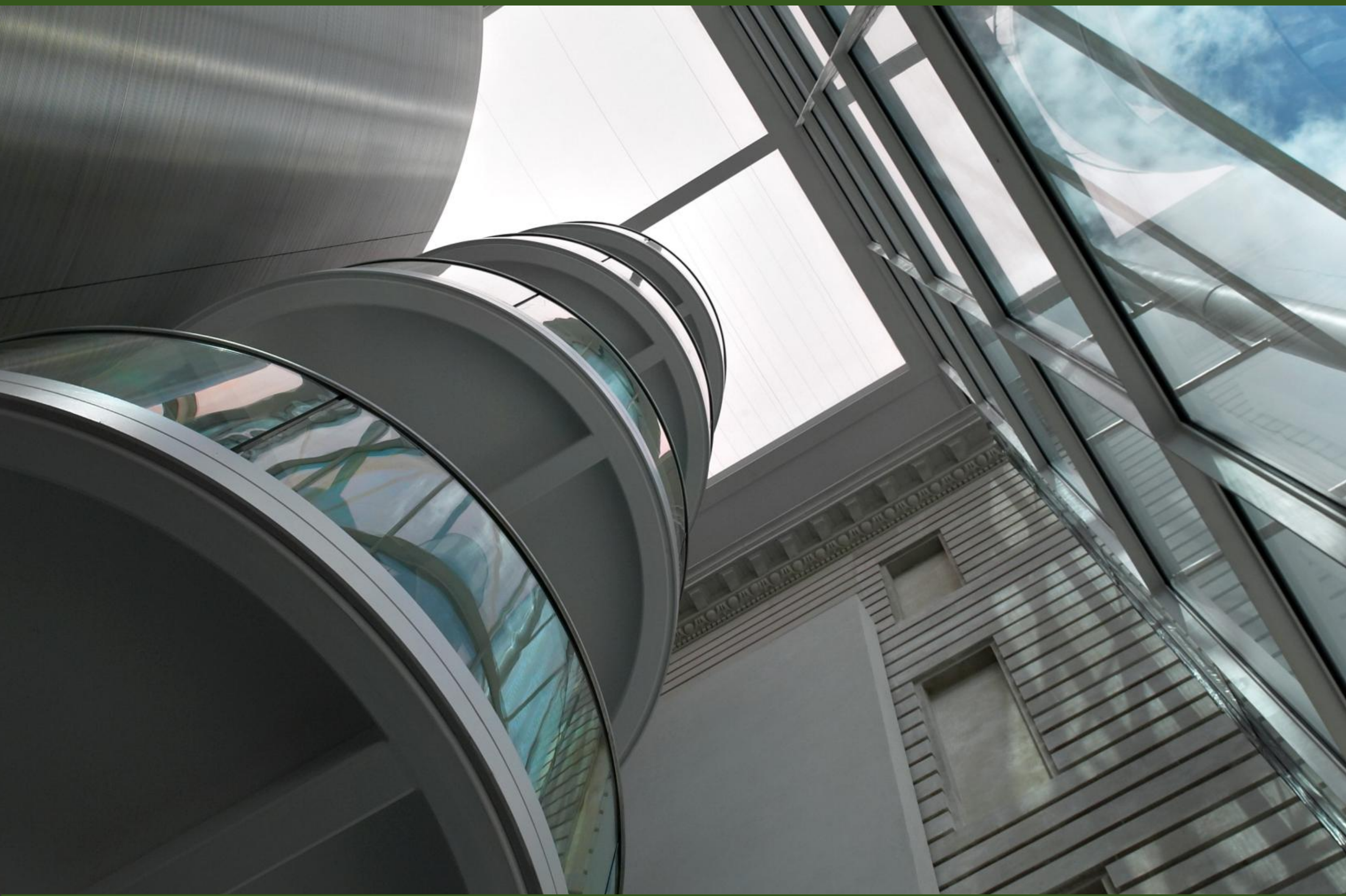
Mariela Dal Borgo, Peter Goodridge, Jonathan Haskel, Annarosa Pesole



Productivity and growth in UK industries: an intangible investment approach

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Productivity and Growth in UK Industries: An Intangible Investment Approach*

Mariela Dal Borgo
University of Warwick

Peter Goodridge
Imperial College Business School

Jonathan Haskel
Imperial College Business School; CEPR and IZA

Annarosa Pesole
Imperial College Business School

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Abstract

This paper tries to calculate some facts for the "knowledge economy". Building on the work of Corrado, Hulten and Sichel (CHS, 2005,9), using new data sets and a new micro survey, we (1) document UK intangible investment and (2) see how it contributes to economic growth. Regarding investment in knowledge/intangibles, we find (a) this is now greater than tangible investment at, in 2008, £141bn and £104bn respectively; (b) that R&D is about 11% of total intangible investment, software 15%, design 17%, and training and organizational capital 22%; (d) the most intangible-intensive industry is manufacturing (intangible investment is 20% of value added) and (e) treating intangible expenditure as investment raises market sector value added growth in the 1990s due to the ICT investment boom, but slightly reduces it in the 2000s. Regarding the contribution to growth, for 2000-08, (a) intangible capital deepening accounts for 23% of labour productivity growth, against computer hardware (12%) and TFP (40%); (b) adding intangibles to growth accounting lowers TFP growth by about 15% (c) capitalising R&D adds 0.03% to input growth and reduces ΔlnTFP by 0.03% and (d) manufacturing accounts for just over 40% of intangible capital deepening plus TFP.

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*Contact: Jonathan Haskel, Imperial College Business School, Imperial College, London SW7 2AZ, j.haskel@imperial.ac.uk. We are very grateful for financial support from NESTA and UKIRC and thank Nick Oulton and Brian MacAulay for useful comments.

1 Introduction

What drives growth in increasingly knowledge-intensive economies? The sources of growth are of course an enduring subject of interest for academics and policy-makers alike, and since at least Solow (1956), have been studied in a growth accounting framework. Whilst this gives the proximate sources, namely capital deepening, skills and total factor productivity, and not the ultimate sources (e.g. legal framework) it is, most are agreed, an important first step in marshalling data and uncovering stylized facts that other frameworks might explain.

The productivity consequences of the ICT revolution have been studied in a growth accounting framework by many authors in many countries (see e.g. Timmer, O'Mahony, van Ark and Inklaar 2010, Jorgenson et al, 2007). But hanging over this literature is an early suggestion, (Brynjolfsson and Hitt 2000) for example, that investment in computer hardware needed complementary investments in knowledge assets, such as software and business processes, to reap productivity advantages. This re-awakened interest in the application of the sources of growth framework to information and knowledge-intensive economies. For free knowledge (e.g. from universities or the internet), the framework is quite clear: if competitive assumptions hold, total factor productivity growth (TFPG) measures the growth contribution of knowledge that is costless to obtain and implement.

However, there are two points illustrated nicely by Tufano's (1998) description of a typical financial product innovation. He states it requires

> *"an investment of $50,000 to $5 million, which includes (a) payments for legal, accounting, regulatory, and tax advice, (b) time spent educating issuers, investors, and traders, (c) investments in computer systems for pricing and trading, and (d) capital and personnel commitments to support market-making*."

First, in this example knowledge is not costless to obtain or commercialise and so cannot be relegated to TFPG. Second, a long-established literature adds R&D to the growth accounting framework. But, some industries e.g. finance and retailing, do no (measured) R&D[1]. Thus one needs to consider knowledge investment besides R&D: this example suggests training, marketing and organisational investments for example. Thus our objective in this paper is to better measure growth and its sources for the UK economy where:

(a) knowledge development and implementation is not costless, and

(b) R&D is not the only knowledge investment.

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[1] The qualification measured is important. In the UK at least, the Business Enterprise R&D survey (BERD) defines R&D to respondents as 'undertaken to resolve scientific and technological uncertainty'. Indeed, up until very recently, no firms in financial intermediation for example were even sent a form. See below for more discussion.

To do this, this paper implements the framework set out in the widely-cited papers by Corrado, Hulten and Sichel (2005, 9, CHS). Whilst CHS builds upon the methods of capitalising tangible assets, and intangible assets such as software which are now capitalised in national accounts, it was the first paper to broaden the approach to a fuller range of intangible or knowledge assets.[2] Thus it fits with the range of innovation investments mentioned above.

More specifically, we seek to do two things in this paper. First, we seek to measure investment in intangible assets at an aggregate and industry level. This part of the paper takes no stand on growth accounting. We believe it of interest for it tries to document knowledge investment in industries where measured R&D is apparently very low, such as finance and retailing. Current data can document the physical, software and human capital deepening in these industries (and also R&D, when capitalised in the National Accounts in 2014). However, this paper tries to ask and answer whether we are missing significant investment in knowledge or ideas in these sectors.[3]

Second, we use these data to perform a sources-of-growth analysis for the UK using the CHS framework. Whilst one might have reservations about the assumptions required for growth accounting, see below, we believe this is also of interest. The main reason is that it enables us to investigate a number of questions that could either not be addressed without these data, or all relegated to the residual. First, as CHS stress, the capitalisation of knowledge changes the measures of both inputs and outputs. Insofar as it changes outputs, it alters the labour productivity picture for an economy. Thus we can ask: what was the productivity performance in the late 1990s when the UK economy was investing very heavily (as we document below) in intangible assets during the early stages of the internet boom?

Second, we can then ask: how was that performance accounted for by contributions of labour, tangible capital, intangible capital and the residual? Here we can describe how sources of growth will differ when R&D is capitalised and how other knowledge contribute and alter TFP. Third, we also ask and try to answer this question at industry level. So we can ask, for example, how much productivity in non-R&D intensive sectors, such as retail and financial, was accounted for by other intangibles or was it mostly TFPG?

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[2] Earlier contributions were made by Nakamura (1999, 2001) and Machlup (1962). For European data see Jona-Lasinio, C., Iommi, M. and Roth, F. (2009) and van Ark, Hao, Corrado, Hulten, (2009).

