Draft Report for NESTA Innovation Index 2008 Summer Projects

An Innovation Index Based on Knowledge Capital Investment: Definition and Results for the UK Market Sector*

Tony Clayton
Economic Analysis, Office of National Statistics

Mariela Dal Borgo
University of Warwick

Jonathan Haskel
Queen Mary, University of London; CeRiBA, CEPR and IZA

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Abstract

We (a) propose an implementable innovation index, (b) relate it to existing innovation definitions and (c) show whole-economy and industry-specific results for the UK market sector, 2000-2005. Our innovation measure starts by observing that we could get more GDP *without* innovation by simply duplicating existing physical capital and labour (e.g. adding a second aircraft and crew on an existing route). Thus we propose to measure innovation as the additional GDP over and above the addition existing physical capital and labour. In our measure this is the contribution to GDP growth of market sector investment in knowledge (or intangible) capital. This contribution is measured from company spending on knowledge/intangible assets and TFP growth. We relate our measure to the literature on innovation definitions, TFP, creative industries and hidden innovation. We implement it for six UK market sector industries, 2000-2005, combining with output and tangible investment data from the EUKLEMS database. Our main findings are as follows. Over 2000-2005, market sector labour productivity grew at 2.74 percentage points per annum (pppa), of which the contribution of knowledge capital, our innovation measure, was 1.24 pppa. In turn, manufacturing accounted for about 60% of this latter figure. If one includes increase in labour skill deepening (0.45 pppa) as innovation, then innovation contributed 61% (=(1.24+0.45)/2.74)of labour productivity growth over the period.

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*Contact: Jonathan Haskel, Queen Mary, University of London, Economics Dept, London E1 4NS, j.e. haskel@qmul.ac.uk. We are very grateful for financial support for this research from a NESTA Summer Project award and the EU FP7 COINVEST programme. It builds on previous work financed by BERR and was carried out at CeRiBA at the Business Data Linking Branch at the ONS; we are grateful to all institutions concerned for their support. The results in section 4 are those from Mariela dal Borgo’s M.Sc Economics thesis at the University of Warwick. All errors are of course our own.

1 Introduction and non-technical summary[1]

A number of agencies have been charged with investigating and developing an innovation index. NESTA (the National Endowment for Science Technology and the Arts) in the UK is obliged to develop an index in 2010. An Advisory Committee to the US Commerce Department, including the CEOs of Microsoft, UPS and 3M have investigated the issue for the US (Innovation Measurement, 2008). The OECD are examining this question en route to an innovation strategy,.

There are three main current approaches to such an index. The first is to propose a definition of innovation and then produce an index. Thus far however whilst there are plenty of proposals there are rather fewer implementations of such proposals. The second approach is the reverse, namely to calculate an index and assume (explicitly or implicitly) it is innovation. The third is to suspend the notion of an index altogether and do something else (Innovation Measurement, 2008).

The aim of this paper is pragmatic, namely to move toward producing an index (or to produce some unimpeachable logic on why it cannot be done). This imposes the constraint that an innovation definition must be implementable with either existing data or data that can be collected quickly. Thus we have four main aims. First, we propose an implementable definition of innovation. Second, we relate to existing literature. Third, we go to the data and report some preliminary measures of what this definition might look like. Fourth, we report on what data would need to be collected to better implement it.

To state our proposal upfront, our innovation measure is the contribution to GDP growth of (market sector) investment in knowledge or intangible capital. This contribution derived from spending on knowledge/intangible assets and from TFP growth. We can also add human capital building into the innovation index. Thus our measure of innovation is the additional GDP over and above the addition due to existing physical capital and labour.

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[1] This initial section is written in the hope that it will be helpful for non-economists. For specialist economists, our definition of innovation is TFP plus the part of capital deepening accounted for by new knowledge investment. It therefore follows the research program set out in the expanded view of capital and TFP measurement proposed by Corrado, Hulten and Sichel (2004, 2006), which builds of course in turn on the work on growth accounting set out for example in the Jorgenson volumes (Jorgenson, 2007). The motivation for the index builds on an argument made by Jorgenson (2007) in his evidence to the Gutierrez committee. An important point of this work is that the Corrado, Hulten and Sichel argument that admission of intangible spending as building a knowledge asset requires both the recomputation of inputs, since knowledge/intangible capital is an additional input *and also* output (value added) since the capitalisation of intangible spending removes it from intermediate spending and so raises value added. Thus both output, inputs and TFP are recalculated relative to the case where intangible spending is treated as an expense. To economists familiar with this work, we hope this paper will still have some interest: we explicitly ask how TFP relates to the many innovation definitions that have been proposed and bring new data on the TFP and intangible spending in the UK economy at the industry level (relative to Giorgio Marrano, Haskel and Wallis, 2007, we have new data on design; we use the industry data on intangible investment in Gill and Haskel (2008) and present industry growth accounting results).

As background, it is worth starting by considering some of the definitions of innovation that have recently been proposed. NESTA (2007) propose "*change associated with the creation and adoption of ideas that are new-to-world, new-to-nation/region, new-to-industry or new-to-firm"* without being very clear on what "change" is and how it might be measured. The Frascati Manual (2002), being the official R&D manual proposes "*Technological innovation activities are all of the scientific, technological, organisational, financial and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and processes"* which confines attention to the technology and does not define how "implementation" might be measured. Whilst the Oslo manual broadens the definition to include organisational innovations, "*A technological product innovation is the implementation/commercialisation of a product with improved performance characteristics such as to deliver objectively new or improved services to the consumer. A technological process innovation is the implementation/adoption of new or significantly improved production or delivery methods. It may involve changes in equipment, human resources, working methods or a combination of these",* it introduces the term "objectively new or improved" without defining it. Finally, the US Advisory Committee propose " *The design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures, or business models for the purpose of creating new value for customers and financial returns for the firm",* which is broad in innovation scope but focuses on commercialised products and so is, as they point out, orientated at a private sector definition (and in any case they end up rejecting the feasibility of an index altogether).

The logic of the approach in this paper contains four key steps. The first is to ask why we are interested in innovation. For many, the reason is because we believe it is a prime cause of economic growth and specifically that the commercialisation of innovations has been a key factor in converting technological improvements to economic growth in the past two hundred years.[2] Thus we propose to concentrate on the output of more and new goods and services as our main reason for interest in innovation. As we stress below, to implement this, we shall measure output as value added or GDP, a key variable which avoids output double counting problems and is tightly related to measures of increased living standards and welfare.

But how does innovation contribute to this increased output? To answer this, the second step follows the question set by Jorgensen (2007) in his evidence to the US Advisory Committee: how would we get more output with *no* innovation? His answer is to use the same ideas, but duplicate existing capital and labour inputs. So Ryanair could fly more passengers on an existing route by

[2] There are at least two reasons why one might disagree with this. First, one might argue that the interest in innovation is because we think that innovation leads to new ideas (which may or may not then lead to growth). The problem of measuring ideas is of course a formidable one, since rating the relative importance of two ideas is very hard. The patents literature is of course a well-developed attempt to solve these problems, but as is well-acknowledged by no means all ideas are patented. Thus we do not study invention in this paper, but innovation, namely the commercialisation of ideas. Second, one might argue that increases in goods are of no interest in themselves since they might not signal a rise in prosperity at all, see e.g. the discussion in de Long (2000).

simply buying another airplane and hiring another set of crew. McDonalds could sell more food by opening at another location buying more cooking equipment and hiring another set of staff. Thus *innovation is not just the production of more goods, but the production of more goods over and above that which would occur with simple duplication of existing labour and physical capital.*

A number of points are worth making. First, how does this relate to the definitions above? The NESTA definition refers to "change" and the Frascati Manual to the production of "objectively new or improved goods". The definition operationalises this by referring to more goods. Second, by referring to more goods net of increases in physical capital and labour, it helps clarify a number of ambiguities in the literature. For example, innovation is sometimes defined as something that is new. Now, many would argue that the advent of low-cost airlines flying routes with an entirely new business model is an innovation. But few would argue that a low-cost airline, already flying from A to B in the morning, who then adds an evening service, has innovated. Similarly, many firms who describe themselves as innovative are often alleged by others not to be so since they are simply adopting the innovations of others. So, buying a new aircraft that flies twice as many passengers as before at the same cost, under the definition above, would not be an example of an innovation in the airline industry. But, under our definition, it would be an innovation in the aircraft industry, for the improved aircraft, assuming that it used new ideas, would be an example of an increase in output over and above that from simply duplicating capital and labour inputs in the aircraft industry.

The third step is to ask: if innovation is the extra output over and above capital and labour, where does this extra output come from? This requires us to make an explicit assumption about what inputs cause output. So we assume that production comes from labour, physical/tangible capital and knowledge/intangible capital. Thus extra production due to innovation, since we have ruled out more physical capital and labour, comes from more knowledge capital or ideas.[3] But where does the increased knowledge capital or ideas come from? Unlike tangible capital, which has a location and cannot be used by others, intangible capital may be non-rivalrous. So some firms might get ideas for free by simply imitating what other firms did. Other firms might discover new ideas themselves. Such discoveries, we assume, will take resources. R&D is the usual measure for the spending needed to generate new ideas, but the innovation definitions above suggest that we broaden the scope of spending to other spending that builds knowledge capital: spending on software, design, training, organisational capital at firms. This assumption is described by Corrado (2007) as tantamount to trying measure innovation spending at all stages of the innovation process: both the upstream spending of scientists, artists and designers on new ideas and the downstream spending on the commercialisation of these ideas by means of marketing, training and organisational change. Both

[3] Jones (2005) reviews what an idea is by quoting Romer (1993) who "divides goods into two categories: ideas and objects. Ideas can be thought of as instructions or recipes, things that can be codified in a bit string as a sequence of ones and zeros. Objects are all the rivalrous goods we are familiar with: capital, labor, output, computers, automobiles, and most fundamentally the elemental atoms that make up these goods. At some level, ideas are instructions for arranging the atoms and for using the arrangements to produce utility". Mokyr (2003) prefers using prescriptive and propositional to describe the body of knowledge, see Appendix.

spending on innovative ideas and obtaining them for free will show up as innovation in our measure, but in different ways, as we shall show below.

The final step is to account for how much this extra spending on knowledge raises output. For this we apply the economic theory of growth accounting, which uses observable prices and quantities to infer the impact of increased inputs on outputs. This step involves a number of assumptions, such as competitive markets, the depreciation of the knowledge stock and prices of knowledge all of which will be tested for robustness and require further work. Thus our proposed index will be the part of capital deepening in the economy that is knowledge capital deepening plus TFP growth.

To preview our results, our main findings are as follows. Over 2000-2005, UK market sector labour productivity grew at 2.74pppa, of which the contribution of knowledge capital, our innovation measure, was 1.24pppa (of the 1.24pppa, investment in knowledge assets contributed 1.19pppa and TFP growth 0.05pppa). In turn, manufacturing accounted for about 60% of the 1.24pppa figure. If one includes increase in labour skill deepening (0.45pppa) as innovation, then innovation contributed 61% (=(1.24+0.45)/2.74)of labour productivity growth over the period.

There are of course a number of things that our work does not do. First, as mentioned above, we do not count new ideas. We count the value of the new output stemming from new ideas and we will count investment in new ideas. Second, since we focus on output, we have obvious problems with the hard-to-measure sectors. Thus at the moment we consider it unlikely that we can obtain good indices of the public sector, and many parts of financial services are also likely to be hard. This might be important depending slightly on the degree of disaggregation needed.

Third, it is often argued that an important, possibly the most important, knowledge capital source is education. To the extent that this is paid for by firms, we count it as firm investment. To the extent that it is paid for by the public sector or households, it shows up (albeit somewhat indirectly) via our labour quality measures.[4] Fourth, our approach of locating innovation via its effect on growth, clearly relies on a number of assumptions, in particular, using, respectively, knowledge capital deepening and TFP as summary measures of the growth impact of new ideas paid and not paid for by firms. For those who find the assumptions in building these measures unacceptable, we do provide data on spending on series of knowledge/intangible assets which should be of interest, (even if the assumptions on the mechanism by which such spending then changes output are of no interest).

The rest of this paper proceeds as follows. Section 2 sets out a formal model of our index and definition, section 3 the relation to other work, section 4 our results and section 5 concludes. Finally, there are four appendices. Appendix 1 sets out the relation between ideas, invention, innovation and technical change. Appendix 2 sets out the details of each of our knowledge/intangible asset measures. Appendix 3 sets out the resources needed for future work and Appendix 4, as requested by NESTA, an assessment of our work against their specified criteria.

[4] As a matter of official National Accounting measurement practice, households are not regarded as producers and so their education spending is not investment.

2 A formal model and definitions

This section follows CHS and Oliner and Sichel (1990) and sets out a formal model of a three sector economy producing, respectively, intangible/knowledge capital goods, tangible capital goods and consumption goods. The model shows how the incorporation of these assumptions leads to new data for GDP, inputs and TFP and relates these data to innovation. Our main objective in setting out this model is to better understand the motivation for the innovation index, namely the growth in output not explained by growth in tangible capital and labour inputs and how it might be measured.