[3] We also shed light on recent considerable interest in "creative" industries, including the software, design, film/television, literary, music, and other artistic industries. Most papers that study such activity select a number of creative industries, and then document their employment or value added from published sources. This understates the output of creative assets, since much intangible creation is done on own-account in industries not in the usual creative list e.g. software spending in financial services or design in retail. Nor does this approach show how much creative industries contribute to economic growth, as we are able to do (conditional on the assumptions we make).

In implementing the CHS framework, we proceed as follows, going, we believe, a bit beyond their work for the US. First, we gather data on the intangible assets that CHS suggest, but by industry (Fukao et al (2009) and van Rooijen-Horsten, van den Bergen and Tanriseven (2008) do this for Japan and Holland, but they do not do growth accounting to derive the contributions of the industries to the total).

Second, we update some of the methods of CHS. For example, much intangible spend, like R&D, is own-account. CHS had no own-account estimates for design or for financial services. We apply the National Accounts software method to estimate such own-account spending, using interviews with design and financial companies to identify occupations and time use and thereby derive intangible spend from wage data.[4] In addition, there is almost no information on the depreciation of intangible assets.[5] Thus we conducted a survey of over 800 companies on the life lengths of their intangible spend, by asset, to gather data on depreciation.

Third, we provide (gross output based) growth accounting results by industry aggregated consistently into value-added based growth accounting for the UK market sector, using the approach of Jorgenson, Ho, Samuels, Stiroh (2007). Thus we can examine the contributions of different industries to overall growth. This then speaks to the question of, for example, how much manufacturing versus financial services contributed to overall TFP growth.

On specifically UK data, our work is mostly closely related to the industry-level work (Basu, Fernald, Oulton, Srinivasan et al. 2004). They incorporated software as a productive asset and looked at productivity and TFPG in 28 industries 1990 to 2000. They did not have data however on other intangible assets and so whilst they were able to document software and hardware spending across industries, they were not able to look at other co-investments in innovation. As will be clear however, we rely heavily on their important work on measuring software and also tangible assets, now embodied in official UK data collection. Likewise, our work is also closely related to EUKLEMS (O'Mahony and Timmer, 2009). Their dataset includes software, and we extend their framework with additional intangibles, explicitly setting out the industry/market sector aggregation.

Whilst growth accounting is an internally consistent method for analysing productivity growth there are of course limits to the analysis that caveat our work. First, in the absence of independent measures of the return to capital we are compelled to assume

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[4] Official own-account software investment is estimated by (1) finding software writing occupations, (2) applying a multiple to their wage bills to account for overhead costs and (3) applying a fraction of time such occupations spend on writing long-lived software as opposed to short term bug fixes, maintenance etc. We duplicate this approach for finance and design.

[5] With the honourable exception of Soloveichik (2010) who estimates depreciation rates for artistic originals and Peleg (2005) who surveyed a small number of Israeli R&D performers.

constant returns to scale and perfect competition to measure the output elasticities of capital residually from the cost share of labour. A consistent framework for growth and innovation accounting with these assumptions relaxed is outside the scope of this current paper. But we hope that readers sceptical of the growth accounting assumptions would still find of interest the findings on knowledge investment and how their addition to the growth accounting framework changes the usual findings (which turns out to be quite considerably). We also hope that readers likewise sceptical of capitalising the full range of intangibles will find our work on R&D, which is to be officially capitalised in 2014, of interest.

Second, like other work in this area, we are of course limited in what we can do by data uncertainty. Measures of intangible assets are clearly difficult to obtain, especially for the own-account part of organisational capital. Deflators for intangibles are as yet uncertain. Our industry data covers seven broad industries in the UK market sector since finer detail on intangible spend is very hard to obtain.

We have two sets of findings (a) on knowledge spending and (b) implications for growth. On *knowledge spending,* first, investment in long-lived knowledge, which creates intangible assets, now exceeds tangible investment, at around, in 2008, £141bn and £104bn respectively. R&D is about 10% of such spend. Training, design and software are the largest categories of intangible investment, and are particularly important in services. The effect on market sector gross value added (MGVA) of treating intangible expenditure as investment is to raise MGVA growth in the 1990s, but slightly reduce it in the 2000s. Second, around 60% of this spending is own account. Thus measures of the "creative economy" (ONS, 2006) that assemble data for a list of "creative industries" are missing significant creative activity outside those industries.

On the *implications for growth,* for 2000-08, the most recent period with data available, intangible capital deepening accounts for 23% of labour productivity growth, a larger contribution than computer hardware (12%), other tangible investments (18%, buildings, vehicles, plant) or human capital (7%). The largest contribution is TFP, at 40%. These findings are quite robust to variations in depreciation and assumptions on intangible measures. Capitalized R&D accounts for about 2% of LPG and lowers the contribution of TFP by 2 percentage points.

Regarding industries, the main finding here is the importance of manufacturing, which contributes just over 40% of the total contribution to MGVA growth of intangible investment and TFPG (but with a 20% employment share). We also find important roles for retail/hotels/transport, (27% of the total contribution), business services (22%) and finance (12%).

The rest of this paper proceeds as follows. Section 2 sets out a formal model, and section 3 our data collection. Section 4 our results and section 5 concludes.

2 A formal model and definitions

In this paper we undertake growth accounting for the UK market sector. But we are also interested in how industries contribute to the overall changes. Thus we follow Jorgenson et al (2007), see also Hulten (1992, 2000). The key point is that at industry level, a value added production function exists under restrictive assumptions and it is therefore preferable to work with TFP computed from gross output. But at the aggregate level, productivity is best defined using value added (to avoid double counting). So what is the relation between the industry components of growth and the whole market sector?

We start with two definitions of TFPG. Supposing there is one capital, labour and intermediate asset (respectively K, L and X) which produce output Y_j in industry j. That capital asset might or might not be intangible capital. Thus for each industry, we have the following gross output defined $\Delta\ln TFP_j$

$$\Delta\ln TFP_j \equiv \Delta\ln Y_j - \bar{v}_{K,j}\Delta\ln K_j - \bar{v}_{L,j}\Delta\ln L_j - \bar{v}_{X,j}\Delta\ln X_j \quad (1)$$

Where the terms in "v" are shares of factor costs in industry nominal gross output, averaged over two periods. For the economy as a whole, the definition of economy wide $\Delta\ln TFP$ based on value added is

$$\Delta\ln TFP \equiv \Delta\ln V - \bar{v}_K\Delta\ln K - \bar{v}_L\Delta\ln L \quad (2)$$

Where the "v" terms here, that are not subscripted by "j", are shares of K and L payments in economy wide nominal value added. Now we write down two definitions. First, define the relation between industry gross output and industry value added as

$$\Delta\ln Y_j \equiv \bar{v}_{V,j}\Delta\ln V_j + \bar{v}_{X,j}\Delta\ln X_j \quad (3)$$

which says that (changes in real) industry gross are weighted averages of changes in real value added and intermediates. Second, write changes in aggregate real value added as a weighted sum of changes in industry real value added as follows.

$$\Delta\ln V \equiv \sum_j \bar{w}_j\Delta\ln V_j, \quad w_j = P_{V,j}V_j \Big/ \sum_j (P_{V,j}V_j), \bar{w}_j = 0.5(w_{j,t} + w_{j,t-1}) \quad (4)$$

We may then write down value added growth in the industry as a weighted average of K, L and (gross output-based) $\Delta\ln TFP_j$

$$\Delta\ln V_j = \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}}\Delta\ln K_j + \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}}\Delta\ln L_j + \frac{1}{\bar{v}_{V,j}}\Delta\ln TFP_j \tag{5}$$

where the weights on K and L are a combination of the shares of K and L in industry gross output and the shares of industry gross output in aggregate value added.

We are now in position to write down our desired relationship, that is the relation between economy-wide real value added growth and its industry contributions

$$\Delta\ln V = \left(\sum_j \bar{w}_j \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}}\Delta\ln K_j\right) + \left(\sum_j \bar{w}_j \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}}\Delta\ln L_j\right) + \sum_j \frac{\bar{w}_j}{\bar{v}_{V,j}}\Delta\ln TFP_j \tag{6}$$

Which says that the contributions of K_j and L_j to whole-economy value added growth depend upon the share of V_j in total V (w_j) the share of K and L in gross and value added. The contribution of $\Delta\ln TFP_j$ depends on the share of V_j in total V (w_j) and the share of industry value added in gross output. As Jorgenson et al point out, the weight on TFP is approximately $(P_{Y,j}Y_j / P_V V)$ which is of course the usual interpretation of the Domar (1961) weight. It sums to more than one, since an improvement in industry TFP contributes directly to the average of all TFPs and indirectly if it produces output that is then an intermediate in other industries.[6]

Finally, in reality we do not of course have one capital and labour unit, but many. These are then aggregated across different types: for labour, see below, we use, education, age (experience), and gender; for capital, different types of both tangible assets and intangible assets. Denoting the capital and labour types *k* and *l* we have following industry and aggregate variables for each type where industry is defined as industry *j* and the aggregate variables are unsubscripted:

[6] As JGHS point out, comparing (6) with (2) gives the relation between this industry aggregated input/output relation and that implied by the TFP expression in (2), which involves some additional terms in reallocation of K and L between industries. These terms turn out to be very small in our data.

$$\Delta \ln K = \sum_k \bar{w}_k \Delta \ln K_k, \quad \textit{capital type k}$$
$$\Delta \ln L = \sum_l \bar{w}_l \Delta \ln L_l, \quad \textit{labour type l}$$
$$\bar{w}_k = P_{K,k}K_k / \sum_k (P_{K,k}K_k), \bar{w}_l = P_{l,l}K_l / \sum_l P_{L,l}K_l, K_j = \sum_j K_{k,j} \forall k, L_j = \sum_j L_{l,j} \forall l, \quad (7)$$
$$\bar{w}_t = 0.5(w_t + w_{t-1})$$

In our results we document the following. First, we set out the gross output growth accounting results for each industry, (1). Second, we take these data and set out the contributions for each industry to the growth of aggregate value added, (6) . Third, we sum up the contributions across industries to the decomposition of aggregate (market sector) value-added, (6) In each case we carry out the decomposition with and without intangibles.

Before proceeding to the data, some further theory remarks on the measurement of capital. As pointed out by e.g. Jorgenson and Grilliches (1967) the conceptually correct measure of capital in this productivity context is the flow of capital services. This raises a number of measurement problems set out, for example, in the OECD productivity handbook (2004). We estimate the now standard measure as follows. First, we build a real capital stock via the perpetual inventory method whereby for any capital asset k, the stock of that assets evolves according to

$$K_{k,t} = I_{k,t} + (1-\delta_{k,t})K_{k,t-1} \quad (8)$$

Where I is investment over the relevant period and δ the geometric rate of depreciation. Real tangible investment comes from nominal tangible investment deflated by an investment price index. Second, that investment price is converted into a rental price using the Hall-Jorgenson relation, where we assume an economy-wide rate of return such that the capital rental price times the capital stock equals the total economy-wide operating surplus (on all of this, see for example, (Oulton 2007) and Oulton and Srinivasan, (2003).

3 Data

3.1 Time period

For the industry analysis, ONS does not publish real intermediate input data and so we used the EUKLEMS, November 2009 release which gives data up to 2007. For intangibles, our industry level data is available 1992-2007 since this is when Input-Output (IO) tables are consistently available from. Data for the whole market sector is available going back to 1980 up to 2008 (the most recent year National Accounts are available). Thus we work with two data sets: (1) market sector, 1980-2008, consistent with National Accounts 2008, and (2) industry level 1992-2007 (the data turn out to be very close over the overlapping years).

3.2 Industries

The EUKLEMS data includes measures of output, and various categories of employment and capital at the industry level for 71 industries, classified according to the European NACE revision 1 classification. We then aggregate these data to the seven industries described in Table 1. The choice of the seven industries is dictated by the availability of the intangible data: training and management consulting data are only available at these aggregated levels.

Table 1: Definition of seven industries

#	**Sectors**	**SIC(2003) code**		**NACE1 sections**
1	Agriculture, Fishing and Mining (AgrMin)	1 - 14	A	Agriculture, hunting and forestry
			B	Fishing
			C	Mining and quarrying
2	Manufacturing (Mfr)	15 - 37	D	Total manufacturing
3	Electricity, Gas and Water Supply (Util)	40 - 41	E	Electricity, gas and water supply
4	Construction (Constr)	45	F	Construction
5	Wholesale and Retail Trade, Hotels and Restaurants, Transport and Communications (RtHtTran)	50 - 64	G	Wholesale and retail trade
			H	Hotels and restaurants
			I	Transport and storage and communication
6	Financial Intermediation (FinSvc)	65 – 69	J	Financial intermediation
7	Business Services (BusSvc)	71- 74	K	Business activities, excluding real estate and renting of dwellings

We measure output for the market sector, defined here as industries A to K, excluding actual and imputed housing rents. Note this differs from the ONS official market sector definition, which includes part of sections O and P, as well as the private delivery of education, health and social care. Since sections O and P include hard-to-measure areas like museums and refuse collection we omitted them. We also used disaggregated real value added data for this industry definition.

For the years where industry level data is available, the data are bottom-up, that is derived at the industry level and aggregated subsequently. Aggregation of nominal variables is by simple addition. Aggregates of real variables are a share-weighted superlative index for changes, benchmarked in levels to 2005 nominal data. For other years, the intangible data are for the market sector and the other output and input data from ONS, latest National Accounts, aggregated from industry values.

3.3 Outputs and tangible and labour inputs.

EUKLEMS also provides growth accounting data, but since we have expanded the amount of capital and changed value added we do our own growth accounting. In addition, the EUKLEMS labour composition data is slightly different to the ONS data (ONS have access to more data). From the output and intermediate accounts of the EU KLEMS dataset we have used the series of industry Gross Output and Gross Value Added at current basic prices, Intermediate Inputs at current purchasers' prices and their corresponding price and volume indices. Intermediate inputs comprise energy, materials and services.

The tangible capital variables from EUKLEMS that we used are nominal and real gross fixed capital formation, the corresponding price index, real fixed capital stock and capital compensation, all disaggregated by type of assets. Capital compensation equals the sum of the gross operating surplus, which includes the remainder of mixed income, plus taxes on production, after subtracting labour compensation of the self-employed. In practice, it is derived as value added minus labour compensation. We shall of course amend capital compensation to incorporate compensation for intangible capital assets.

The EUKLEMS capital data distinguishes nine asset types, of which we use transport equipment, computing and communications equipment and other machinery and equipment, and total non-residential investment. We use ONS estimates for software. We excluded residential structures (they are not capital for firm productivity analysis).

Depreciation rates for ICT tangible capital are as in the EUKLEMS, which in turn follows Jorgenson et al. (2005). Depreciation is assumed to be geometric at rates for vehicles, buildings, plant and computer equipment of 0.25, 0.025, 0.13 and 0.40 respectively. As for intangible assets, they are assumed to be the same for all industries. Given that the EU KLEMS database does not provide data on capital tax rates by country, industry and year and that Timmer et al. (2007) point out that evidence for major European countries shows that their inclusion has only a very minor effect on growth rates of capital services and TFP, we did not introduce a tax adjustment.

3.4 Labour services

The labour services data are for 1992-2007 and are our own estimates based on EUKLEMS person-hours by industry. We use these along with LFS microdata to estimate composition-adjusted person hours, where the adjustment uses wage bill shares for composition groups for age, education and gender. Person hours are annual person-hours, with persons including the employed, self-employed and those with two jobs. For the longer period based on market sector aggregates, we use an equivalent method, using LFS microdata to generate wages and average hours worked at the individual level and then gross up using population weights.

3.5 Comparison with ONS data

To form ONS data on value added and capital services, we use industry level ONS value added and capital services data and add up sectors A to K, subtracting off residential real estate, as described above. How do the KLEMS data compare with the disaggregated ONS data? The real output data are almost exactly the same, as are the capital services data. The labour input data are different. First, the KLEMS data has fewer workers in financial services, but more in business services than the ONS data. We suspect this may be due to the treatment of agency workers of whom there are many in financial services, but employed by agencies in business services and hence their appropriate treatment is a problem. This means that productivity growth in financial services is much higher in KLEMS relative to the ONS, but somewhat less in business services. Second, the KLEMS quality adjusted labour series grows faster than the ONS series.

3.6 Labour and capital shares

The Compensation of Employees (COE) data are consistent with the labour services data. Mixed income is allocated to labour according to the ratio of labour payments to MGVA excluding mixed income. With intangibles capitalised, MGVA changes, and the allocation is done on the basis of this changed ratio. Gross operating surplus (GOS) is always computed as MGVA less COE so that GOS +COE =MGVA by construction.

3.7 Details of measurement of intangible Assets

CHS (2006) distinguish three classes of intangible assets:

i) *computerised information*; software and databases

ii) *innovative property;* (scientific & non-scientific) R&D, design (including architectural and engineering design) , product development in the financial industry, exploration of minerals and production of artistic originals.

iii) *economic competencies*. firm investment in reputation, human and organisational capital.

Our intangible data update industry-level data reported in Gill and Haskel (2008). Own account investment is allocated to the industry wherein the investment is carried out. Purchased is allocated to industries via the input output tables. Particular industry categories (e.g. product development in finance, exploration of minerals, copyright) are allocated to that industry.[7]

3.7.1 Computerised information

Computerised information comprises computer software, both purchased and own-account, and computerized databases. Software is already capitalised and thus we use these data, by industry, as described by Chesson and Chamberlin (2006). Purchased software data are based on company investment surveys and own-account based on the wage bill of employees in computer software occupations, adjusted downwards for the fraction of time spent on creating new software (as opposed to, say routine maintenance) and then upwards for associated overhead costs (a method we use for design below). Software is already included in the EUKLEMS, but for consistency, we subtract it out of all variables and build our own stock and implied service flow using the ONS data.

3.7.2 Innovative property

For business *Scientific R&D* we use expenditure data by industry derived from the Business Enterprise R&D survey (BERD). To avoid double counting of R&D and software investment, we subtract R&D spending in "computer and related activities" (SIC 72) from R&D spending since this is already included in the software investment data.[8]

Like computerised information, *mineral exploration, and production of artistic originals* (copyright for short) are already capitalised in National Accounts and the data here are simply data for Gross Fixed Capital Formation (GFCF) from the ONS. The production of artistic originals covers, "original films, sound recordings, manuscripts, tapes etc, on which musical and drama performances, TV and radio programmes, and literary and artistic output

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[7] Copyright, or more accurately, investment in artistic originals, is problematic for the correct allocation likely is somewhere between publishers (manufacturing) and artists, since each have some ownership share of the final original. The latter are mostly in the omitted sector "O", which covers a miscellany of businesses from performing arts to museums to recycling. Overall however, the numbers are very small and any error likely trivial.

[8] The BERD data gives data on own-account spending. Spending is allocated to the industry within which the product upon which firms are spending belongs. That is we assume that R&D on say, pharmaceutical products takes place in the pharmaceutical industry. General R&D spending is allocated to business services. Thus the BERD data differs from that in the supply use tables, which estimates between-unit transactions of R&D.

are recorded." Based on work currently in progress for the IPO (Goodridge and Haskel, 2011) we suspect that these investment numbers are understated and so should be regarded as a lower bound on the true numbers. Expenses on *mineral exploration* are valued at cost (ONS National Accounts, 2008) and explicitly not included in R&D.

The measurement methodology for *New product development costs in the financial industry* follows that of own account software above (and therefore replaces the CHS assumption of 20 percent of intermediate consumption by the financial services industry). This new method reduces this category substantially. Further details are in Haskel and Pesole (2009) but a brief outline is as follows. First, we interviewed a number of financial firms to try to identify the job titles of workers who were responsible for product development. Second, we compared these titles with the available occupational and wage data from the Annual Survey on Hours and Earnings (ASHE). The occupational classification most aligned with the job titles was 'economists, statisticians and researchers'. Third, we asked our interviewees how much time was spent by these occupations on developing new products that would last more than a year. Some firms based their estimates on time sheets that staff filled out. Fourth, we asked firms about the associated overhead costs with such workers. Armed with these estimates, we went to the occupational data in the ASHE and derived a time series of earnings for those particular occupations in financial intermediation. Own-account investment in product development is therefore the wage bill, times a mark-up for other costs (capital, overheads etc.), times the fraction of time those occupations spend on building long-term projects. All this comes to around 0.52% of gross output in 2005 (note that reported R&D in BERD is 0.01% of gross output).