2.1 Formal model

The CHS model assumes three sectors. The final goods sector produces consumption goods, that is goods that have no investment property. The other two sectors produce investment goods, that is goods that create an asset. These sectors produce new tangible capital (I) and new knowledge/intangible capital (N). The tangible capital stock accumulates according to

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

where K is the real stock of tangible capital, and I investment in tangible capital. The intangible capital stock is given by R_t which also accumulates according to

$$R_t = N_t + (1-\delta_R)R_{t-1} \tag{2}$$

Where N is the value of new ideas produced in the period. This then captures the notion that new ideas boost the knowledge stock.

All sectors rent tangible and knowledge capital so that their production functions and profit identities can be written

$$\begin{aligned}
&\text{(a) Intangible sector}: N_t = F^N(L_{N,t}, K_{N,t}, R_{N,t}, t); \quad P_t^N N_t = P_t^L L_{N,t} + P_t^K K_{N,t} + P_t^R R_{N,t} \\
&\text{(b) Tangible sector}: I_t = F^I(L_{I,t}, K_{I,t}, R_{I,t}, t); \quad P_t^I I_t = P_t^L L_{I,t} + P_t^K K_{I,t} + P_t^R R_{I,t} \qquad (3)\\
&\text{(c) Consumption sector}: C_t = F^C(L_{C,t}, K_{C,t}, R_{C,t}, t); \quad P_t^C C_t = P_t^L L_{C,t} + P_t^K K_{C,t} + P_t^R R_{C,t}
\end{aligned}$$

We have excluded from (3) any intermediate goods, such as raw materials that are used up in production. Of course, it is standard in most accounting treatments to treat (most) intangible spending this way as well and we deal with that case below.

We may now write down the following definitions. Nominal GDP and the growth rate of real GDP are defined as

$$P^V V = P^C C + P^I I + P^N N$$
$$\Delta \ln V = \frac{P^C C}{P^V V}\Delta \ln C + \frac{P^I I}{P^V V}\Delta \ln I + \frac{P^N N}{P^V V}\Delta \ln N \qquad (4)$$

Where the first term follows from the definition of GDP and the second term is an index number defining real GDP growth. Finally, we assume that all inputs are paid the same across all sectors giving economy-wide definitions as

$$X = \sum_{i=C,I,N} X^i, \quad X = K, L, N$$
$$\Delta \ln X = \sum_{i=C,I,N} \frac{P^X X^i}{P^X X}\Delta \ln X^i, \quad X = K, L, N \qquad (5)$$

Where the first term simply defines economy-wide employment of input X to the sum across industries and the second defines the growth of aggregate real inputs as the share-weighted industry-specific growth.

We are now in a position to write how real aggregate output grows i.e. the relation between increased output and increased human, tangible and intangible inputs. Differentiating the production functions in (3) and substituting the resulting expressions for ΔlnC, ΔlnI and ΔlnN into (4) and using (5) we can write the following the sources of economy-wide value added growth in terms of economy-wide input growth as the following

$$\Delta \ln V = s^K \Delta \ln K + s^L \Delta \ln L + s^R \Delta \ln R + \Delta \ln TFP \qquad (6)$$

where

$$s^X = (P^X X / P^V V), \quad X = K, L, R$$
$$\Delta \ln TFP = \sum_{Y=C,I,N} \left(\frac{P^Y Y}{P^V V}\right)\Delta \ln TFP^Y, \quad Y = C, I, N \qquad (7)$$

Which says that s^X terms are the input factor shares of value added, which weight the primary factors, and economy wide value-added TFP growth is the sum of the Domar weighted sector ΔlnTFP terms. Equation (6) has the following interpretation. Economy value grows due to primary factors and TFP growth in each sector. The primary inputs in this case are K, L and the stock of intangible knowledge R. These growth rates are weighted by the shares of each factor in final output. The TFP growth rates are rates of technical progress in each sector and they are weighted by the ratio of each sector's output to final output Q (Domar weights, Domar, 1961). The Domar weights add to more than unity since a

TFP increase in a given sector raises overall TFP by both the direct contribution of the increase plus the indirect contribution of that good into other sectors.

What is the implication of this model for innovation? Equation (6) shows that the economy can grow due to ΔlnK and ΔlnL i.e. with the addition of more tangible capital and labour alone (at the moment are vague about exactly the definition of output and capital, these are discussed more below). Thus if our innovation index is to exclude this effect, it will be

$$\begin{aligned} II &= \Delta \ln V - (s^K \Delta \ln K + s^L \Delta \ln L) \\ &= s^R \Delta \ln R + \Delta \ln TFP \end{aligned} \qquad (8)$$

The intuition behind this expression is as follows. The TFP terms are straightforward since they reflect increases in technical change that raises output for any given inputs (of course in practice they also will incorporate measurement error and the like). The first term on the left hand side, namely the share weighted change in the stock of knowledge is a little more complicated. It consists of the change in the knowledge stock, which as set out in (2), captures the notion the innovation is about the growth of ideas. It is weighted by the share term for the following reason. Given our definition, we require a way of converting the ΔlnR into extra output. Consider then a firm paying for a new idea (contracting to hire scientists with an R&D company for example). At its cost minimising point, the cost of knowledge will just equal the extra revenue flow from such knowledge. From this, it can be shown that the proportional effect on output of a proportional change in the knowledge stock is the payments to knowledge as a proportion of total output value.

2.2 Discussion

We now discuss some of the features of the model and the issues that it raises, moving term by term in (8).

2.2.1 Output measure

The model makes clear that the output measure we shall use for the final output measure is value added. To measure economy-wide output, it is important to use value added since it is a consistent measure not involving double-counting. In addition, under various assumptions, it is closely related to welfare (see the discussion in Hulten, 2001). At the industry level, there is case for examining technology using gross output since that allows one to calculate TFP without imposing restrictive conditions on technology. The relation between gross output industry Δln*TFP* and overall value added based Δln*TFP* is set out below.

Second, it is worth mentioning that other innovation studies have used other output measures such as patents, trademarks or answers to innovation questions. Some have criticised such measures as being too narrow but we take no stand on this matter here. This framework says nothing about whether those measures are sensible measures of innovation output or not, merely that under this framework, value added is the implied output measure.

Third, using a definition of innovation in terms of output, valued at market prices, implicitly imposes a market test on whether an innovation is successful or not. One advantage of this is that we let the market decide on whether an innovation is desirable or not. Note that this does not bias the measure against a piece of freely available research, like calculus. Freely available work shows up in this framework as $\Delta \ln TFP$. The point is that the implicit valuation of calculus is made here via the commercialised output that it has engendered in the marketplace, rather than the beauty of the concept to other mathematicians.

Fourth, an important issue for measurement is that if this framework is accepted, then we need immediately to face up to the fact that most innovation is not in value added as currently measured. This is set out in more detail below, the but key point is that (1) we are not saying here that we are seeking to measure how innovation has impacted on a given amount of output, but that it has also changed output and (2) we will need to measure the knowledge stock and its share of payments in total costs.

To see this point, we replace the model above with one where we assume that the intangible sector produces knowledge that is an intermediate input into the other sectors. Thus we have

$$\begin{aligned}
&\text{(a) Intangible sector}: N_t = F^N(L_{N,t}, K_{N,t}, t); \quad P_t^N N_t = P_t^L L_{N,t} + P_t^K K_{N,t} \\
&\text{(b) Tangible sector}: I_t = F^I(L_{I,t}, K_{I,t}, N_{I,t}, t); \quad P_t^I I_t = P_t^L L_{I,t} + P_t^K K_{I,t} + P_t^R N_{I,t} \\
&\text{(c) Consumption sector}: C_t = F^C(L_{C,t}, K_{C,t}, N_{C,t}, t); \quad P_t^C C_t = P_t^L L_{C,t} + P_t^K K_{C,t} + P_t^R N_{C,t}
\end{aligned} \tag{9}$$

Which replaces the flow of new intangibles produced in the intangible sector as intermediate inputs to the other sectors, rather then the knowledge stock as an input to the other sectors. In this case, nominal GDP and the growth rate of real GDP are defined without the output of intangibles capital since it is treated as an intermediate

$$\begin{aligned}
&P^{Q'}Q' = P^C C + P^I I \\
&\Delta \ln Q' = \frac{P^C C}{P'^Q Q'} \Delta \ln C + \frac{P^I I}{P'^Q Q'} \Delta \ln I
\end{aligned} \tag{10}$$

Where a prime on Q denotes that we are considering the case where intangibles are expensed. We assume the same concerning inputs K and L and similar manipulations give the sources of measured value added growth as the following

$$\Delta \ln Q' = s'^K \Delta \ln K + s'^L \Delta \ln L + \Delta \ln TFP \tag{11}$$

Where

$$s'^X = (P^X X / P'^Q Q'), \quad X = K, L, R \qquad (12)$$

From which we can see that the innovation index here would be only $\Delta\ln TFP$. This differs from (8) in that (a) output is different (b) $\Delta\ln TFP$ is different because the factor shares are evaluated at different amounts and (c) the intangible index is less explained since we are not accounting for investments building the knowledge stock.

Finally, in measuring output we face the formidable difficulty of measuring public sector and service sector output. For reviews of measurement of public sector output, see the ONS productivity handbook (2007) and for service sector, see Haskel (2007). Due to data problems discussed therein, we do not deal with the public sector in the data below and we regard our data for financial and business services as tentative.

2.2.2 Input measures: tangible 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). Conceptually, an advantage of using capital services is to locate innovation in the correct sector and not double count it. Consider as an example our sectors above being the following: the consumption sector is an airline using aircraft which are the tangible goods sector, who in turn buy in ideas from the intangible goods sector (let us suppose here either that aircraft manufacturers buy in all new knowledge or that they perform it in house but that we measure this in-house production). Thus a new discovery that raises, say efficiency of the aircraft, following R&D by the intangible sector will show up as $\Delta\text{lnTFP}^{\text{I}}$ in the tangible goods sector. But the aircraft now yields a greater flow of capital services which shows up therefore as $\Delta\text{lnK}^{\text{C}}$ i.e. an increase in capital services to the consumption sector, not $\Delta\text{lnTFP}^{\text{C}}$. This is correct, since the TFP improvement is not due to the airline but the aircraft manufacturer. Note however that an innovation in the airline business such as ticketless boarding onto the same aircraft would correctly show up at $\Delta\text{lnTFP}^{\text{C}}$.

The issue of innovation and tangible capital goods is sometimes posed in the innovation literature terms of a puzzle related to adoption: does a firm who buys a typewriter for the first time in the computer age innovate? The answer in terms of our framework is no. The typewriter would yield presumably very low capital services and so would have a very low price. Thus it would raise the flow of capital services available to the firm (although likely only to a small extent) and output of typed documents would rise. However, recall that our definition is that innovation is increased output net of those increased capital services. Thus if the firm simply produces more typed documents at the prevailing market price there is no innovation. If however, firms marketed successfully to nostalgic consumers who wished to pay premium prices for old-fashioned typewritten documents, the resulting extra output would be innovation and the value of reputation capital from the marketing account for part of it.

2.2.3 Input measures: labour

Our labour input measure is composition-adjusted labour input. The following points are worth noting. First, any labour improvement due to firm-specific training is in the intangible measures. One might ask if there is double counting with the labour quality measures, but the implicit assumption is that if firms are willing to pay for training it will be firm-specific and so they reap the returns of higher productivity rather then the returns internalising into wages. Second, since households are not counted as firms, they cannot do any investment and hence their acquisition of human capital is not counted. Since much of this is public sector, this suggests that we might ascribe increases in labour quality as, in part due to the public sector, but of course the mix of labour might change due to e.g. immigration or flows from/to the unemployment register, which is of course not entirely due to public sector education provision. Third, one might argue that labour quality improvement is part of innovation since it reflects building knowledge capital in the labour force. We see no reason to exclude it and so the data on labour composition is presented below.

2.2.4 Input measures: intangible capital and $\Delta\ln TFP$

To measure the growth of intangible/knowledge capital at the firm, one has to make some assumptions about how firms acquire knowledge. There would appear to be at least three sources. First, firms might get it for free: observing what other firms do for example. Second, the firm might invest its resources in-house. Finally, firms might buy in knowledge from the outside

At least two issues arise: (a) in practice, how are we to measure these sources? and (b) in theory, is using existing knowledge (e.g. obtained for free) an addition to the overall knowledge stock? Regarding (a) the following points are worth noting. First, free knowledge will be part of ΔlnTFP. However, ΔlnTFP also includes other effects such as mismeasurement, the impact of non-constant returns and imperfect competition etc. Second, in-house spending will be missed if one only looks at output of the creative industries, although such output should help understand bought-in innovation.

The question of whether these three sources of knowledge constitute increases in the overall knowledge stock is difficult. Presumably in-house spending would do so; if it is performed in house, it suggests that firms either cannot find knowledge elsewhere. The other sources are more complicated.

The crucial question for our purposes is whether any spending on ideas (a) creates a new idea and (b) creates an asset. If spending on buying ideas that are used up in the production process, can be identified, the conceptual answer is to treat them as intermediate consumption. For example, spending by a cinema to buy a film to project for example is expressly treated as intermediate consumption (which has the convenient property of raising only the knowledge stock at the filmmaker).