For new *architectural and engineering design* we again updated the CHS method (that used output of the design industry). To measure better such spending, we used the software method for own-account, and purchased data, by industry, are taken from the supply-use tables, see details in Galindo-Rueda et al (2011). The choice of occupations and the time allocation are, as in financial services, taken from interviews with a number of design firms. Interestingly, almost all of the design firms we interviewed have time sheets for their employees which break out their time into administration, design and client interaction/pitching for new business (almost all firms target, for example, that junior designers spend little time on administration and senior more time on pitching). Finally, *R&D in social sciences and humanities* is estimated as twice the turnover of SIC73.2 "Social sciences and humanities", where the doubling is assumed to capture own-account spending. This is a small number.

3.7.3 Economic competencies

Advertising expenditure is estimated from the IO Tables by summing intermediate consumption on Advertising (product group 113) for each industry. *Firm-specific human capital*, that is training provided by firms, was estimated as follows. Whilst there are a number of surveys (such as the Labour Force Survey) who ask binary questions (such as whether the worker received training around the Census date), to the best of our knowledge there is only one survey on company training spending, namely the National Employer Skills Survey (NESS) which we have available for 2004, 2006, 2007.[9] We also have summary data for 1988 (from an unpublished paper kindly supplied by John Barber). The key feature of the survey, like the US Survey of Employer-provided Training (SEPT) used in CHS, is that it asks for direct employer spending on training (e.g. in house training centres, courses bought in etc.) and indirect costs via the opportunity cost of the employee's time whilst spend training and therefore not in current production.[10] This opportunity costs turns out to be about equal to the former.

One question is whether all such surveyed training creates a lasting asset or is some of it short-lived. We lack detailed knowledge on this, but have subtracted spending on Health and Safety training, around 10% of total spend. Whilst this subtraction lowers the level of training spending, it turns out to affect the contribution of training to growth at only the 4th decimal place. A second question is the extent to which such training financed by the firm might be incident on the worker, in the sense of reducing worker pay relative to what it might have been without training, unobserved by the data gatherer. O'Mahony and Peng (2010) use the fraction of time that training is reported to be outside working hours, arguing that such a fraction is bourne by the worker. Our data is all for training in working hours.

Finally, our data on investment in *organisational structure* relies on purchased management consulting, on which we have consulted the Management Consultancy Association (MCA), and own-account time-spend, the value of the latter being 20% of managerial wages, where managers are defined via occupational definitions. We test the robustness of the 20% figure below.

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[9] For example NESS07 samples 79,000 establishments in England and spending data is collected in a follow-up survey among 7,190 establishments who reported during the main NESS07 survey that they had funded or arranged training in the previous 12 months. Results were grossed-up to the UK population. To obtain a time series, we backcast the industry level series using EU KLEMS wage bill data benchmarking the data to four cross sections.

[10] Firms are asked how many paid hours workers spend away from production whilst training and the hourly wage of such workers.

3.8 Prices and depreciation

Rates of depreciation and the prices of intangible assets are less well established. The R&D literature appears to have settled on a depreciation rate of around 20%, and OECD recommend 33% for software. Solovechik (2010) has a range of 5% to 30% for artistic originals, depending on the particular asset in question. To shed light on this and the deprecation of other assets, in our intangible assets survey we asked for life lengths for various intangibles (Awano, Franklin, Haskel and Kastrinaki, 2009). The responses we obtained were close to the assumed depreciation rates in CHS, depending on the assumptions one makes about declining balance depreciation. Thus we use 33% for software, 60% for advertising and market research, 40% for training and organisational investments, and 20% for R&D. Once again, we shall explore the robustness of our results to depreciation, but note in passing that our assets are assumed to depreciate very fast and so are not very sensitive to deprecation rates, unless one assumes much slower rates, in which case intangibles are even more important than suggested here.

The asset price deflators for software are the official deflators (own-account and purchased), but otherwise the GDP deflator is used for intangible assets. This is an area where almost nothing is known, aside from some very exploratory work by the BEA and Corrado, Goodridge and Haskel (2011). These papers attempt to derive price deflators for knowledge from the price behaviour of knowledge intensive industries and the productivity of knowledge producing industries. Two observations suggest that using the GDP deflator overstates the price deflator for knowledge, and so understates the impact of knowledge on the economy. First, many knowledge-intensive prices have been falling relative to GDP. Second, the advent of the internet and computers would seem to be a potential large rise in the capability of innovators to innovate, which would again suggest a lowering of the price of knowledge, in contrast to the rise in prices implied by the GDP deflator. Thus our use of the GDP deflator almost certainly understates the importance of intangible assets.

3.9 Relation of intangible approach to other approaches

Haskel et al (2009, 2010) discusses how this work relates to the definition of innovation and the Frascati and Oslo manuals. It is clearly consistent with the work on IT and economic growth, see, for example, Jorgenson, Ho and Stiroh (2007), the capitalisation of software and the forthcoming capitalisation of R&D in national accounts, both of which are part of the process of recognizing spending on intangibles as building a (knowledge) capital stock. Van Ark and Hulten (2007) point out that with an expanded view of capital following the CHS argument innovation "*…would appear in several forms in the sources of growth framework: through the explicit breakout of IT capital formation, through the addition of intangible capital to both the input and output sides of the source of growth equation, through the* *inclusion of human capital formation in the form of changes in labor "quality," and through the "multifactor productivity" (MFP) residual"* For shorthand, we refer to "innovation" contribution as the sum of the intangible contribution and TFP (and sometimes labour composition), but take no stand on this: we provide other components for the reader.

3.10 Accuracy of intangible measures

The following points are worth making. First, data on minerals, copyright, software and R&D are taken from official sources. As mentioned above, preliminary work suggests an undercounting of copyright spending. Second, data on workplace training are taken from successive waves of an official government survey, weighted using ONS sampling weights. Once again one might worry that such data are subject to biases and the like but this does look like the best source currently available.

Third, data on design, finance and investment in organisational capital are calculated using the software method for own-account spending, but the IO tables for bought-in spend. The use of the IO tables at least ensures the bought in data are consistent with the Blue Book. The use of the own account software method means that we have to identify the occupations who undertake knowledge investment, the time fraction they spend on it and additional overhead costs in doing so. For design and financial services we have followed the software method by undertaking interviews with firms to try to obtain data on these measures. Such interviews are of course just a start but our estimates are based then on these data points. For own-account organisational change we use an assumed fraction of time spent (20%) by managers on organisational development. We have been unable to improve on this estimate in interviews and so this remains a subject for future work: below we test for robustness to this assumption.

To examine all further, we undertook two further studies. First, we used survey data kindly supplied by Stephen Roper and described in detail in Barnett (2009). These data ask around 1,500 firms about their spending on software, branding, R&D, design and organisational capital. The firms are sampled from service and hi-tech manufacturing industries. Comparison of the proportions of spend on the intangible assets with those proportions in our manufacturing and business services gives similar answers.

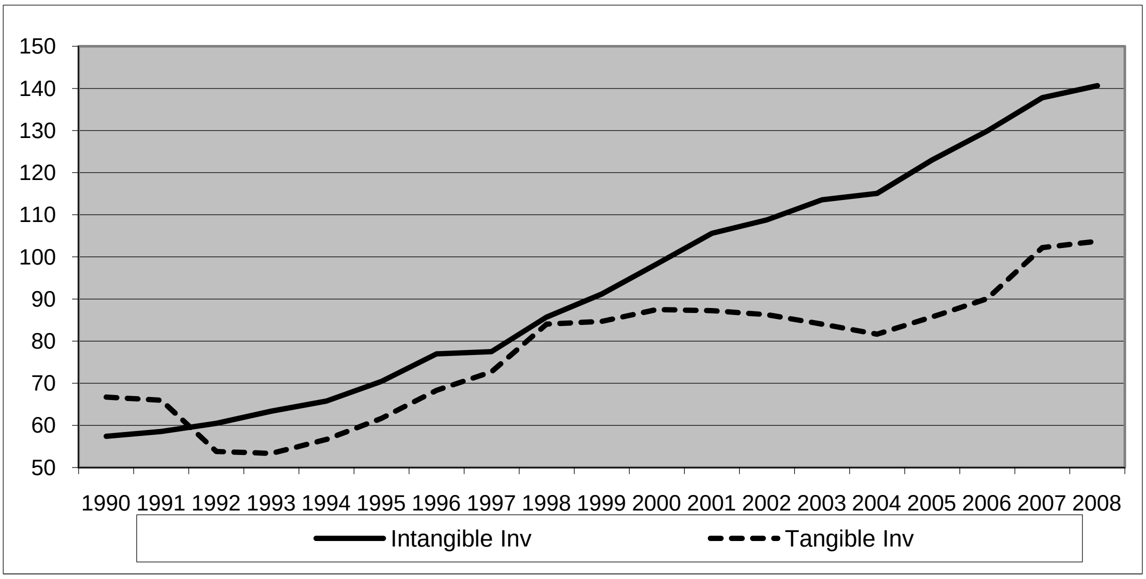
Second, we undertook an new survey of firms, the results of which are fully documented in Awano et al (2010). In terms of the spending numbers here, that micro study found spending on R&D, software, marketing and training to be in line with the macro-based numbers in this report. However, the implied spending on design and organisational capital were very much lower in the survey. This again suggests that these investment data require further work.

4 Results

4.1 Intangible spending: market sector over time

Figure 1 presents market sector nominal total tangible and intangible investment data. In the late 1990s intangible investment has exceeded tangible. Note that, intangible investment falls less and recovers more quickly during recessions. However, see below, depreciation rates for intangible assets are significantly faster than those for tangibles. Thus a relatively small slowdown in intangible investment turns out to generate the same fall in capital stock as a steep fall in tangible spend, so the changes in resulting capital services are similar.

Figure 1: **Market sector tangible and intangible investment, £bn, 1990-2008**



Source: ONS data for tangibles, this paper for intangibles. All data in current prices

Table 1 shows investment by intangible asset for 1990, 1995, 2000 and 2008 with tangible investment for comparison. The intangible category with the highest investment figures is training, growing to approximately a third of tangible investment by 2008. For information we also report GDP and MGVA excluding intangibles.

Table 1: **Tangible and Intangible Investment, £bns**

Year	**1990**	**1995**	**2000**	**2008**	***2008***
All tangibles	***67***	***62***	***87***	***104***	
Intangible category					*% total*
Software	6	10	16	22	*15%*
R&D	8	9	12	16	*11%*
Design	13	13	15	23	*17%*
Minerals & Copyright	3	3	2	4	*3%*
Branding	5	7	12	15	*11%*
Training	14	17	24	30	*22%*
Organisational	9	12	17	31	*22%*
All intangibles	***57***	***70***	***98***	***141***	*100%*
Memo					
MSGVA	*374*	*458*	*600*	*881*	
GDP	*495*	*640*	*840*	*1,295*	

Note to table. Data are investment figures, in £bns, current prices: italicized data are asset shares of total intangible investment in 2008. ‘Design’ refers to architectural & engineering design. R&D refers to both scientific and non-scientific R&D, and financial product development. MSGVA is market sector gross value added without intangibles, that is sector A to K, excluding real estate and software and mineral investment. GDP is UK GDP from KLEMS.
Source: ONS and KLEMS data for tangibles, this paper for intangibles.

4.2 Industry intangible investment

Table 2 reports tangible and intangible investment by industry, 1997-2005. Finance and manufacturing invest very strongly in intangibles relative to tangibles: in both sectors, intangible investment is three times that in tangibles. It is interesting to note in passing that this raises important questions on how to classify manufacturing since it is undertaking a very good deal of intangible activity (manufacturing own-account intangible investment is 15% of value added by 2007 for example).

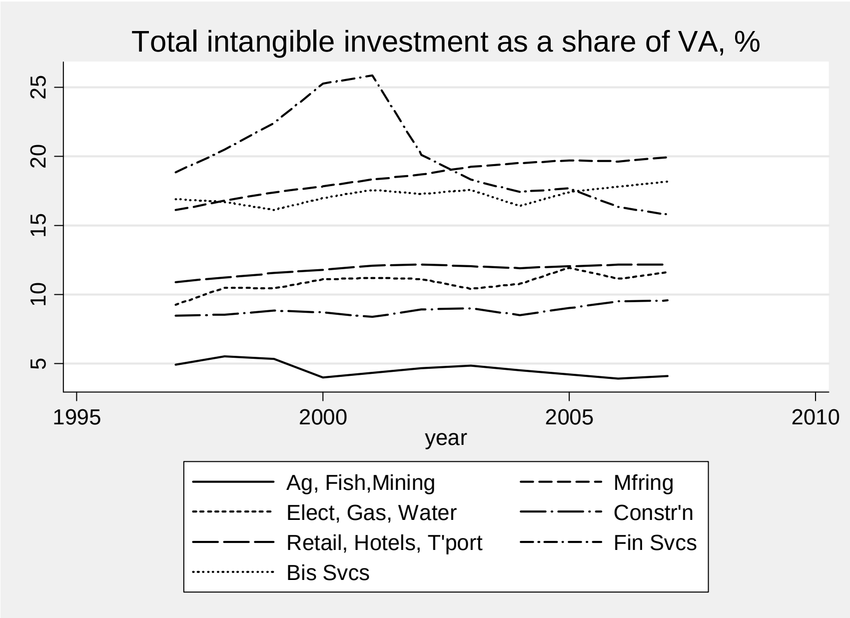
Table 2: Tangible and Intangible investment, by industry, 1997-2007, Current Prices £bns

	Agriculture, fishing and mining		**Manufacturing**		**Utilities**		**Construction**		**Retail, hotel and transport**		**Financial intermediation**		**Business services**		**Market sector**	
Year	*Tangible*	*Intangible*	*Tangible*	*Intangible*	*Tangible*	*Intangible*	*Tangible*	*Intangible*	*Tangible*	*Intangible*	*Tangible*	*Intangible*	*Tangible*	*Intangible*	*Tangible*	*Intangible*
1997	6.98	1.45	18.11	27.45	4.98	1.57	1.80	3.44	28.43	19.19	4.05	9.06	8.23	15.35	72.58	77.51
1998	7.76	1.43	18.47	29.14	5.26	1.81	1.70	3.69	33.14	21.76	6.24	10.36	13.81	17.51	86.37	85.70
1999	6.22	1.45	16.54	30.14	5.56	1.78	1.89	4.07	33.94	23.82	5.26	11.24	13.70	18.67	83.11	91.17
2000	5.04	1.37	16.18	30.47	5.06	1.91	1.99	4.33	38.60	25.66	5.25	12.72	12.82	21.85	84.95	98.32
2001	6.13	1.40	14.67	31.47	5.33	1.92	2.15	4.60	38.13	27.70	4.74	13.54	12.09	24.94	83.24	105.57
2002	7.24	1.50	12.26	31.51	4.77	1.94	3.12	5.32	38.11	28.91	4.91	14.17	10.53	25.45	80.94	108.77
2003	6.88	1.58	11.93	32.20	4.82	1.84	3.11	5.85	35.08	29.92	4.23	14.27	10.41	27.88	76.47	113.55
2004	6.81	1.57	11.78	32.84	2.68	1.88	3.63	6.10	36.65	30.87	3.62	14.29	8.46	27.51	73.63	115.06
2005	6.63	1.63	11.57	33.68	3.73	2.20	2.70	6.87	35.58	32.00	5.02	15.53	10.54	31.13	75.78	123.03
2006	7.04	1.72	11.16	34.40	5.04	2.44	3.20	7.75	35.81	33.45	4.63	16.08	11.60	34.05	78.49	129.90
2007	8.26	1.81	11.98	35.53	6.92	2.69	3.15	8.42	39.81	34.89	5.46	17.50	12.99	36.94	88.58	137.79

Source: authors' calculations using EUKLEMS data for tangibles and methods in this paper for intangibles.

Figure 2 shows the ratios of total investment in all intangible categories to industry value added (where industry value added equals conventional value added plus additional intangible investment not officially capitalised). Note the initial very high level in financial services due to the software boom in the late 1990s, especially in the run up to Y2K. Since, then it is worth noting that manufacturing and business services are the most intangible investment intensive.

Figure 2:Ratio of investment to (adjusted) value-added ratios, by industry



Note to figure: Industry value-added has been adjusted to account for the capitalisation of intangible assets

Which particular intangible assets are most important in which industries? Table 3 shows the asset share of total intangible spending by industry (in 2007 the shares are very stable over time). Starting with manufacturing, the largest share of all intangible spending is innovative property (56%), with software 8%. Compare with financial intermediation, where innovative property accounts for only 19% whereas “ecom” (training, branding and organization building) accounts for over 50%, whilst software is 27%. Similarly, in retailing, software and economic competencies are much more important than innovative property.

To shed light on the importance of non-R&D spend outside manufacturing, the lower panel sets out some detail on selected individual measures. As the top line shows, R&D accounts, in manufacturing, for 31% of all intangible spend, but 0% in finance, and 5% in trade. Training, line 2, accounts for 10% in manufacturing, 31% in trade and 8% in finance.

Investment in organisational capital, line 3, is 19% in manufacturing, 22% in trade and a considerable 31% in finance. Finally, branding is twice as important in trade and finance as in manufacturing. Thus we can conclude that the “non-R&D” intangible spend, outside manufacturing, is mostly due to software, training, organisational capital and branding.

Table 3: Shares of total industry intangible investment accounted for by individual intangible asset categories (for 2007)

`	AgrMin	Mfr	Utilities	Constr	RtHtTrs	FinSvc	BusSvc
Shares							
soft	0.12	0.08	0.21	0.05	0.17	0.27	0.14
innop	0.34	0.56	0.16	0.40	0.16	0.19	0.28
ecom	0.55	0.36	0.63	0.55	0.67	0.54	0.58
	100%	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
Individual assets:							
R&D	0.04	0.31	0.01	0.00	0.05	0.00	0.02
Training	0.30	0.10	0.23	0.30	0.31	0.08	0.32
Organisation	0.22	0.19	0.32	0.19	0.22	0.31	0.14
Branding	0.03	0.06	0.07	0.04	0.11	0.12	0.08

Notes to table: “Soft” is Software; “ecom” is economic competencies; “innop” is Innovative Property. Where: economic competencies are advertising & market research, training and organisational investment and innovative property is R&D, mineral exploration and copyright creation, design, financial product development and social science research. All data are shares of total investment: upper panel sums to 100% since categories are exhaustive, lower panel shows a sample of individual assets that are part of the asset groups in the upper panel.

5 Growth accounting results: market sector

5.1 Growth accounting results for the market economy

Our growth accounting results are set out in Table 2 (Panel 1). Consider Table 2 which reads as follows. The first column is labour productivity growth in per hour terms. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times the share of labour in MGVA. Column 3 is growth in computer capital services times the share of payments for computer services in MGVA. Column 4 is growth in other tangible capital services (buildings, plant, vehicles) times share in MGVA. Column 5 is growth in intangible capital services times share in MGVA. Column 6 is TFP, namely column 1 minus the sum of columns 2 to 5. Column 7 is the share of labour payments in MGVA. Columns 8 to 10 are the shares of particular contributions, shown in the table heading, in labour productivity growth.

Consider first the top panel of data, which reports the contributions to growth in a standard framework that *doesn't* include intangibles. LPG rose in the 1990s and then fell back somewhat in the 2000s. The rise in the late 1990s is due to the FISIM effect, and other methodological changes in the 2009 National Accounts, see Haskel et al (2009).[11] The contribution of labour quality, column 2, is fairly steady throughout. Tangible capital input grew quickly in the 1990s, but fell in the 2000s, especially computer hardware. Thus the overall TFP record was a rise in the second half of the 1990s and then a fall.