Another example where ideas are rented is a licence e.g. to use a production technology. Spending on such licences are typically excluded from R&D in the official numbers; so for example, spending on a technology licence is only counted as R&D if the knowledge from such a licence is a key part of the ongoing R&D process in the firm[5]. Although such licences are excluded from R&D spending, there may be a problem if they are included in other spending numbers. One issue here is software, where OECD rules mandate that spending on software licences is counted as investment in intangible assets, despite the view that such spending is merely double counting the (discounted) value of the investment by Microsoft in the knowledge asset. The rationale for its inclusion is that such software is often not capitalised by the software writer originally anyway and that the licence to use the software is generally for a period of time, which then follows the convention that leasing assets for a long period e.g. aircraft is treated as renting of capital by the lessor. One conservative view might then be to treat own-account spending on software as innovation spending in case purchased spending includes such licence payments and double counting.

Although there is not a licence, there may be other spending categories where existing ideas are bought in; purchased management consulting for example. Presumably firms are buying knowledge from consultants, who, since they already have the knowledge, may constitute an addition to the firm's knowledge stock, but does not constitute an addition to the overall knowledge stock. There are number of points here. First, the market test implicit in our definition answers those who argue that management consultants have no useful knowledge to impart. Second, it is not clear that such knowledge is the duplication of ideas held at the management consultancy, for it may be that the service being sold is the application of such ideas to provide new ideas at the firm. Attempting to measure whether an idea is fundamentally new or not is beyond the purview of this paper and so we shall again fall back on the market test to rule on this question. Rather then debate on whether it is truly new idea we use the market test, if a firm bought it, it must have some value in expectation to the firm as an idea, and if it raised output then the firm must have commercialised it successfully.

Third, it is of course quite likely that spending on ideas, even if they are exactly the same as those existing outside the firm is an input into business change within the firm. So upgrading from software version X to version Y would seem like an example where it is only the idea itself that is bought in. But if it is a necessary part of upgrading knowledge in the business as a whole then new ideas are involved. Untangling what fraction of purchases are genuinely new and what are existing is very hard. So this again suggests two ways in which one might proceed. A conservative approach would be to regard own-account spending as generating new ideas and purchased spending as wholly of existing ideas. Another approach would be to allow the admission of all spending.

In sum, some payments for ideas that are used up in production (e.g. licences to show movies or use a production process) we shall exclude and count as intermediate consumption. Other payments for ideas we shall generally treat as adding to overall knowledge stocks, whilst acknowledging that there may be some double counting of ideas production.

Finally, we need then to convert spending on knowledge into increases in the knowledge stock and the impact on output. We do this by assuming a certain fraction of spending to be investment, a depreciation rate and a price for knowledge, the latter being essentially the GDP deflator. All these assumptions are discussed in Giorgio Marrano, Haskel and Wallis (2007). These are clearly all areas where more research on establishing these parameter is needed: for the moment, we note that GHW test the robustness of the model to changes in e.g. the fraction of innovation spending we think it investment, or depreciation. In addition Appendix 3 sets out a rough indication of where we think further research is necessary to better understand the gaps in our knowledge, focussing on knowledge capital building in financial services and organisations.

3 Relation to other work

There are (at least) four broad areas of related work. First, are the various definitions of innovation that have been postulated. Second, is the TFP work. Third, there is other work that discusses, for example, the distinction between innovation, invention, adoption etc, and fourth the work on creative industries and hidden innovation.

3.1 Relation to innovation definitions

3.1.1 Frascati Manual (2002)

The Frascati Manual (2002) definition is perhaps the natural starting point since it is the definition from the R&D data. It is as follows (Para 1.5.3)

Technological innovation activities are all of the scientific, technological, organisational, financial and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and processes.

The main feature of this definition is the stress on activities, which may be thought of in our context as inputs to the knowledge stock. The outputs are not expressly set out. In particular the verb "implementation" is somewhat broad. It fits with the idea of using marketed output but could also be non-marketed. Note that the emphasis here is on technological rather then organizational: the latter is taken up by the Oslo manual.

[5] The ONS Business Enterprise R&D survey says "Exclude such activities as: Royalties payments for the use of the results of research and development unless required as an essential part of the research and development programme within the unit.

3.1.2 Oslo manual def of innovation

24. A technological product innovation is the implementation/commercialisation of a product with improved performance characteristics such as to deliver objectively new or improved services to the consumer. A technological process innovation is the implementation/adoption of new or significantly improved production or delivery methods. It may involve changes in equipment, human resources, working methods or a combination of these.

The first part of this definition uses the notion to "deliver objectively new or improved". There is no definition of "objectively", but our use of the market would be one (but by no means all: one might have, for example, industry experts coming to a view on significant innovations as in the SPRU data). Note that the definition of inputs is wide and includes organisational innovation.

3.1.3 "Innovation metrics" definition

The definition adopted by the Gutierrez group is as follows.

The design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures, or business models for the purpose of creating new value for customers and financial returns for the firm.

This definition fits with ours closely. First, it concentrates in the final part of the sentence on commercialised products (as they point out, it is orientated at a private sector definition) and so is in line with our proposed measure that effectively focuses on market tested innovation. Second it is broader in its inclusion of new products and services than just scientific and technological ideas, includes organizational ideas too. It does not however, as we do, explicitly exclude new value that arises due to the application of existing capital and labour and ideas but since it does mention new extensively.

3.1.4 NESTA (2008)

NESTA offer the following definition:

Change associated with the creation and adoption of ideas that are new-to-world, new-to-nation/region, new-to-industry or new-to-firm.

This definition suffers from the problem of being rather vague in talking about "change", it not being clear whether this is more output as a result of innovation or input of both. It is helpful in pointing out that an innovation to firm A can be something that another firm has already implemented, but this can lead to some problems as set out above.

3.1.5 Other definitions

Barber (2008) reviews a number of definitions. First he points out the DTI (Department of Trade and Industry, now split into two separate departments) definition namely the *'exploitation of new ideas'* which focuses on new knowledge, but it not clear on how to measure exploitation. Second, he reviews Nelson's definition (), *"the processes by which firms master product designs and production processes that are new to them, if not to the world, nation or sector"* which is not clear on how to measure mastering. Third, he suggests *"Innovation is the process by which firms and other organisations master new product designs, production processes and business methods and commercially exploit them or bring them into use. New means new to the firm or organisation, if not to the world, nation or sector"* which fits well with the Gutierrez definition and explicitly stresses both the "mastering" of a new design or processes and its commercialisation .

3.2 Innovation and other aspects of creative activity: discovery, invention, ideas and adoption

3.2.1 Invention, innovation and technical change.

Three often used terms in the economics literature are invention, innovation and technical change. These are discussed in for example Schumpeter (1943) and see also Rutter (1956) for an early discussion.

Schumpeter's viewed the entrepreneur as taking an invention to market which therefore constituted an innovation. He therefore argued that an invention does not necessarily produce innovation. Schumpeter defined an innovation as follows: "*we will now define innovation more rigorously by means of the production function…this function describes the way in which quantity of products vary as quantity of factors vary. If, instead of quantities of factors we vary the form of the function, we have an innovation* (Schumpeter, quoted by Ratter, p.598)". As Ratter points out this is very close to Solow's (1957) definition of technical change "*…I am using the phrase "technical change" as a shorthand expression for any kind of a shift in the production function*" and Fellner's (1958) comment that such a shift might be due as well to organisational change (indeed Rutter argues against excluding organisational change from innovation but rather suggests using invention to describe the part of innovation on which a patent can be obtained). In this view, the question of where inventions come from (a great genius, a combination of small steps etc.) whilst interesting, is thus only part of the innovation process which refers to the translation of the invention into a sellable product. We take no stand on where inventions come from, other than to assume that the invention and innovation process requires some firms to spend resources whilst some can obtain it costlessly.

Thus a number of points are worth making regarding this approach. Our measure of innovation measures only in part a shift in the production function. To the extent that firms can obtain ideas for free it is a shift in the production function where the production function consists of human and physical capital. To the extent that firms have to spend resources to build up firm-specific intangible capital, it is the shift along the production function in per employee output/intangible capital space (or a shift of the function in per employee output/tangible capital space). Thus it fits with the new Growth Theory notion that invention is due to deliberate research and development activities that arise in the course of market competition.[6]

This can create complications with adoption to which we now turn.

3.2.2 Adoption[7]

Here we distinguish between adoption of capital and ideas.

First, a firm who adopts a new piece of capital which may have many ideas embodied in it, is not, according to our definition, innovating. Of course, if the capital performs its function better than the old capital (e.g. a better aircraft) there has been innovation, but in the aircraft sector not the airline sector. In practice however, a number of problems arise. First it is difficult to measure improved quality well and so it is likely that improved capital might show up as increased sales for given capital and appear to be an improvement in TFP. Indeed, Whelan (2005) casts the debate on the important of embodied technical change in this light (see also Hulten, 1992, and the exchange between Greenwood and Krussel, 2007 and Oulton, 2007, 2008). Second, it is also likely that in practice a new piece of capital will be introduced with new organisational change (e.g. new work practices) and so, to the extent that this is not measured, an improvement in TFP.

Second, what if a firm adopts an existing idea? This would seem to be similar in spirit to a firm adopting an existing piece of capital stock which we have ruled out as not being innovation. Indeed in the model above, firms simply rent ideas from the idea-producing sector, which would

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[6] Thus our framework is clearly in line with the endogenous growth literature where increases in knowledge capital, which raise growth in endogenous growth models, are due to spending by firms. However, unlike these models we do not solve endogenously for the allocation of spending on R&D in the knowledge sector. Nor do we explore the problems for competitive equilibrium of the non-rivalrous nature of ideas For all this, see e.g. the survey by Jones (2005). Some observations on his results in relation to our discussion here are as follows. First, in a broad sense, there is still TFP in these models, but that TFP is explained by R&D labour input, which, since R&D labour input is endogenous, depends on the population. So, in his model for example, his equation 30 shows the standard production function holds and that in 31 shows that, along the balanced growth path, there is a level relation between output per person and capital per person and TFP. The "TFP terms" are then endogenised in terms human capital but also the stock of knowledge. That stock depends in turn, equation 32, on the number of researchers etc. via the knowledge production function. In the Aghion and Howitt model, there are a number of different sectors and so GDP is rather complicated by the purchase of intermediates from various sectors, but see their note XX in. Note finally the Aghion and Howitt (2007) also argue that since knowledge and capital accumulation are all ultimately endogenous ascribing growth to one or the other is correct in an accounting sense, but may not be correct in a causation sense.

[7] One question relating to adoption question is whether a particular new product is really new or not (e.g. a mobile phone is simply different version of a phone or a new fashion that reproduces an old fashion). Such arguments are rather in the history of technology domain; and sidestepped here by applying the market test. Since innovation is measured in terms of its sales to consumers, an adopted innovation that sells for a pound is the same as a new-to-the-world innovation that sells for a pound (a mobile phone introduced today in a country that previously had no mobile phones for example).

appear to be duplication of ideas and not addition to the ideas capital stock. This takes us back to the discussion above on whether purchased ideas raise total knowledge stock, as opposed to just that at the firm. We summarised the view there that we will assume that the commercialisation of such purchases likely did create new knowledge or else existing firms would have been able to exploit it.

3.2.3 Discoveries and inventions

Patent law, permits the patenting of inventions (additions to prescriptive knowledge) but not of discoveries (additions to propositional knowledge). Either addition to knowledge, insofar as it is commercialised, will be counted as an innovation. For more on this, see Appendix 1.

3.3 Relation to TFP, ICT and intangibles literature

3.3.1 TFP

Our index is firmly in the Jorgensonian tradition and indeed the motivation builds directly on an example suggested by Jorgenson (2007) in his evidence to the Gutierrez committee. He suggests the consequences of innovation are best captured by TFP and argues as follows. "*What is the relationship between TFP and innovation? To answer this question it is useful to begin by considering economic growth without innovation. This can take place through expansion of the labor force as the population grows and expansion of capital services through investment in existing technologies. If there is no innovation, output will increase in proportion to the growth in capital and labor inputs. New or altered processes, systems, organizational structures or business models generate growth of output that exceeds the growth of capital and labor inputs. This produces growth of Total Factor Productivity. Total Factor Productivity growth also captures innovation through new and improved products and services. These innovations create new value for consumers and generate financial returns for successful innovators. The new and improved products and services are included in the measures of output. Output expands more than in proportion to the growth of inputs. For example, new computers, telecommunications equipment, and software compete with existing products. If they are successful in penetrating markets for information technology, they are included in the gross domestic product, as well as in the outputs of the industries where the new products and services originate.*"

3.3.2 ICT

Much of the recent economics work focusing on ICT can be thought of as very much trying to improve our understanding of capital deepening and innovation. Regarding hardware, improved deflators, quality adjustment and the development of industry data are part of the attempt to build better measures of the tangible capital stock and understand and measure better the TFP changes in the economy (e.g. how TFP in the semi-conductor sector translates into higher LPG and $\Delta\ln TFP$ in the whole economy). Regarding software, the incorporation of software as an asset is again part of the process to recognize spending on intangibles as building a (knowledge) capital stock. Both these developments are commented on in the Oslo manual (see e.g. para 55) without an explicit reference to innovation. See, for example, Jorgenson, Ho and Stiroh (2007) for work.

3.3.3 Intangibles

This work is clearly related to recent work on intangibles and growth. Beginning with the Oslo manual, it discusses measuring intangible investment as another way of examining the ways by which firms improve prod and performance. They define first investment as spending expected to give a return over more than a year. On categories, they say "There is no standard definition, but it is generally taken to cover expenditure on non-routine marketing, training, software and some other similar items, in addition to current expenditure on R&D. It covers current expenditure on TPP innovation but also comprises elements which are not part of TPP current innovation expenditure (for example it includes all of the firm's training and marketing expenditure in general, not simply training or marketing in connection with the introduction of technologically new products and processes). It does not cover tangible investment such as capital TPP innovation expenditure, which includes capital expenditure on R&D, acquisition of new machinery and equipment related to TPP innovations." So all of this is again consistent with our headings and discussion.

Two explicit papers on the relation of the intangible spending research programme to innovation are van Ark and Hulten (20007) and Corrado (2007). Van Ark and Hulten (2007) discuss the relation between intangibles investment and innovation. As they point out, current statistical practice often does not measure innovation well: on the input side, R&D measurement is somewhat crude and not broad and on the output side, intangible spending is not capitalised and new products sometimes not well measured. They 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, which includes the effects of technological externalities and spontaneous improvements in organization and technology of production (although this cannot be separated from other factors in the residual, like measurement error).*" So this then is consistent with our framework. Later in their paper they identify innovation with knowledge capital, as we do in this paper, but they have a slightly different defintion"*The restated sources of growth analysis in CHS (2006) contains another message. The combined importance of intangibles, IT capital, and labor quality (which largely reflects human capital) explains nearly 60 percent of productivity growth. This reflects the* *importance of 'knowledge capital' – our measure of innovation – as a driver of growth (p.11*" We are defining here innovation as knowledge capital, but to exclude IT capital, this being part of the physical capital stock.

Finally, Corrado, summarising the CHS work argues that the CHS focus was a macro level measure founded on innovation and further states "*The average businessperson knows that innovation is a complex, gradual process, and that it often involves many firms making incremental investments in a range of activities over many years."* Mokyr (2005) calls these micro inventions, as distinct from larger scale inventions that change process and market organisations. We do not distinguish in this paper between such innovations (or indeed continuous and discontinuous innovations) but rather measure them in terms of their output impact per input (which might of course be higher with some types of inventions), see also Baumol (2003) and Mokyr (2002).

3.3.4 Creative industries and hidden innovation

Our work here is clearly in line with this work, for it will be important, in measuring knowledge investment, to measure all such investment. Some might be purchases from the creative industries e.g. design. But some might be undertaken in house and so the size of creative industries might understate such activity. For example, in Galindo Rueda, Haskel and Pesole (2008), using occupational data on design occupations, we find four designers employed outside the design industry for every designer employed inside.

4 Results[8]

4.1 Section summary

This section sets out results for different industries. Thus we make a number of contributions. First, we set out spending data on intangibles for each sector. Second, we set out the results for growth accounting including intangible investment in each industry. This is of interest beyond the innovation index but can also be used to give an innovation index for the sectors. Finally, we show how the industries combine to produce overall data which will attempt to understand how each sector has contributed to overall innovation.

4.2 Industry data sources

4.2.1 Intangible definitions and sources

We set out the results for each industry's spending on intangible assets. Table 1 sets out our industry definitions, which exclude the public sector. Note that real output measures in group 6 are likely poorly measured.

[8] These results use the findings in Mariela dal Borgo's MSc Econmics thesis at the University of Warwick.

Table 2 sets out our intangible investment categories. They are by now standard and the interested reader is referred to GHW for a discussion. A number of issues are worth summarising here. First, measurement of own-account spending will potentially be important. As discussed above, this is important so that the contribution of knowledge spending is not just restricted to the creative industries. Second, the list of intangible assets is that set out by CHS and may not be exhaustive. More research is clearly necessary on this question. Third, the translation from spending to investment requires an assumption about what fraction of measured spending creates an enduring asset. Our current assumption is set out in column 4. Again, this is an area where more work is required. Fourth, as the table sets out one needs to make assumptions about depreciation/deterioriation rates, see column 5. Whilst more data is clearly needed in this area, our work in GHW suggested that some of the key findings were robust to changes in these assumptions. Fifth, price deflators are assumed, see column 6, and remain an untested work area.

Our industry-level data are availed from 1997 to 2005. They start in 1997 because IO tables are available from this time and IO tables end in 2005.

4.2.2 Output, capital and labour

The data source for output, capital and labour is the UK component of the EU KLEMS Growth and Productivity Accounts, which covers the period 1970-2005 (. However, we are going to rely only on the period 1997-2005 that is for which industry-level data on intangible are available. This database includes measures of output, and various categories of employment and capital at the industry level. Data are presented for 71 industries, classified according to the European NACE revision 1 classification. We then have carried out the aggregation needed to collapse these data according to the six industries described in Table 1. Note that EUKLEMS provide growth accounting data, but since we have expanded the amount of capital and changed value added we have to modify these results.

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 correspondent price and volume indices. Intermediate inputs comprise energy, materials and services.

To measure labour services we needed the series on labour compensation and total hours worked by person engaged, which include hours worked by self-employed and family workers. Labour compensation reflects total labour costs and also includes both labour compensation of employees and of self-employed. Note that, as labour compensation of self-employed is not registered in the National Accounts, the EU KLEMS data are based on an assumption that the compensation per hour of self-employed is equal to the compensation per hours of employees.

To obtain the composition of labour component, we need the more detailed labour input tables, where the shares of various labour types in total compensation or total hours are given. In particular, the breakdown is provided for 18 types of labour, resulting from crossing the following categories: educational attainment (high, medium and low skill), gender (male and female) and age (15 to 29, 30 to 49 and 50 and over).

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 mixed income, plus taxes on production, after subtracting compensation of employees. 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.

Real series are given at 1995 prices and price indices also take 1995 as the base year (1995 =1). The EU KLEMS dataset distinguishes nine type of assets, of which we are going to take data for only five, four categories from Machinery and Equipment (Transport equipment, Computing and Communications equipment and Other machinery and equipment) and only one from Construction (Total non-residential investment). As we have our own estimates for software, we are not going to use the data from EU KLEMS, except for the price index. We excluded residential structures because they should not be considered for productivity-measurement purposes.

Depreciation rates for ICT tangible capital are the same as in the EU KLEMS database, which in turn follows Jorgenson et al. (2005). Like for intangible assets, they are assumed to be the same for all industries and were set in 0.315 for Computing equipment and in 0.115 for Communication equipment. For the other tangible assets that we are considering here we also used EU KLEMS rates that are based on the BEA. Note that these rates vary over industries but not over time and, when it was necessary (industries 1, 2, 5 and 6), we took the average of all the rates that correspond to each industry of our classification.

In theory, taxes should be included to account for differences in tax treatment of the different asset types and different legal forms. In equations (27) and (42) for the rental price, we included the adjustment needed to take these tax rates into account. However, 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 introduced the tax adjustment.

4.3 Industry intangible spending results

Here we use data from 2000 to 2004 (our investment data starts in 1997 and so we think that data before 2000 is too dependent on perpetual inventory starting values).

Table 3 reports the levels of investment, both in tangible and intangible assets, for the six industries and the whole market sector for the period 1997-2005. The Financial sector emerges as one of the more important investors in intangibles, with outlays for £45bn in the last year. Note too the intangible investment in manufacturing is 2½ times that of tangible investment. Overall, tangible investment is smaller than intangible investment.

Figure 1 shows the fraction of all intangible investment in 2000 and 2004 accounted for by each intangible asset type. In both years, investment in firm-specific human capital was the most important in terms of its share in total intangible investment (above 20%). If we consider together the purchased and own-account components of design, then it occupies the second place with a participation of near 18% in both years. Looking at the three broader classes, investment in economic competencies was the more significant in both years, with a share representing approximately half of total intangible investment (50% in 2000 and 54% in 2004). Innovative property represented around a third of total investment (34% in 2000 and 32% in 2004) and it more than doubles the share of the only ICT component of intangibles (software), which declined from 16% in 2000 to 14% in the last year. Therefore, comparing year 2000 with year 2004, there seems to be a reallocation of expenses in intangibles towards categories that create economic competencies (with the exception of advertising) against those related with innovative property and computerized information (except for own-account architectural and engineering design).

Figure 2 shows the series of total investment in intangibles categories, for the period 1997-2005. Note that most of the intangible categories either follow an increasing trend over time or stay flat, with the exception of Copyright licenses and Mineral exploration that present a substantial decline during this eight-year period. The more dynamic between 1997 and 2005 are categories from economic competencies: Market research (but still the spending there is relatively low), Organizational structure and Training. In terms of absolute levels, Training (£28bn), Organizational structure (£20.6bn) and Software (£17.4bn) concentrated most of the investment in 2005.

To get a sense of the data by industry, Figure 2 shows the ratios of total investment in all intangible categories to industry value added plus intangible investment. This shows that manufacturing and financial and business services are the most investment intensive.

Figure 3 shows the data by category. Training, design and software are the most important categories. Lastly, Figure 4 shows data by category and industry. The financial sector emerges as one of the more important investors in intangibles, having invested near £45bn in the last year. Figure 3 shows that it lead the investment levels in five categories (Software, Purchased design, Advertising, Market research and Organizational structure), and also was one of the fastest growing over the period with an expansion of 79%. It is followed by the Manufacturing industry, which invested £31.4bn in 2005, and Trade, hotels and transport with £31.2bn. In the case of Manufacturing, the bulk of the investment was concentrated in R&D, Own-account design and Organizational structure, but overall it did not show great dynamism (a 20% increase from 1997 to 2005). Instead, investment of Trade, hotels and transport experienced a large expansion over this period, particularly for Own-account design and categories from economic competencies. The remaining industries, i.e. Agriculture, Electricity, gas and water and Construction, invested a total of £9.7bn in 2005, which represents a growth of 42% in comparison with 1997. Only outlays in the agricultural sector have fallen over this period, due to a decline in most categories of intangibles. The conclusion that emerges from these figures is that service sectors are performing relatively better than goods producing sectors in terms of investment in intangibles. In 2005, Finance and Trade, hotels and transport invested 86% more than the other four industries, which represents a difference of £35bn.

4.4 Industry growth accounting results

4.4.1 Theory

We follow Jorgenson et al. (2007) in relating industry data on TFP growth to aggregate level data from value added. If we assume that due to competition each capital asset type and worker type is paid the same across industries then we have the following industry and aggregate variables for each type where industry is defined as industry *j* and the aggregate variables are unsubscripted:

$$\begin{aligned}
&\Delta \ln K = \sum_k \overline{w}_k \Delta \ln K_k, \quad \textit{capital type k} \\
&\Delta \ln L = \sum_l \overline{w}_l \Delta \ln L_l, \quad \textit{labour type l} \\
&\overline{w}_k = P_{K,k} K_k / \sum_k (P_{K,k} K_k), \overline{w}_l = P_{l,l} K_l / \sum_l P_{L,l} K_l, K_j = \sum_j K_{k,j} \forall k, L_j = \sum_j L_{l,j} \forall l, \\
&\overline{w}_t = 0.5(w_t + w_{t-1})
\end{aligned} \tag{13}$$

The definition of real aggregate value added depends on the assumptions one makes about value added at the industry level. If all factors are paid the same, a value added function exists at the industry level which is the same across industries and capital and labour are paid the same, then aggregate real value added is simply the sum of industry real value added. If we relax these assumptions and assume a PPF at the industry level then aggregate real value added is

$$\Delta \ln V \equiv \sum_j \overline{w}_j \Delta \ln V_j, \quad w_j = P_{V,j} V_j \Big/ \sum_j (P_{V,j} V_j), \overline{w}_j = 0.5(w_{j,t} + w_{j,t-1}) \tag{14}$$

For each the industry level, we have the following gross output defined $\Delta LNTFP$

$$\Delta \ln TFP_j = \Delta \ln Y_j - \overline{v}_{K,j} \Delta \ln K_j - \overline{v}_{L,j} \Delta \ln L_j - \overline{v}_{X,j} \Delta \ln X_j \tag{15}$$

where industry gross output is defined as

$$\Delta \ln Y_j = \overline{v}_{V,j} \Delta \ln V_j + \overline{v}_{X,j} \Delta \ln X_j \tag{16}$$

Finally, we have the definition of econ wide $\Delta LNTFP$

$$\Delta \ln TFP \equiv \Delta \ln V - \bar{v}_K \Delta \ln K - \bar{v}_L \Delta \ln L \qquad (17)$$

We are now in a position to write down the industry contributions to aggregate value added, which consists of capital input, labour input and TFP

$$\begin{aligned} \Delta \ln V &\equiv \sum_j \bar{w}_j \Delta \ln V_j \\ &= \left(\sum_j \bar{w}_j \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}} \Delta \ln K_j \right) \\ &+ \left(\sum_j \bar{w}_j \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}} \Delta \ln L_j \right) \\ &+ \sum_j \frac{\bar{w}_j}{\bar{v}_{V,j}} \Delta \ln TFP_j \end{aligned} \qquad (18)$$

with each industry's contribution to the aggregate growth in V, K and L and TFP i.e. the terms in (18) being

$$\begin{aligned} CT\_V_j &= \bar{w}_j \Delta \ln V_j \\ CT\_K_j &= \bar{w}_j \frac{\bar{v}_{K,j}}{\bar{v}_{V,j}} \Delta \ln K_j \\ CT\_L_j &= \bar{w}_j \frac{\bar{v}_{L,j}}{\bar{v}_{V,j}} \Delta \ln L_j \\ CT\_TFP_j &= \frac{\bar{w}_j}{\bar{v}_{V,j}} \Delta \ln TFP_j \end{aligned} \qquad (19)$$

where CT defines the contributions of each component and summing each CT term gives the aggregate contribution. Thus the tables below do the following. First, we set out the gross output growth accounting results for each industry. Second, we take these data and set out the contributions for each industry to the growth of aggregate value added. Third, we sum up the contributions across industries to the decomposition of aggregate (market sector) value-added. For in each case we carry out the decomposition with and without intangibles.