Consider now the second set of results in panel 1. The inclusion of intangibles raises output growth in the 1990s, with little effect in the 2000s, due to a decline in intangible investment growth in the 2000s following the boom in intangible investment in the preceding years. The impact of labour quality, column 2 falls due to the fall in the labour share. The contribution of tangible capital, columns 3 and 4, falls somewhat relative to the upper panel as the inclusion of intangibles alters the factor shares of these inputs. In column 5 we see the contribution of the intangible inputs; stronger in the 1990s and weaker – though still important – in the 2000s. Thus the overall TFPG record in column 6 is acceleration in the late 1990s and then some weakening.

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[11] Note that a market sector TFP growth rate of over 1.5% is comparatively high by historical data (that is, based on studies pre-FISIM). The reason for this is that FISIM has added around 0.5 pppa to ALPG, all of which adds to TFPG almost directly since no new inputs are involved. Thus even without intangibles, the productivity picture changes.

Table 4: Growth accounting for market sector with and without intangibles

	1	2	3	4	5	6	7	8	9	10
	DlnV/H	**sDln(L/H)**	**sDln(K/H) cmp**	**sDln(K/H) othtan**	**sDln(K/H) intan**	**DlnTFP**	***Memo: sLAB***	*(6/1)*	*(5+6)/1*	*(2+5+6)/1*
1) Baseline Results: With and without intangibles										
Without intang										
1990-95	2.94%	0.20%	0.25%	0.84%		1.66%	*0.66*	*0.56*	*0.56*	*0.63*
1995-00	3.25%	0.29%	0.57%	0.32%		2.07%	*0.64*	*0.64*	*0.64*	*0.73*
2000-08	2.23%	0.19%	0.31%	0.54%		1.19%	*0.66*	*0.53*	*0.53*	*0.62*
With intang										
1990-95	2.94%	0.17%	0.22%	0.73%	0.64%	1.19%	0.57	0.40	0.62	0.68
1995-00	3.53%	0.25%	0.49%	0.25%	0.67%	1.87%	0.56	0.53	0.72	0.79
2000-08	2.25%	0.16%	0.26%	0.41%	0.51%	0.90%	0.57	0.40	0.63	0.70
2) Robustness checks										
only software										
2000-08	2.27%	0.18%	0.30%	0.53%	0.09%	1.16%	*0.64*	*0.51*	*0.55*	*0.63*
software and rd										
2000-08	2.24%	0.18%	0.30%	0.51%	0.12%	1.13%	*0.63*	*0.50*	*0.56*	*0.64*
halve dep rates										
2000-08	2.25%	0.16%	0.26%	0.40%	0.64%	0.80%	*0.57*	*0.36*	*0.64*	*0.71*
double dep rates										
2000-08	2.25%	0.16%	0.26%	0.43%	0.41%	0.98%	*0.57*	*0.44*	*0.62*	*0.69*
Own-account org = 5% manag time										
2000-08	2.23%	0.16%	0.27%	0.43%	0.45%	0.93%	*0.58*	*0.42*	*0.62*	*0.69*

Notes to table. Data are average growth rates per year for intervals shown, calculated as changes in natural logs. Contributions are Tornquist indices. First column is labour productivity growth in per hour terms. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times share of labour in MGVA. Column 3 is growth in computer capital services times share in MGVA. Column 4 is growth in other tangible capital services (buildings, plant, vehicles) times share in MGVA. Column 5 is growth in intangible capital services times share in MGVA. Column 6 is TFP, namely column 1 minus the sum of columns 2 to 5. Column 7 is the share of labour payments in MGVA. Columns 8-10 are fractions of column 1.

The final columns set out the shares of LPG of various components. What are the main findings? First, the inclusion of intangibles lowers TFPG as a share of LPG. Consider column 8 in the upper panel. TFPG is above 50% of LPG without intangibles, but around 10 percentage points less with intangibles. Second, the contribution of the "knowledge economy" to LPG is very significant, whether measured as column 9 or 10. In column 9, TFPG and intangible capital deepening are between 62% and 72% of LPG, with the fraction particularly large in 1995-00. Column 10 adds the contribution of labour quality taking the figure to around 70%. Note how high this contribution is in the late 1990s when intangible capital deepening was very fast.

5.2 Growth accounting: further details and robustness checks

As we have seen, we necessarily make a number of assumptions when implementing the growth accounting exercise. How robust are our findings to key assumptions? This is shown in the rest of the table, where for easy of reading we just show the results for this century. All results for all other periods are available.

Panel 2 a) (in Table 2) shows the results when only software is included as an intangible. Thus this row corresponds closely to current National Accounts practice, although copyrights and mineral explotion are also capitalized in official data. As can be seen, relative to the very top panel, which excludes software, capitalization of software raises ΔlnV/H and lowers, very slightly, ΔlnTFP. Note from column 5 that the contribution of software is 0.09%pa, against the total intangible contribution of 0.51%pa.

The next row capitalises both software and R&D and thus a comparison with the software line estimates the difference due to R&D capitalization (a step recommended in the System of National Accounts, 2003, and to be implemented in the UK by 2014).[12] Relative to software, the contribution of intangibles rises very slightly and ΔlnTFP falls very slightly. So capitalization of R&D adds about 0.03%pa to input contribution and TFP falls by the same.

The next two rows double and halve the assumed intangible depreciation rates. This lowers and raises the contribution of intangible capital respectively, as would be expected. They more or less directly affect ΔlnTFP, so that, if for example, intangibles depreciated half as fast as we have assumed, ΔlnTFP falls from 0.90%pa to 0.80%pa.

Finally, since own account organizational capital is particularly uncertain, the final row reduces such spending by 75% (that is, managers are assumed to spend 5% of their time

[12] The precise details of this capitalisation are to be confirmed, but we have used similar depreciation and deflator assumptions to the preliminary work in Galindo Rueda (2007). He documents a fairly consistent rise in nominal GDP 1997-2004, of between 1.20 an 1.55% (he does no growth accounting).

on organizational capital. In this case contribution of intangible capital falls from 0.51%pa to 0.45% pa and ΔlnTFP rises from 0.90%pa to 0.93%pa.[13]

One way of looking at the robustness of these results is to calculate the fraction of overall ΔlnV/H accounted for by intangibles, ΔlnTFP and ΔlnL/H under the various different scenarios. It is in fact quite robust. As row 3, top panel shows, without intangibles, the ΔlnTFP fraction is 0.53 or and (ΔlnTFP+ΔlnL/H) 0.62, a result that is very similar with just software or just software and R&D. With intangibles, the fractions are 0.40 for ΔlnTFP, 0.63 for ΔlnTFP+ΔlnK/H(intan) and 0.70 for ΔlnTFP+ΔlnK/H(intan)+ΔlnL/H. But the interesting thing to note is that these fractions are almost identical with the experiments on depreciation and organizational capital. Thus the inclusion of the full range of intangibles lowers the share of the contribution of ΔlnTFP, but consistently raises the share of the contribution of ΔlnTFP, intangible capital deepening and labour composition combined, such that the latter has accounted for 70% of ΔlnV/H over this century.

5.3 Contributions of individual intangible assets

Contributions of each intangible asset are set out in Table 4. Column 5 shows that software is an important driver, with a very strong contribution in the 1990s of between 0.18% and 0.23% p.a., but less so this century, contributing 0.10% p.a . Note that in the late 1990s the contribution of software came close to that of non-computer tangibles, a remarkable result highlighting the importance of knowledge assets. Column 6 shows a small contribution for mineral exploration and artistic originals. Column 7 and 8 show the contribution of design to be above that of R&D in the most recent period, at around 0.09%pa with R&D at 0.05% p.a (this is larger than that above since it includes R&D in financial services and social sciences). In columns 8 to 12, we shows the contribution of advertising and marketing, training and organisational capital. Organisational capital is the most important here, particularly in the 2000s, with training important in the early decade in particular.

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[13] We also looked at year by year changes and in particular the impact of the recession. We only have one year to work with here. Between 2007 and 2008, there was a decline of -0.85% in adjusted labour productivity, with intangible capital deepening and labour composition largely unchanged . Measured TFP falls by 1.85%. It is likely however that in very severe recessions we do not measure the actual fall in tangible capital that likely comes about due to premature scrapping and underutilisation and since TFP is a residual, this renders TFP negative. Thus we should be careful about interpreting year-to-year movements in the innovation index.

Table 5**: Contributions of individual assets: Detailed breakdown**

	1	2	3	4	5	6	7	8	9	10	11	12	*13*
	DlnV/H	**sDln(L/H)**	**sDln(K/L) cmp**	**sDln(K/L) othtan**	**sDln(K/L) software**	**sDln(K/L) min & cop**	**sDln(K/L) design**	**sDln(K/L) r&d**	**sDln(K/L) adv & mr**	**sDln(K/L) training**	**sDln(K/L) org**	**DlnTFP**	***Memo: sLAB***
1990-95	2.94%	0.17%	0.22%	0.73%	0.18%	0.02%	0.07%	0.05%	0.07%	0.10%	0.14%	1.19%	*0.57*
1995-00	3.53%	0.25%	0.49%	0.25%	0.23%	0.00%	-0.02%	0.04%	0.14%	0.15%	0.13%	1.87%	*0.56*
2000-08	2.25%	0.16%	0.26%	0.41%	0.10%	0.00%	0.09%	0.05%	0.03%	0.08%	0.17%	0.90%	*0.57*

Notes to table. Data are average growth rates per year for intervals shown. First column is labour productivity growth in per hour terms. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times share of labour in MGVA. Column 3 is growth in computer capital services per hour times share in MGVA. Column 4 is growth in other tangible capital services per hour (buildings, plant, vehicles) times share in MGVA. Column 5 is growth in software capital services per hour times share in MGVA. Column 6 is growth in capital services from mineral exploration and copyright per hour times share in MGVA. Column 7 is capital services from design per hour times share in GVA. Column 8 is growth in broadly defined R&D (including non-scientific R&D and financial product development) capital services per hour times share in GVA. Column 9 is capital services from advertising and market research per hour times share in MGVA Column 10 is capital services from firm-level training per hour times share in MGVA. Column 10 is organisational capital services per hour times share in MGVA. Column 12 is TFP, namely column 1 minus the sum of columns 2 to 11. Column 13 is the share of labour payments in MGVA.