4.4.2 Results for whole market sector

Let us start by considering the results for the whole market sector. These are set out in Table 4. They use the direct aggregation across industries approach. The growth rates are in the top panel and the contributions to LPG are in the bottom. Note that the row corresponding to hours worked differ between each column because they are weighted by the share of industry value-added. The columns entitled without software are data which excludes all intangibles including software; that entitle with intangibles includes all intangibles with software. Overall value-added growth per hours worked is positive under both settings and equals 2.74 p.p. for the period 2000-2005 (this is just a coincidence because value-added might change when intangibles are accounted for).

Note that the final column, relative to the without software column, shows much more capital deepening and less $\Delta\ln TFP$. Indeed, the contribution of $\Delta LNTFP$ is almost zero in the final column. So on this measure, what would our innovation index say? One way of expressing it is that the innovation index (intangible capital deepening plus $\Delta LNTFP$) grew 1.19+0.05=1.24pppa, 2000-2005, which is 45% of overall LPG ((1.24+0.45)/2.74) (61% if one includes labour quality). Note that if one calculates this from the column excluding intangibles, one obtains $\Delta\ln TFP$ as 1.07/2.74=40% of LPG, suggesting that ignoring knowledge capital building, under these assumptions, understates the role of innovation over this period.

In sum, the innovation index presented here suggests that innovation accounted for 45% of market sector growth in GDP per person, 2000-2004.

4.4.3 Results by industry

What was the industry contribution to this overall figure? The results for the sources of growth of labour productivity (LPG), described in equation (10), are displayed in Table 5 for the period 2000-2005. This shows in the first two columns the growth rates of gross output and of hours worked, the difference between the two being LPG in column 3.

The top panel corresponds to the base case in which we exclude software and all other intangibles from published data, whereas the bottom panel corresponds to the case including all intangibles. In the fourth column we show total capital deepening contribution to LPG (defined as the product of the value share of capital and the growth rate of capital services per hour worked), decomposed into the ICT tangible and non-ICT tangible components and also the intangible component in the bottom panel. Next, we present labour quality contribution (the product of the value share of labour and the growth rate of labour services per hour worked), intermediate input deepening (the product of the share of intermediate input and its growth rate per hour worked) and TFP growth, which contributes to LGP one-for-one. Note that the differences in gross output and LPG growth between the top and the bottom panel are mainly due to errors of approximation in the building of the real growth series. Hence, we can take the values from the first three columns, as well as those corresponding to labour quality contribution, as the same with or without intangibles, just as our analysis of the previous section suggests.

The following points emerge from the Table. First, the high performing LPG sectors were "Manufacturing" and "Trade, Hotels and Transport", with an expansion of 3.79 pppa and 3.03 pppa respectively, followed by Construction (2.10 pppa.) and Finance (1.69 pppa.). Agriculture and Electricity, Gas and Water slowed down.

Second, what are the causes of these changes? We can see that in the base case (excluding software), the main sources of growth are intermediate input deepening (as in Manufacturing, Construction and Trade). Without software, total capital deepening never exceeds 0.67pppa (with the exception of agriculture). With all intangibles, total capital deepening is never below 0.68pppa. So total capital deepening rises and $\Delta LNTFP$ falls with the addition of intangibles.

Third, the source of the rise in overcall capital deepening is of course intangible capital deepening. The effect of intangible capital deepening, relative to tangible capital deepening is smallest in Agriculture and Electricity, and highest in Manufacturing. Trade and Financial services have seen about equal intangible capital deepening and tangible capital deepening, but note the importance of ICT tangible capital deepening in Financial intermediation in particular.

Further details on capital deepening are set out in Table 6. This shows the capital deepening term per hour worked for each type of capital decomposed into its share (column 1, capital weight), its growth rate (column 2, capital growth) and its total contribution (column 3, capital deepening). We can see there that the shares of intangible assets in total capital are larger than the shares of ICT but still lower than the shares of the other tangible assets. In turn, their growth rates are much faster than the growth rates of the latter and very close to the high rates of ICT assets. Not surprisingly, this combination of high shares and soaring growth rates implies that the investment in intangibles accounts for a sizeable fraction of economic growth and productivity, even higher than the one derived from ICT use.

What of TFP? Returning to Table 5, it shows that TFP, before the incorporation of intangibles, did not play a prominent role among the sources of output growth and moreover, in the case of Agriculture, its contribution was negative. With the addition of intangibles, we cannot predict a priori how it is going to change. What our estimates reveal is that there was a large decline in TFP growth in the six industries. The consequence of this was that in other three industries -Electricity, Gas and Water, Construction and Finance- TFP growth became negative. Finally, if we rank our set of industries according to TFP growth, we will find that Manufacturing and Trade, Hotels and Transport are at the top of the list, meanwhile Electricity, Gas and Water and Agriculture present the lower rates of productivity growth in the market sector. This picture emerges either with or without intangibles and also if we use for the ranking the alternative measure of productivity, LPG.

Since we have seen that capital deepening is a major contribution to LPG, we can ask what industries are contributing to the overall capital deepening? For example, we have seen fast intangible capital deepening in manufacturing, but if manufacturing is a small weight in the overall economy, does it have an impact? Table 7 answers this question. The sum of the contributions in the bottom lineof the panel equals the figure in Table 3. For capital, we included the industry contribution for total capital and for the sub-components, ICT tangible, non-ICT tangible and in the bottom panel also for intangible capital. In the case of total capital we also reported the industry share (column 1) and the growth rate of total capital input per hours worked (column 2). For labour input we also presented first the industry share (column 7), then the growth rate of labour quality (column 8) and finally the product of these two terms that defines the industry contribution to aggregate labour quality. We also included in the last two columns, for comparative purposes, the sum of the weights of capital and labour input (which equals the value-added weights displayed in the first column of Table 7) and the industry employment level as a share of total employment. Table 7, bottom panel shows two interesting findings. First, regarding ICT tangible capital deepening, the leading sector contributions are Trade and Financial and Busisness Services. Second, regarding intangible capital deepening, the leading sector contributions are Manufacturing , Trade and Financial et al. Indeed, manufacturing has contributed 0.54/1.19=45% of intangible capital deepening despite being 15% of employment.

Finally, Table 8 reports the contribution of each industry to aggregate value-added and TFP growth for the period 2000-2005 (see also equations (19) and (35)). Notice that the figures for the whole market sector are obtained as the sum of each row and the contributions are the same as the ones reported before in Table 6. For value-added, we showed in the first column the average share of industry value-added in the aggregate, in the second column the growth rate and in the last one the product of these two terms, which measures the industry contribution to aggregate value-added per hours worked. For TFP growth, we included the Domar-weight, the industry TFP growth and the product of these terms that is the industry contribution to aggregate TFP. Note that the Domar-weights sum to 2.35 and 2.02 in the top and bottom panel respectively, which are values higher than 1.

This table reveals that LPG growth for the whole market sector, is pushed up by Manufacturing, Trade, Hotels and Restaurants and Finance, whereas the others industries has a very small contribution or even a negative one (like Agriculture). But even when aggregate LPG growth is the same (2.74 p.p.) with or without capitalizing intangibles, the contribution of each industry differs somewhat. Indeed, Finance loses importance vis-à-vis Manufacturing and Trade, Hotels and Restaurants when intangibles are accounted because it suffers a deceleration. Regarding TFP contribution, it experiences a fall after adding intangibles, determined mainly by the slowdown in the TFP of Manufacturing and Finance (which actually become negative) and to a lesser extent, of Trade, Hotels and Restaurants. In conclusion, to understand the productivity performance –both LPG and TFP- of the whole market sector, we need to track the evolution of those industries with the largest value-added and Domar weights (Manufacturing, Trade, Hotels and Restaurants and Finance).

4.4.4 Relation to innovation

Table 9 presents the innovation index. Each column shows the intangible capital deepening term and $\Delta LNTFP$ and their sum and the bottom panel expresses all this as a sum of LPG of 2.74pppa. We see the following. First, the overall intangible capital deepening term and $\Delta LNTFP$ terms account for about 45% of total LPG. Second, the most important contributors to overall intangible capital deepening are manufacturing, followed by trade and financial services. These sectors account for

58%, 38% and 14% of intangible capital deepening. Finally, if one were to include labour quality, from Table 7, lower right panel, one would add 0.45pppa to these figures, making the innovation index contribution 61% (=(1.24+0.45)/2.74)of labour productivity growth over the period, with manufacturing, trade and financial services contributing 0.16pppa, 0.13pppa and 0.14pppa to the labour quality growth of 0.45pppa.

5 Conclusion

In this paper we have tried to

(a) propose an implementable innovation index,

(b) relate it to existing innovation definitions and

(c) show whole-economy and industry-specific results for the UK market sector, 2000-2005. Our innovation measure starts by observing that we could get more GDP without innovation by simply duplicating existing physical capital and labour (e.g. adding a second aircraft and crew on an existing route). Thus we propose to measure innovation as the additional GDP over and above the addition existing physical capital and labour. In our measure this is the contribution to GDP growth of market sector investment in knowledge/intangible capital. This contribution is measured by spending on knowledge/intangible assets and TFP growth. We have related our measure to the literature on innovation definitions, TFP, creative industries and hidden innovation. We have argued that it captures many of the intentions in the various innovation definitions, whilst focussing on innovation as opposed to invention. Our measure in very much in line with the growth accounting approach in Economics and, by adopting conventions to measure own-account spending our data incorporates work on the creative industies and the hidden innovation point that innovation takes place outside such industries.

We implement our measure for for six UK market sector industries, 2000-2005, combining with output and tangible investment data from EUKLEMS. Our main findings are as follows. Over 2000-2005, labour productivity grew at 2.74pppa, of which the contribution of market sector knowledge capital was 1.24pppa. In turn, manufacturing accounted for about 60% of this latter figure. If one includes increase in labour skill deepening (0.45pppa) as innovation, then innovation contributed 61% (=(1.24+0.45)/2.74)of labour productivity growth over the period.

Appendix 1: Knowledge, ideas and technical change

Underlying the view in this paper is, in very broad terms, very notion that modern capitalism has, as for example Baumol (2001) argues, made ideas production into routine production. Some of the subtleties underlying this notion are set out in the essay by Mokyr (2005). This appendix can hardly do justice to the brilliance of his argument, but it attempts to set out some of the key notions that he defines that are useful as background understanding.

Mokyr defines the stock of useful knowledge in society is consisting of prescriptive and propositional knowledge. A technique is an example of prescriptive knowledge, being like a recipe it is an instruction that allow people to "produce" defined by him as "to exploit natural phenomena and regularities in order to improve human material welfare".

Propositional knowledge is the epistemic base upon which prescriptive knowledge is based: that is the knowledge of nature on which it is based. It is called propositional knowledge, since it contains a set of propositions about the physical world. Every technique requires this because it involves the manipulation and harnessing of natural regularities.

Thus we can define the distinction between an invention (an additions to prescriptive knowledge) and a discoveries (additions to propositional knowledge). Examples of discoveries, as additions to propositional knowledge, are planet Neptune and the structure of DNA, which were not "invented" since they were there prior to discovery. Engines or aircraft are inventions however. Note that patent law permits the patenting of inventions but not discoveries.

Mokyr argues that the distinguishing feature of the industrial revolution has been its ability to generate sustainable growth for economies. To make his argument very crude, he argues, in the spirit of the paper above, that such sustainable growth is due to the increased weight of technical change in the growth process. Pre-1750 growth, he argues, was primarily based on gains from trade and more efficient allocations due to institutional changes.

The key point can be illustrated by the distinction between invention and growth. As Mokyr points out, "Medieval Europe was an innovative society which invented many important things (including the mechanical clock, movable type, gunpowder, spectacles, iron-casting) and adopted many more inventions from other societies (paper, navigational instruments, Arabic numerals, the lateen sail, wind power). Yet, when all is said and done, it is hard to argue that the impact of these inventions on the growth of GDP or some other measure of aggregate output were all that large."

What changed in the Industrial Revolution, he argues, was not the additional prescriptive knowledge of new things. Instead, it was the widening and dissemination of the epistemic base that supported the these prescriptive inventions. He gives many interesting examples, one such is food preserving as follows.

"[T]he canning of food was invented in 1795, by (a Frenchman) Nicolas Appert. He discovered that when he placed food in champagne bottles, corked them loosely, immersed them in boiling water, and then hammered the corks tight, the food was preserved for extended periods. Neither Appert nor his English emulators who perfected the preservation of food in tin-plated canisters in 1810 really understood why and how this technique worked, because the definitive demonstration of the notion that microorganisms were responsible for putrefaction of food was still in the future. It is therefore a typical example of a working technique with a narrow epistemic base.

The canning of food led to a prolonged scientific debate about what caused food to spoil. The debate was not put to rest until Pasteur's work in the early 1860s. …his work on the impossibility of spontaneous generation clearly settled the question of why the technique worked and provided the epistemic base for the technique in use. When the epistemic base of food-canning became wider, techniques improved: the optimal temperatures for the preservation of various foods with minimal damage to flavor and texture were worked out by two MIT scientists, Samuel Prescott andWilliam Underwood. A University of Wisconsin scientist, H.L. Russell, proposed to increase the temperature of processing peas from 232◦ to 242◦, thus reducing the percentage spoiled can from 5 percent to 0.07 percent"

As he points out, much of modern progress has been the widening of the epistemic base. Computers for example have helped with this by both reducing access to knowledge but also helping inventions (e.g. by allowing for the simulation of previously unsolvable equations). This speeds invention since the wider the actual epistemic base supporting a technique, it is less likely for a researcher to spend resources in trying to create something that cannot work. A good example that he cites is alchemy, which occupied some of the best minds of the scientific revolution, above all Isaac Newton. It only declined by the nineteenth century when chemists knew this was a misallocation of human capital.

Finally, he argues that the widening and dissemination of the epistemic base that supported the prescriptive inventions (what he calls the Industrial Enlightenment) was facilitated in the UK by set of factors and people, like Bacon. To quote “The Industrial Enlightenment can be viewed in part as a movement that insisted on asking not just “which techniques work” but also “why techniques work” – realizing that such questions held the key to continuing progress. In the terminology introduced above, the intellectuals at its centre felt intuitively that constructing and widening an epistemic base for the techniques in use would lead to continuing technological progress.”

Appendix 2: Details of measurement of each asset category

Following, CHS (2006) and Giorgio Marrano and Haskel (2006) we can distinguish three main classes of intangible assets: i) computerized information; ii) innovative property and iii) economic competencies. The first comprises software and databases, the second mainly scientific and non-scientific R&D, and the last one firm investment in reputation, human and organizational capital. Our primary source to build these assets are figures on intangible spending at industry level, available for the period 1997-2005 in many categories, and for 1997-2004 in others. In those cases, we opted to repeat the observation from 2004 in 2005.

The methodology and sources used to get the data on intangible expenditure by industry are described in the Report for the UK Department for Business, Enterprise and Regulatory Reform (BERR) (2008), carried out by XXX. Most of the sources and methods used there follow CHS (2006) and GHW, which conduct their estimates for the total private sector. But some changes were needed to estimate the series at industry level.

According to this Report, the original sources used to compile aggregate data provide an industry breakdown that not always is related to a standard classification like the SIC. This is because some of the sources are not official ONS data or have been collected for other purposes that do not require a SIC classification. In consequence, based on the available data, they combine the SIC codes at the lowest possible level of aggregation and this gives six main sectors that are described in Table 1. In that Table we also included the correspondences with the NACE industry classification because it is followed by the EU KLEMS Growth and Productivity Accounts that we will use for output, tangible capital and labour. Note that the categories described in Table 1 exclude activities mostly outside the market sector like Public administration (L), Education (M), Health (N), Personal services (O), Private households (P) and Extra-territorial organizations (Q).

Table 2 summarizes the categories of intangible assets that we are going to consider in this work, the primary data sources used to measure expenditure in intangibles, the proportion of spending considered as investment and the depreciation rates allocated to each asset.

The third column of the table shows the fraction of current spending that might be considered investment based mainly on the assumptions of CHS (2006). The idea of their study is first to estimate expenditures on each type of intangibles and then, based on economic research and evidence, it determines how much of each category of expenditure might be considered business investment depending on whether it could yield future consumption. We used these conversions factors to obtain our estimates of intangible assets.

The last column reflects the depreciation rates for each type of asset based also on CHS (2006) assumptions. They point out that relatively little is known about depreciation rates for intangibles. In consequence, due to the limited information available, they have to assume constant rates, which imply a geometric depreciation pattern. Moreover, both conversion factors and depreciation rates are assumed to be the same for all industries.

Finally notice that as there are no deflators available for intangible assets, we assumed that they are all equal to the value added deflator. The approach of using a price measure rather than a wage measure as a proxy for the price of intangibles is also advocated by CHS (2006), until specific deflators for intangibles can be estimated . This assumption can introduce a bias in the estimates of the VICS, but the direction of the bias is not clear. If intangible prices grow less than value added prices, then we may be underestimating the overall growth of capital services.

In the following paragraphs we are going to expand the information summarized in Table 2 based on the Report for the BERR (2008).

i) Computerized information

Computerized information comprises computer software, both purchased and own-account, and computerized databases. The main source for computer software investment is contained in the ONS work described by Chesson and Chamberlin (2006). The estimates of purchased software are based on company investment surveys . And for own-account software, they use the earnings of employees in computer software occupations . Note that to avoid double counting additional spending on computerised databases is not considered as it is already included in the ONS software estimates. The third column from Table 2 shows that the 100 percent of software spending should be considered as investment. The depreciation rate appearing in the last column is estimated in 33 percent, which is the BEA's assumption for own-account software.

ii) Innovative property

For Scientific R&D performed by business in the UK, expenditure data are derived from the Business Enterprise R&D survey (BERD). This survey intends to capture R&D aimed at solving scientific and technological problems and, therefore, it includes explicitly items such as design and market research. To avoid double counting of R&D and software investment, R&D spending in "computer and related activities" (SIC 72) was subtracted from the R&D spending of the financial sector (industry 6). Also, in order to derive an actual measure of the UK R&D expenditure, it was necessary to subtract R&D exports (included in BERD data) and to add R&D imports (excluded from BERD), by sector. International trade data on R&D is taken from the ONS. Table 2 also shows that the proportion of Scientific R&D expenditure that goes to investment is 100 percent. The depreciation rate assumed is 20 percent, in the middle of the range of the rates reported in the existing literature on R&D, according to CHS (2006). With the exception of new architectural and engineering design, these assumptions are used also for the rest of the categories that comprise innovative property.

Mineral exploration and Copyright and license costs are already capitalized in the National Accounts. Mineral exploration includes the cost of drilling and related activities such as surveys. As it is only undertaken by the mining sector (included in industry 1) a breakdown by industry is not provided. In the case of copyright and license costs, only the publishing of artistic originals can be accounted as part of the market sector because the rest corresponds to recreational and cultural activities (SIC 92), which is not part of our definition of market sector. In this case there is also no industry breakdown because all publishing is imputed to manufacturing. Hence, estimates for these two intangibles are the same as those presented in GHW.

The estimates of New products development costs in the financial industry are also the same as in GHW and they are all carried out by the financial sector. Thus, there is no industry breakdown in this case either. Following CHS (2006), expenditure is calculated as the 20 percent of total intermediate consumption by the financial services industry, after subtracting the purchase of other intangibles that are already counted elsewhere. Data are taken from the Use Table.

As regards New architectural and engineering design, the industry data are obtained using a different methodology than CHS (2006) and GHW, given that purchased and own-account designs are estimated separately. The purchased component is estimated from the IO Tables using data on "Architectural activities and technical consultancies". Turnover data from ABI are used to subtract part of this aggregate that cannot be considered an investment asset . Own account output is estimated using data on the design industry output and on the wage bill of designers working inside and outside the design sector, which were taken from the Annual Survey of Hours and Earnings (ASHE). Note that in this case we rely on our own assumptions for the conversion factors, setting investment as the 50% of total spending, due to these methodological changes.

R&D in social sciences and humanities is estimated as twice the turnover of R&D in "Social sciences and humanities" (SIC 73.2), where the double is assumed to capture own-account spending as in GHM. Turnover data are taken from ABI.

iii) Economic competencies

Advertising expenditure is estimated from the IO Tables by summing intermediate consumption in Advertising (product group 113) across all industries. It is remarked in the Report that these figures are not capturing the own-account component that should be computed, but in contrast, they do include the classified advertising (i.e. small advertising at the end of newspapers, typically for sale or vacancies), which is unlikely to be asset building. In addition, CHS (2006), based on the existing literature on advertising, estimate that only about 60 percent of total advertising expenditures can be considered investment, i.e., have effects that last more than one year. Note that together with market research this category presents the main deviations from unity among the conversion factors in the third column. They also conclude that advertising had a service life of less than 3 years, with a depreciation rate of 60 percent per year, as the last column shows.

Market research by industry is estimated with data on market research and management consultancy (product group 111) from the Use Table and the IO Table. ABI data on value-added are used to extract the market research component from the aggregate of product group 111. Final figures are doubled to consider the own account market research. Assumptions on the fraction of expenditure that is capitalized and on depreciation rates are the same as for advertising.

The Firm-specific human capital expenditure is estimated as the costs of employer-provided worker training. Our data were estimated using the National Employer Skills Survey (NESS2004), which collects data on employer expenditure on on-the-job and off-the-job training. As the split by sector is provided for 2004 only, an industry-level time series is built by backcasting 2004 figures with the EU KLEMS wage bill time series. Also, it was introduced an adjustment to consider all UK because the NESS covers just England. CHS (2006) assumed that all training expenditure is capitalized and estimated the depreciation rate in 40 percent, averaging the rates for advertising and R&D. This is because training combines a long-lasting dimension similar to R&D and a short-lived dimension similar to advertising. The first is derived from the link between employer-provided training and firm-level productivity and the second from the fact that investment through strategic planning, adaptation and reorganization reflects the constant need of the business to adapt to changing economic conditions.

Organizational structure reflects management time to enhance the productivity of the firm. It has a purchased component, represented by management consultant fees, and an own-account component, represented by the value of the executive time spent on improving the effectiveness of business organizations. The first is estimated as the revenues of the management consulting industry, using a survey conducted by the UK Management Consulting Association (MCA). The industry breakdown is provided for 2005 only, thus, the time series are constructed following a backcasting procedure similar to the one used for Firm-specific human capital. Also, it is necessary to add management consultancy imports to consider the consulting services purchased from abroad. As regards own-account expenditure, it is estimated as 20 percent of the managers' earnings, following CHS (2006) assumption that 20 percent of their time is spent on organization building activities. Data on earnings are taken from ASHE. The third column indicates that 80 percent of the purchased organizational structure and all the own-account are capitalized. In this study we use the total sum of the two components, and therefore, we take the average of the conversion factors that is 90 percent. The depreciation rates are the same as for investment in training, 40 percent.

Appendix 3: Our index compared with NESTA criteria

We have been asked (email from NESTA , 29th August 2008) to include a self-critical SWOT analysis of the approach based on the Index criteria. I have found the following from a NESTA document Innovation Index plan for expert group, May 29th 2008.

Proposed objectives

The new Index must track the innovation that matters most to the UK and embed this understanding at the heart of innovation policymaking.

1. Be complete (on its own terms) by 2010, with a meaningful interim deliverable in 2009.

2. Contain clear insights for the main innovation actors in the UK.

3. Account for 'hidden innovation', open innovation, user-led innovation, absorptive capacity and innovation in public services.

4. As far as practicable, be comparable across similar sectors across different countries.

5. Produce a series of outputs that are accessible to the media and policymakers.

6. Form a framework for a systematic body of work on innovation measurement and recommendations for the improvement of underlying statistics

Our comments on this are as follows.

1. *Be complete (on its own terms) by 2010, with a meaningful interim deliverable in 2009.*

We think we can do this, but for the market sector and using existing assumptions. We have already completed work over the summer for 2000-2005. Updating to 2009 would likely be very difficult owing to the lag in data that the ONS produces. Further discussion with ONS would have to establish this.

2. Contain clear insights for the main innovation actors in the UK.

The index describes the contribution to growth of knowledge capital by industry. So it establishes some facts. as It does not do the following. First, it does not say what the government should or should not do as a matter of policy, although the framework, with more work can explore this. Second, it is not a firm-by-firm analysis, so it cannot distinguish between firm A and firm B.

3. Account for 'hidden innovation', open innovation, user-led innovation, absorptive capacity and innovation in public services.

The index does account for hidden innovation, via the calculation of own-account investment. It accounts for open innovation in the sense that as long as an invention is commercialised, it will be measured, although we are not able to distinguish between the identities of different people who produce the innovation. It accounts for absorptive capacity indirectly in the sense that an industry with poor absorptive capacity will see less impact on growth from a given amount of spending or spend less. It cannot yet measure innovation in public services.

4. As far as practicable, be comparable across similar sectors across different countries.

Since the index is based on standardised National Accounts data, which is designed to be consistent across countries it does this by design. Whether in practice measurement systems are comparable is a difficult question that many international studies have attempted to correct for.