6 Growth accounting results: industry-level

Our industry growth accounting is feasible between 2000-07.[14] Thus we start with comparing our aggregated market sector results with those using ONS data to check the two are closely comparable. Then we look more closely industry by industry.

6.1 Comparing aggregated KLEMS industry data with ONS data

Table 6 sets out our results**.** The top row shows the use of ONS data, with intangibles, 2000-07 (the above include 2008, when ΔlnV/H fell sharply, but all the contributions are about the same, and TFP is larger). The second row shows the results for 2000-07, with intangibles, using the aggregated industry data. ΔlnV/H is 13 percentage points higher with EUKLEMS, but the contribution of ΔlnL/H is 14 percentage points higher, with ΔlnTFP very similar. So the results are quite comparable.

6.2 Results by industry

To build up the industry contributions to these overall figures we start with the industry-by-industry results in Table 7. These are on a gross output basis: we show how they relate to the whole economy value-added level below.

[14] We have data based on the Supply-Use Tables back to 1992, but due to uncertainty about initial capital stocks we confine ourselves to growth accounting starting in 2000.

Table 6: Growth accounting: comparison of ONS market sector and Domar-weighted Market Sector Aggregates, 2000-07

	1	2	3	4	5	6	7
		Capital deepening contributions:					
		Total	Computers	Other, tang	Intan		
	DlnV/H	**sDln(K/H)**	**sDln(K/H) cmp**	**sDln(K/H) othtan**	**sDln(K/H) intan**	**sDln(L/H)**	**DlnTFP**
ONS data, with intan	2.69	1.23	0.28	0.40	0.55	0.17	1.30
KLEMS, with intang	2.82	1.16	0.31	0.32	0.53	0.31	1.35

Note: All figures are average annual percentages. The contribution of an output or input is the growth rate weighted by the corresponding average share. Columns are annual average change in natural logs of: column 1, real value added, column 2, person-hours, column 3, value added per person hour, column 4, contribution of total capital (which is the sum of the next three columns), column 5, contribution of computer capital, column 6, contribution of other non-computer tangible capital, column 7, contribution of intangibles, column 8, contribution of labour quality per person hour, column 9, TFP, being column 3 less the sum of column 4 and column 8. Row 1 is based on ONS data with the capitalisation of intangibles for the market sector. Row 2 is EUKLEMS data, with intangibles, 2000-07, aggregated to the market sector. In each the market sector is defined using our definition of SIC(2003) A-K excluding dwellings.
Source: authors' calculations

Table 7: Industry level gross output growth accounting, 2000-2007, including intangibles

Industry	**DlnY/H**	**sDln(K/H)**	**sDln(K/L) cmp**	**sDln(K/L) othtan**	**sDln(K/L) intan**	**sDln(L/H)**	**sDln(M/H)**	**DlnTFP**
2000-07								
AgrMin	0.74	1.29	0.00	1.28	0.00	0.24	1.19	-1.97
Mfr	3.65	0.71	0.07	0.14	0.5	0.17	1.7	1.06
Util	-3.58	0.02	0.16	-0.14	0.01	-0.02	-3.47	-0.11
Construction	2.11	0.17	0.02	0.21	-0.06	-0.07	1.61	0.4
TrHtTran	2.71	0.73	0.21	0.28	0.24	0.16	1.22	0.6
FinSvc	1.55	-0.12	0.33	-0.27	-0.18	0.35	-0.03	1.36
BusSv	2.23	0.80	0.23	0.03	0.54	0.16	0.47	0.80

Note: All figures are average annual percentages. The contribution of an output or input is the growth rate weighted by the corresponding average share. Columns are annual average change in natural logs of: column 1, real gross output, column 2, person-hours, column 3, gross output per person hour, column 4, contribution of total capital (which is the sum of the next three columns), column 5, contribution of computer capital, column 6, contribution of other non-computer tangible capital, column 7, contribution of intangibles, column 8, contribution of labour quality per person hour, column 9, contribution of intermediates, column 10, TFP, being column 3 less the sum of column 4, 8 and 9. Note also that Health & Safety training are excluded from the investment figures used for the above calculation.
Source: authors' calculations

We just report the results including all intangibles. Column 1 shows ΔlnY/H, growth in *gross* output per employee-hour. It is negative in Electricity, Gas, Water, otherwise positive particularly in manufacturing and Trade. Column 2 shows total capital deepening per employee-hour, being strongly positive in manufacturing and business services, but negative in financial services. Columns 3, 4 and 5 shed some light on this. The contribution of computer hardware is strongest in financial and business services, and note particularly weak in manufacturing. The contribution of other tangibles (buildings, vehicles etc.) is actually negative in financial services, as is the contribution of intangibles in that industry. It is worth nothing that employee-hours are growing very fast in financial services (the second largest growth in the economy behind business services) and that intangible capital is falling after the massive investment in the late 1990s. So capital deepening per head is falling, thus rendering the contribution of growth in capital per hour negative. However, this also slows down ΔlnY/H, so it turns out that ΔlnTFP still falls in financial services when we add intangibles (see table Appendix 1, without intangibles, ΔlnTFP=1.51%): thus intangibles do help account for the TFP residual. Columns 6 and 7 show the contributions of labour composition and intermediates, and column 8 shows ΔlnTFP. ΔlnTFP grows particularly fast in finance and manufacturing.

So the overall picture of intangibles at the industry level is as follows. In manufacturing, labour productivity is high, particularly with a lot of labour shedding. About 30% of that LPG is due to TFPG, with 15% due to intangible growth and 5% due to labour quality. In financial services, measured labour productivity is lower, but TFP accounts for almost 90% of it. The rest is due to labour quality and computers, with intangible investment intensity falling over the period. So manufacturing is very much driven by within-industry intangible investment, whilst finance is very much driven by TFP (would could of course reflect within-industry spillovers of intangible investment). In retailing, computers and intangibles account for around 19% of LPG.

Finally, the appendix shows the impact of adding intangibles, which is that ΔlnY/H is higher and ΔlnTFP is lower than without intangibles. Thus for example, without intangibles one would conclude ΔlnTFP=1.87% instead of 1.35% here with.

6.3 Contributions of individual industries overall performance

The contribution of each industry to the overall market economy is a combination of their contributions within each industry and the weight of each industry in the market sector. Thus for example, there may be much innovation in manufacturing but it might be a small sector in the market sector as a whole. Table 8 sets this out.

Table 8: **. Industry contributions to growth in aggregate value added, capital deepening, labour quality and TFP (growth rates and contributions are %pa per employee hour)**

	1	2	3	4	5	6	7	8	9	10	11	12	13	*14*	15
	Value added			Capital contributions					Labour contrib		TFP				
					contrib to agg K	*of which*									
Industry	VA weight	DlnVA	contrib to agg va	Cap weight		Contrib to agg ICT dlnK	contrib to agg non-ICT dlnK	contrib to agg Intan	Lab weight	contrib to agg lab qual	Domar weight	DlnTFP	Contrib to agg TFP	*Memo: % total employ*	
AgMin	0.05	-0.64	-0.03	0.03	0.10	0.00	0.10	0.00	0.01	0.02	0.07	-1.97	-0.14	*3%*	
Mfr	0.22	4.75	1.03	0.07	0.38	0.04	0.08	0.27	0.14	0.09	0.53	1.06	0.55	*19%*	
Utilities	0.02	-0.64	-0.01	0.02	0.00	0.01	-0.01	0.00	0.01	0.00	0.07	-0.11	-0.01	*1%*	
Cons	0.09	1.21	0.1	0.02	0.04	0.00	0.04	-0.01	0.07	-0.02	0.21	0.40	0.08	*11%*	
ReHtTran	0.32	2.74	0.88	0.11	0.43	0.13	0.16	0.14	0.22	0.09	0.59	0.60	0.35	*39%*	
FinSvc	0.10	3.32	0.31	0.05	-0.03	0.06	-0.05	-0.04	0.05	0.07	0.20	1.36	0.27	*5%*	
BusSvc	0.21	2.59	0.55	0.07	0.25	0.07	0.01	0.17	0.14	0.05	0.31	0.80	0.25	*22%*	
Sum	***1***		***2.83***		***1.17***	***0.31***	***0.33***	***0.53***		***0.3***	***1.98***		***1.35***	***100%***	
%ages of summed contributions															*(8+13)/(Σ 8+ Σ 13,*
AgMin			*-1%*		*9%*	*0%*	*30%*	*0%*		*7%*			*-10%*	*3%*	*-5%*
Mfr			*36%*		*32%*	*13%*	*24%*	*51%*		*30%*			*41%*	*19%*	*46%*
Utilities			*0%*		*0%*	*3%*	*-3%*	*0%*		*0%*			*-1%*	*1%*	*0%*
Cons			*4%*		*3%*	*0%*	*12%*	*-2%*		*-7%*			*6%*	*11%*	*2%*
ReHtTran			*31%*		*37%*	*42%*	*48%*	*26%*		*30%*			*26%*	*39%*	*26%*
FinSvc			*11%*		*-3%*	*19%*	*-15%*	*-8%*		*23%*			*20%*	*5%*	*6%*
BusSvc			*19%*		*21%*	*23%*	*3%*	*32%*		*17%*			*19%*	*22%*	*25%*
Sum			*100%*		*100%*	*100%*	*100%*	*100%*		*100%*			*100%*	***100%***	*100%*

Note: All figures are annual averages. Weights depend on the industry share in aggregate value-added, the input share in gross output and the share of value-added in gross output. Contributions are the product of the weights and the input growth averaged over years. Employment is the share of the industry's hours worked over total hours worked by persons engaged. Column 5 is the sum of columns 6, 7, 8. Column 13= column 11 times 12.
Source: authors' calculations

In the left panel columns 1, 2 and 3 show respectively the industry weights in market sector value added, average ΔlnV/H and the contribution to aggregate value added (which is not quite the product of columns 1 and 2, since the average of a product is not the product of two averages). In the final row, the weights on value added sum to unity and the sum of contributions is the market-sector total as shown in row 2 of table 6 above. The middle panels show the capital and labour contributions which again sum to the market sector total. The right panel shows industry ΔlnTFP and its Domar weight, each industries contribution and confirms the weighted sum duplicates the aggregate. Finally, as a memo item, column 14 shows employment as a fraction of the total. The lower panel shows the contributions as a proportion of the total.