5. P*roduce a series of outputs that are accessible to the media and policymakers.*

Media and policy makers are accustomed to growth figures. This index attempts to account for such growth and so is a natural extension of these data. Growth accounting is, however, a hard matter to explain, but has been done so before, e.g. in various RES press releases.

6. F*orm a framework for a systematic body of work on innovation measurement and recommendations for the improvement of underlying statistics*

Measurement issues are key and recommendations are set out in the Appendix.

Appendix 4: Discussion of future work

The following tables set out the current gaps in our knowledge that would have to be filled to complete the index. There are two broad options (a) undertake the index based on current knowledge (b) new work expanding our knowledge.

Appendix Table 1a

Appendix Table 1b

Appendix 4, Table 2: Work on aspects of innovation index

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Table 1: Assignment of SIC codes and NACE1 sections to our 6 industries

TABLE 1
Assignment of SIC codes and NACE1 sections to our 6 industries

	Proposed sector categories	SIC code		NACE1 sections
1	Agriculture, Fishing and Mining	1 - 14	A	Agriculture, hunting and forestry
			B	Fishing
			C	Mining and quarrying
2	Manufacturing	15 - 37	D	Total manufacturing
3	Electricity, Gas and Water Supply	40 - 41	E	Electricity, gas and water supply
4	Construction	45	F	Construction
5	Wholesale and Retail Trade, Hotels and Restaurants, Transport and Communications	50 t- 64	G	Wholesale and retail trade
			H	Hotels and restaurants
			I	Transport and storage and communication
6	Financial Intermediation and Business Services	65 - 74	J	Financial intermediation
			K	Real estate, renting and business activities

Table 2: Sources and assumptions used to build investment and capital stock in intangibles

TABLE 2

Sources and assumptions used to build investment and capital stock in intangibles

	Type of intangible investment	Source	% of spending considered as investment	Depreciation rate
	Computarized information			
(1)	Computer software and computarised databases	ONS estimates	1	0.33
	Innovative property			
(2)	Scientific R&D	Estimates based on Business Enterprise R&D survey (BERD) and ONS data	1	0.2
(3)	Mineral exploration	National Accounts	1	0.2
(4)	Copyright and license costs	National Accounts	1	0.2
(5)	New product development costs in the financial industry	Estimates based on ONS data (Use Table) and CHS methodology	1	0.2
(6)	Purchased new architectural and engineering designs	Estimates based on IO Tables and turnover data from ABI	0.5	0.2
(7)	Own-account new architectural and engineering designs	Estimates based on data from the Annual Survey of Hours and Earnings (ASHE)	0.5	0.2
(8)	R&D in social sciences and humanities	Estimates based on turnover data from ABI and GHW methodology	1	0.2
	Economic competencies			
(9)	Advertising	Estimates based on IO Tables	0.6	0.6
(10)	Market research	Estimates based on Use and IO Tables and data from ABI	0.6	0.6
(11)	Firm-specific human capital	Estimates based on the National Employer Skills Survey 2004 (NESS2004)	1	0.4
(12)	Organizational structure		0.9	0.4
	Purchased	Estimates based on data from a survey set up by the UK Management Consulting Association (MCA)	0.8	0.4
	Own-account	Estimates based on data from the Annual Survey of Hours and Earnings (ASHE)	1	0.4

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Total tangible and intangible investment by industry, 1997-2005 (£bn).

	Agriculture, Fisihing & Mining		Manufacturing		Electricity, Gas & Water		Construction		Trade, Hotels & Rest., Transport & Comm.		Financial & Business Services		Total Market Sector	
	Tangibles	Intangibles	Tangibles	Intangibles	Tangibles	Intangibles	Tangibles	Intangibles	Tangibles	Intangibles	Tangibles	Intangibles	Tangibles	Intangibles
1997	7.2	2.5	19.8	26.1	5.3	1.1	1.9	3.2	30.8	17.6	16.1	25.1	81.0	75.6
1998	7.9	2.0	20.2	27.7	5.6	1.3	1.8	3.5	35.6	20.1	24.2	29.2	95.2	83.7
1999	6.4	1.7	18.2	28.5	5.9	1.3	2.0	3.9	37.0	22.1	26.4	33.1	95.9	90.5
2000	5.2	1.5	17.5	29.1	5.4	1.4	2.1	4.2	41.5	24.2	27.8	36.0	99.5	96.5
2001	6.2	1.6	16.0	30.6	5.7	1.4	2.2	4.7	41.1	26.4	27.6	39.5	98.8	104.2
2002	7.3	1.7	13.3	30.2	5.1	1.7	3.2	5.3	40.8	27.8	27.7	41.8	97.4	108.5
2003	7.0	1.7	12.9	31.0	5.1	1.5	3.2	6.0	37.5	29.0	28.5	42.9	94.2	112.1
2004	6.9	1.8	11.9	31.3	5.3	1.4	3.5	6.4	36.4	30.7	30.3	44.1	94.3	115.6
2005	6.5	1.8	13.0	31.4	5.4	1.5	2.5	6.4	37.0	31.2	31.9	45.0	96.3	117.3

Table 3: Total tangible and intangible investment by industry

Figure 1: Intangible investment by type as percentage of total

FIGURE 1

Intangible investment by type as percentage of total

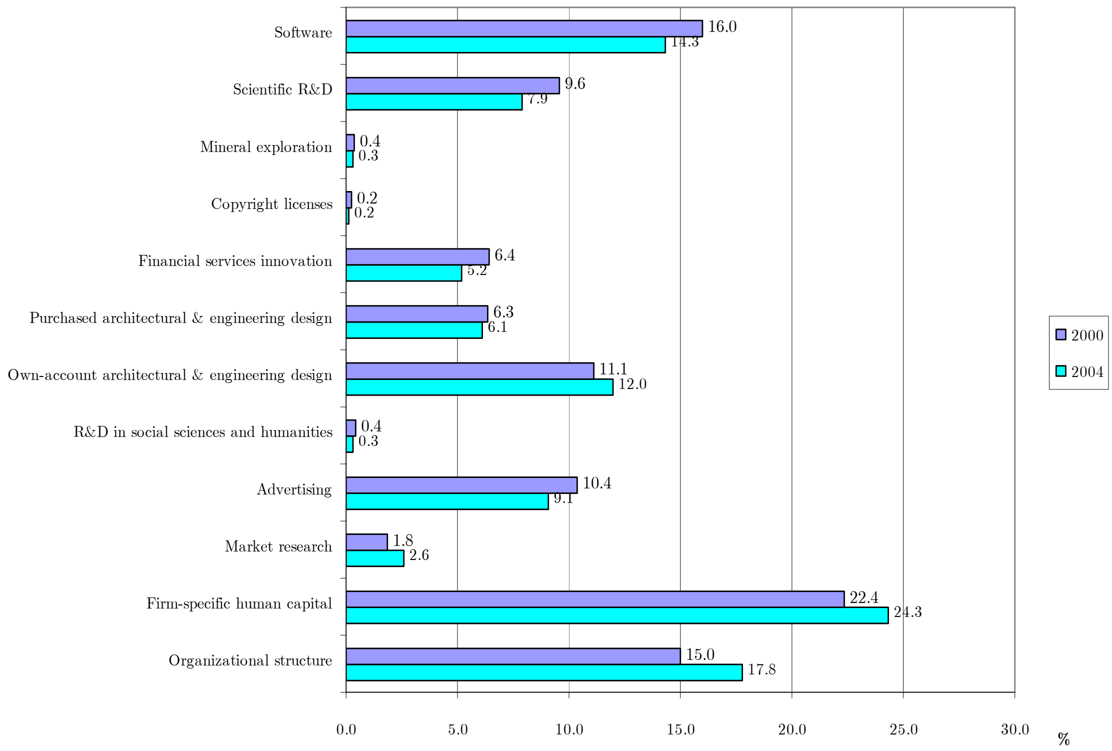
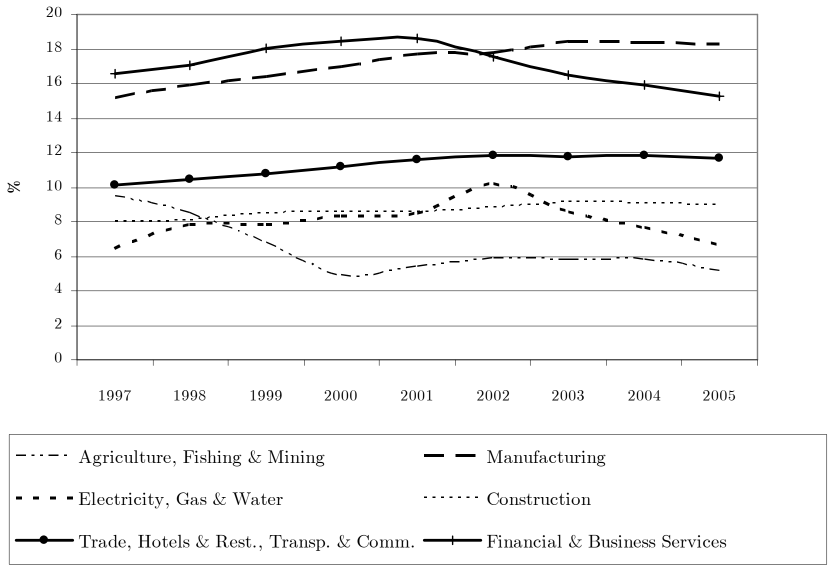


Figure 2: Total intangible investment by industry as a share of industry value-added, in percentages

Figure 1

Total intangible investment by industry as a share of industry value-added, in percentages



Note: industry value added is EUKLEMS value added plus intangible investment.