What do we learn about the economy from this table? Let us start by considering manufacturing. As the top panel shows, column 1, its value added weight in the market sector is 22%, although column 14 shows the employment weight is 19% (note these are higher than the shares in the whole economy which are the weights usually quoted). Column 5 shows that the contribution of manufacturing capital deepening to aggregate capital deepening is 0.38%pa, which is, lower panel, 32% of the total. Column 8 shows that the contribution of intangibles in manufacturing is significant: 51% (see lower panel) of the total intangible contribution. Columns 10 and 13 show the contribution of labour quality and ΔlnTFP, 30% and 41% respectively of the total. Finally, Column 15 (lower panel), shows that manufacturing contributes 46% of the total contribution of intangible capital deepening and ΔlnTFP. Thus manufacturing, accounting for 22% of value added and 19% of employment, accounts for 51% of total intangible capital deepening and 41% of ΔlnTFP. The importance of intangible investment in manufacturing of course suggests that a significant component of the activity of firms allocated to manufacturing in the SIC is the production of knowledge assets, which might be regarded as producing a service.

What of other industries? The other large contributions of capital deepening are from retail and business services. Within these, ICT capital deepening is very important in trade, whose ICT capital deepening accounts for 42% of the total. Intangible capital deepening in business services and trade account for 32% and 26% of the total as well.

Turning to labour composition, manufacturing and trade alone account for 50% of it. Finally, on ΔlnTFP, after manufacturing, retail trade accounts for 26%, so that just these two sectors combined account for 61% of market sector ΔlnTFP. Finance and business services account for 35%. Note that whilst the ΔlnTFP of finance exceeds that of manufacturing, the Domar weight for finance is smaller, so the contribution to total ΔlnTFP is much smaller. Retail has a much larger value added, but lower ΔlnTFP and a similar Domar weight to manufacturing, so the trade contribution is lower.

Finally, one might summarise these results by asking what industries account for the contribution of knowledge investment to ΔlnV/H? If we define knowledge investment as the contributions of ΔlnTFP+sΔlnK/H(intang) to the total, we see that manufacturing accounts for 46%, trade 26%, business services 25% and financial services 6% (the numbers are very similar if we add sΔlnL/H, namely 41%, 27%, 22% and 12%).

One important question, we believe, is to ask how these results compare to those without intangibles? The results without intangibles are set out in the appendix, but the main results are as follows. First, without intangibles, ΔlnTFP is 1.87 (against 1.35 above). But note that the contribution above of ΔlnTFP and intangible capital deepening is 1.35+0.53 = 1.86, almost exactly equal to ΔlnTFP without intangibles, which accounts for 1.86/2.99= 62% of economic growth against 1.83/2.83=65% without intangibles. So in this calculation the total "innovation" contribution turns out to about the same, but intangibles accounts about 1/3rd of the residual. Second, the industry contributions are different. As we have seen here with intangibles, manufacturing and financial services account for 46% and 6% of final innovation. Without intangibles, manufacturing and financial services ΔlnTFP account for 39% and 19% of ΔlnV/H. So without intangibles financial services ΔlnTFP is overstated.

7 Conclusions

This paper tried to combine a number of threads of recent work on the rise of the knowledge economy. First, analysis of ICT suggested that computers need complementary investment in organizations, human capital and reputation. Second, a growing perception that the knowledge economy is becoming increasingly important has led to the treating of software and R&D in the national accounts as investment. To study the questions that arise we have used the CHS framework, extended its measurement method somewhat using new data sets and a new micro survey, and implemented it on UK data for all intangibles in addition to R&D and software. We have documented intangible investment in the UK and tried to see how it contributes to economic growth. We find the following.

1. *Investment in knowledge.*
   a. Investment in knowledge, which we call intangible assets, is now greater than investment in tangible assets, at around, in 2008, £141bn and £104bn respectively, 16% and 12% of MSGVA, quantifying the UK move to a knowledge-based economy.
   b. In 2008, R&D was about 11% of total intangible investment, software 15%, design 17%, and the largest categories (22%) training and organizational capital. 60% of intangible investment is own account.
   c. The most intangible-intensive industry is manufacturing (intangible investment as a proportion of value added =20%). Manufacturing, financial services and business services all invest about 3:1 on intangibles:tangibles.

d. The effect of treating intangible expenditure as investment is to raise growth in market sector value added in the late 1990s (the internet investment boom), but slightly reduce growth in the 2000s.

2. *Contribution to growth, 2000-08*.

   a. For the most recent period of 2000-2008, intangible capital deepening accounts for 23% of growth in market sector value added per hour ($\Delta\ln V/H$), a larger contribution than computer hardware (12%), other tangible investments (18%, buildings, vehicles, plant) or labour quality (7%). The largest contribution is $\Delta\ln TFP$, being 40%.

   b. With (without) intangibles $\Delta\ln V/H$ 2.25%pa (2.23%pa) and $\Delta\ln TFP$ is 0.90%pa (1.19%pa). Thus adding intangibles to growth accounting lowers $\Delta\ln TFP$ and $\Delta\ln V/H$ unaffected.

   c. Capitalising R&D relative to the current practice of capitalizing software (plus mineral exploration and artistic originals) adds 0.03% to input growth and reduces $\Delta\ln TFP$ by 0.03%, with $\Delta\ln V/H$ unaffected.

   d. If innovation is measured as $\Delta\ln TFP$ plus the contribution of intangible capital deepening, then innovation has contributed 63% of growth in labour productivity with intangibles and 53% without. Adding the contribution of labour composition gives 70% of $\Delta\ln V/H$ with intangibles and 62% without.

3. *Contribution by industries to growth*. The main finding here is the importance of manufacturing, which accounts for just over 40% innovation (measured either as intangible capital deepening plus TFP, or intangible capital deepening plus TFP plus labour quality) in the UK market sector. This is due to a combination of its high intangible investment (51% of total intangible contribution) and TFP (41% of total contribution), even though manufacturing is a comparatively small sector in terms of employment share (19% of market sector employment). We also find important contributions of retail/hotels/transport, accounting for 27% of innovation, business services contributes 25% and finance 6%.

In future work, we hope to improve the measures of all variables. We also wish to explore policy and the total contributions of various assets by looking for spillovers. So, for example, it is quite conceivable that R&D spillovers will greatly amplify the contribution of R&D.

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Table Appendix 1. Excluding intangibles, industry contributions to growth in aggregate value added, capital deepening, labour quality and TFP (growth rates and contributions are %pa per employee hour)

	1	2	3		4	5	6	7	8		9	10		11	12	13		*14*	15
	Value added				**Capital contributions**						**Labour contrib**			**TFP**					
						contrib to agg K	*of which*												
Industry	VA weight	DlnVA	contrib to agg va		Cap w eight		Contrib to agg ICT dlnK	contrib to agg non-ICT dlnK	contrib to agg Intan		Lab w eight	contrib to agg lab qual		Domar weight	DlnTFP	Contrib to agg TFP		*Memo: % total employ*	
Agriculture; I	0.05	-0.67	-0.03		0.04	0.12	0	0.12	na		0.02	0.02		0.09	-1.99	-0.17		*3%*	
Manufacturir	0.21	4.7	0.98		0.04	0.14	0.04	0.09	na		0.17	0.11		0.62	1.2	0.73		*19%*	
Utilities	0.02	-0.51	-0.01		0.02	0	0.01	-0.01	na		0.01	0		0.08	-0.06	-0.01		*1%*	
Construction	0.09	1.28	0.11		0.01	0.08	0.01	0.07	na		0.08	-0.02		0.24	0.21	0.05		*11%*	
Distribution; I	0.33	2.84	0.93		0.08	0.32	0.14	0.18	na		0.25	0.11		0.69	0.73	0.5		*39%*	
Finance	0.09	4.91	0.43		0.03	0	0.09	-0.09	na		0.06	0.08		0.23	1.51	0.35		*5%*	
Business Se	0.2	2.86	0.58		0.04	0.1	0.09	0.01	na		0.16	0.06		0.36	1.16	0.42		*22%*	
Sum	***1***		***2.99***			***0.76***	***0.38***	***0.37***				***0.36***		***2.31***		***1.87***		***100%***	
%ages of summed contributions																			*13/ Σ 13*
Agriculture; Mining			*-1%*			*16%*	*0%*	*32%*				*6%*				*-9%*		*3%*	*-9%*
Manufacturing			*33%*			*18%*	*11%*	*24%*				*31%*				*39%*		*19%*	*39%*
Utilities			*0%*			*0%*	*3%*	*-3%*				*0%*				*-1%*		*1%*	*-1%*
Construction			*4%*			*11%*	*3%*	*19%*				*-6%*				*3%*		*11%*	*3%*
Distribution; Hotels; Transport			*31%*			*42%*	*37%*	*49%*				*31%*				*27%*		*39%*	*27%*
Finance			*14%*			*0%*	*24%*	*-24%*				*22%*				*19%*		*5%*	*19%*
Business Services			*19%*			*13%*	*24%*	*3%*				*17%*				*22%*		*22%*	*22%*
Sum			*100%*			*100%*	*100%*	*100%*				*100%*				*100%*		***100%***	*100%*

Note: See notes to Table 8. All figures are annual averages. Weights depend on the industry share in aggregate value-added, the input share in gross output and the share of value-added in gross output. Contributions are the product of the weights and the input growth averaged over years. Employment is the share of the industry's hours worked over total hours worked by persons engaged. Column 5 is the sum of columns 6 and 7 . Column 8 blank since no intangibles are included . Column 13= column 11 times 12.
Source: authors' calculations

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Imperial College Business School
Tanaka Building
South Kensington Campus
London SW7 2AZ
United Kingdom

T: +44 (0)20 7589 5111
F: +44 (0)20 7594 9184

www.imperial.ac.uk/business-school