Figure 3 Total intangible investment, by category

FIGURE 2

Total intangible investment, by category

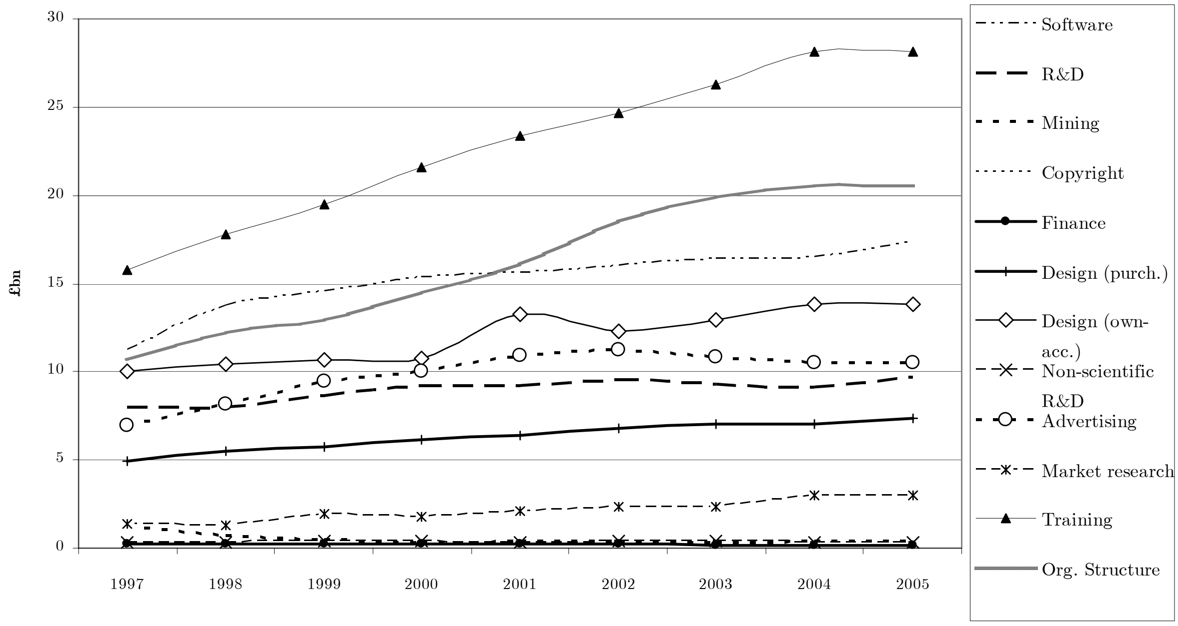


Figure 4 Total intangible investment, by industry and category

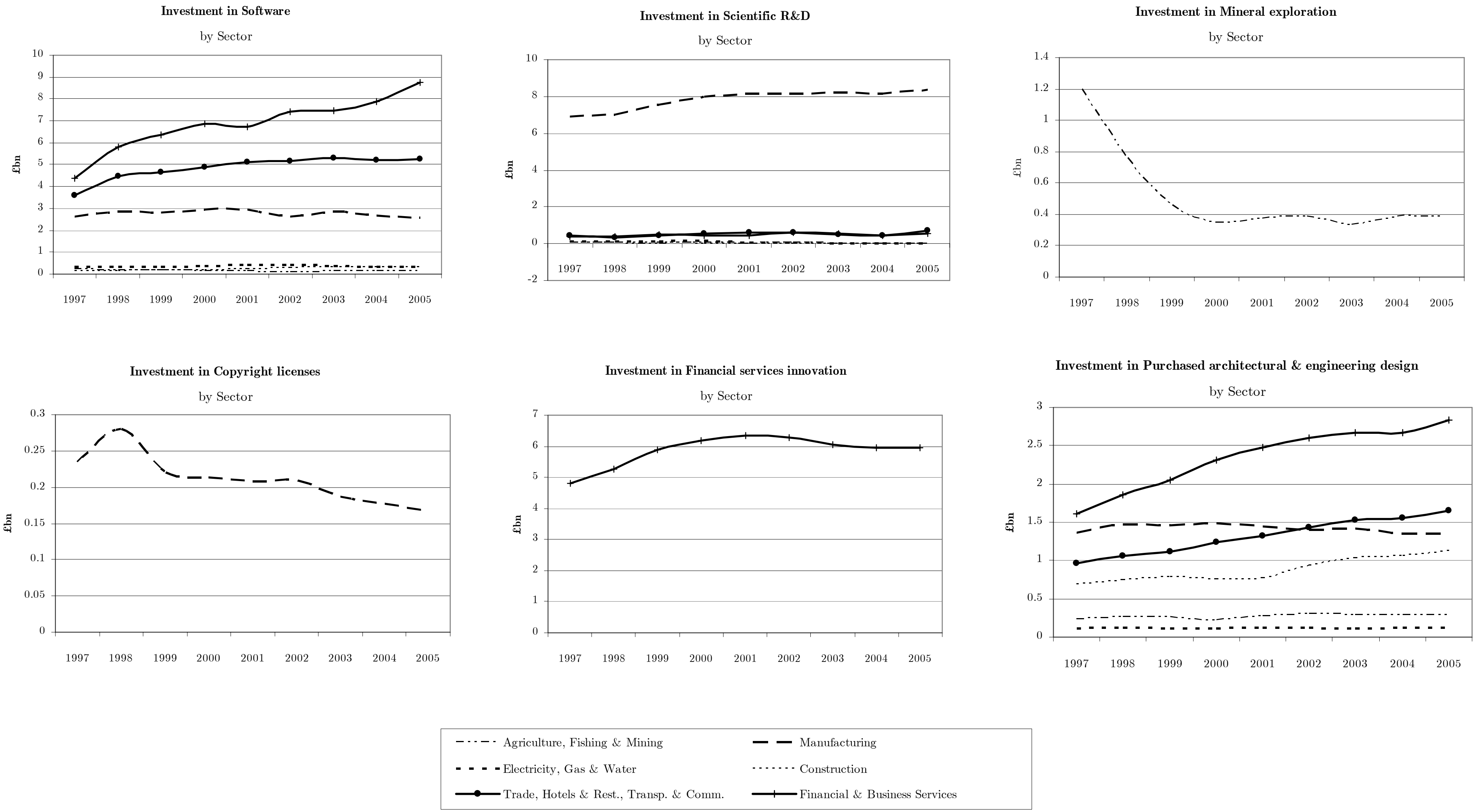


FIGURE 3 (cont.)

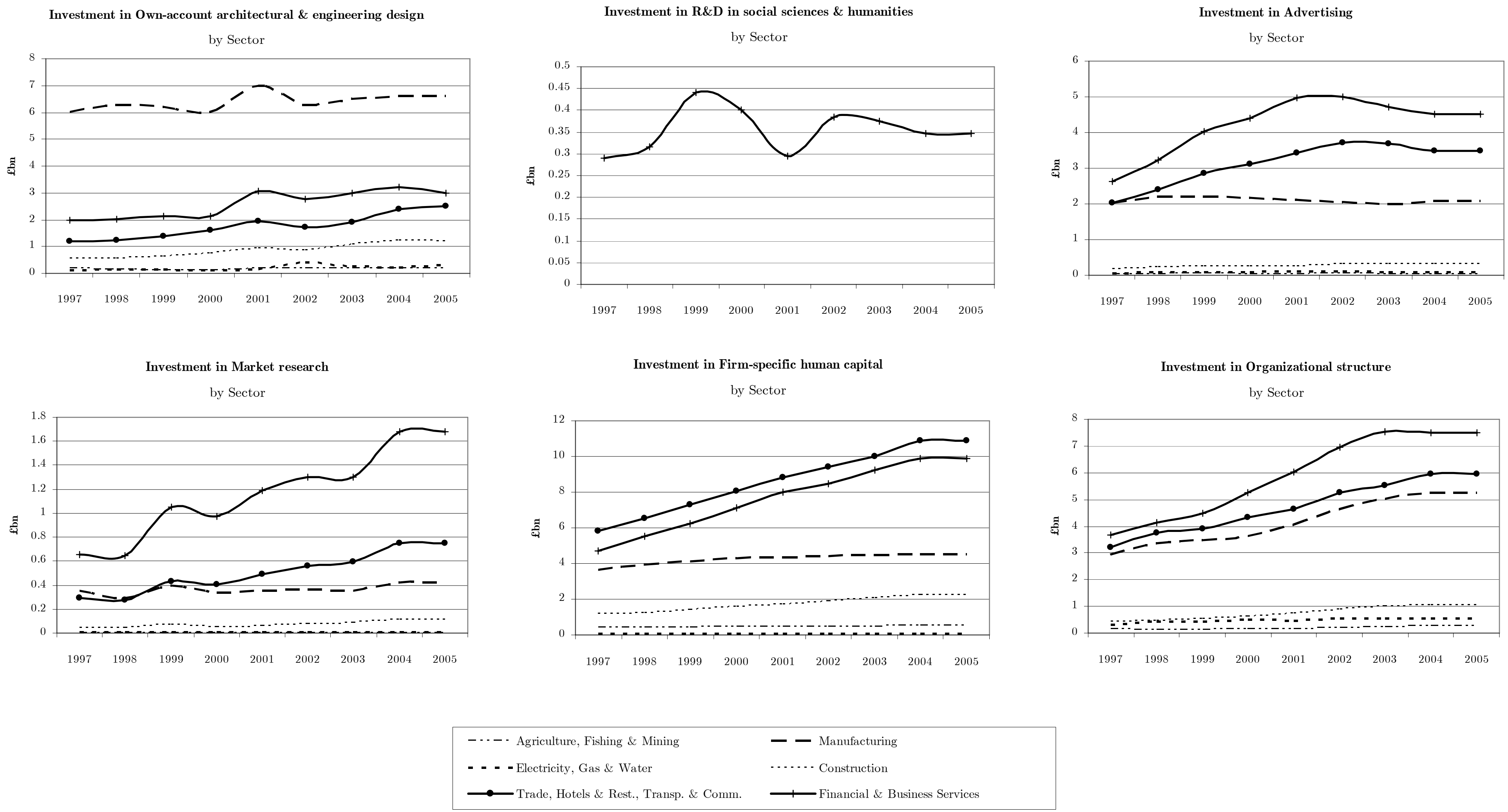


Table 4: Decomposition of aggregate labour productivity

Decomposition of aggregate labour productivity

	Excluding Software	Including All Intangibles
	Growth Rates	
Aggregate Value-Added	2.81	2.80
Average labour productivity	2.74	2.74
Hours	0.08	0.07
	Contributions	
Average labour productivity	2.74	2.74
Capital Deepening	1.15	2.23
ICT Tangible Capital Deepening	0.52	0.47
Non-ICT Tangible Capital Deepening	0.63	0.58
Intangible Capital Deepening	-	1.19
Labour Quality	0.52	0.45
Aggregate TFP	1.07	0.05

Note: All figures are average annual percentages. The contribution of an output or input is the growth rate weighted by the corresponding average share. Column entitled excluding software excludes software and other intangibles, other column includes all intangibles.

Table 5: Contributions to labour productivity, 2000-200

Contributions to labour productivity, 2000-2005

					Excluding Software					
					Capital Deepening					
		Gross Domestic Product	Hours worked	Labour Productivity	Total Capital Deepening	ICT Tangible Capital Deepening	Non-ICT Tangible Capital Deepening	Labour Quality	Intermediate Input Deepening	Total Factor Productivity
1	Agriculture, Fishing and Mining	-3.56	-3.39	-0.16	1.30	0	1.29	0.12	0.93	-2.51
2	Manufacturing	-0.87	-4.66	3.79	0.30	0.09	0.20	0.29	2.31	0.89
3	Electricity, Gas and Water Supply	-1.60	-0.72	-0.88	0.67	0.2	0.47	0.03	-1.58	0.01
4	Construction	3.43	1.33	2.10	0.32	0.03	0.29	0.06	1.59	0.13
5	Trade, Hotels and Restaurants, Transport and Communications	3.82	0.80	3.03	0.56	0.33	0.23	0.22	1.64	0.61
6	Financial Intermediation and Business Services	4.63	2.94	1.69	0.54	0.33	0.21	0.25	0.5	0.41

					Including All Intangibles						
					Capital Deepening						
		Gross Domestic Product	Hours worked	Labour Productivity	Total Capital Deepening	ICT Tangible Capital Deepening	Non-ICT Tangible Capital Deepening	Intangible Capital Deepening	Labour Quality	Intermediate Input Deepening	Total Factor Productivity
1	Agriculture, Fishing and Mining	-3.58	-3.39	-0.19	1.48	0.00	1.30	0.18	0.12	0.96	-2.76
2	Manufacturing	-0.92	-4.66	3.73	1.31	0.10	0.24	0.97	0.29	1.77	0.37
3	Electricity, Gas and Water Supply	-1.60	-0.72	-0.89	0.95	0.20	0.48	0.28	0.03	-1.59	-0.28
4	Construction	3.37	1.33	2.05	0.68	0.03	0.26	0.39	0.06	1.45	-0.13
5	Trade, Hotels and Restaurants, Transport and Communications	3.87	0.80	3.07	1.12	0.35	0.27	0.50	0.22	1.42	0.32
6	Financial Intermediation and Business Services	4.66	2.94	1.72	1.03	0.34	0.22	0.47	0.25	0.61	-0.17

Note: All figures are average annual percentages. The contribution of each input is the product of its weight and the corresponding growth rate. The differences in gross domestic product and labour productivity growth between the top and the bottom panel are due to errors of approximation in the building of the real growth series. Panel entitled “excluding software” excludes software and other intangibles, other panel includes software and all intangibles.

Table 6: Capital weight, capital growth and capital deepening by industry and type of assets, 2000-2005

		Total Capital			ICT Tangible Capital			Non-ICT Tangible Capital			Intangible Capital		
		Capital Weight	Capital Growth	Capital Deepening	Capital Weight	Capital Growth	Capital Deepening	Capital Weight	Capital Growth	Capital Deepening	Capital Weight	Capital Growth	Capital Deepening
1	Agriculture, Fishing and Mining	39.1	3.68	1.48	0.1	7.48	0.00	36.8	3.42	1.30	2.2	8.33	0.18
2	Manufacturing	14.4	9.04	1.31	0.6	17.17	0.10	7.4	3.17	0.24	6.4	15.80	0.97
3	Electricity, Gas and Water Supply	25.5	3.72	0.95	1.4	14.01	0.20	21.7	2.18	0.48	2.4	11.62	0.28
4	Construction	8.2	8.19	0.68	0.1	20.94	0.03	4.0	6.37	0.26	4.1	9.97	0.39
5	Trade, Hotels and Restaurants, Transport and Communications	17.5	6.32	1.12	2.6	12.35	0.35	10.1	2.63	0.27	4.8	10.91	0.50
6	Financial Intermediation and Business Services	21.7	4.95	1.03	1.9	16.67	0.34	10.6	2.08	0.22	9.2	5.75	0.47

Note: All figures are annual averages. Capital weight is the average share of the corresponding capital payment to industry gross output in percentages. Capital deepening is the product of the weight and the growth rate. ICT tangible capital includes computing and communications equipment. Non-ICT tangible capital includes transport, other machinery and equipment and non-residential assets. Intangible capital comprises software, scientific R&D, mineral exploration, copyright and license costs, new product development in financial services, purchased and own-account architectural and engineering design, R&D in social sciences and humanities, advertising, market research, training and organizational structure.

Table 7: Industry contributions to aggregate capital deepening and labour quality growth, 2000-2005

Excluding Software

		Capital Deepening: Total Capital: Capital Weight	Capital Deepening: Total Capital: Capital Growth	Capital Deepening: Total Capital: Contribution to Aggregate Capital	Capital Deepening: Contribution to Aggregate ICT Tangible Capital	Capital Deepening: Contribution to Aggregate Non-ICT Tangible Capital	Labour Quality: Labour Weight	Labour Quality: Labour Quality Growth	Labour Quality: Contribution to Aggregate Labour Quality	Capital + Labour Weight	Employment (% of total employment)
1	Agriculture, Fishing and Mining	0.03	3.42	0.11	0.00	0.11	0.02	0.67	0.01	0.04	0.03
2	Manufacturing	0.04	4.21	0.19	0.06	0.13	0.17	1.06	0.19	0.22	0.20
3	Electricity, Gas and Water Supply	0.02	2.94	0.05	0.02	0.04	0.01	0.27	0.00	0.02	0.01
4	Construction	0.01	6.82	0.07	0.01	0.07	0.07	0.17	0.01	0.08	0.11
5	Trade, Hotels & Rest., Transport & Comm.	0.08	4.87	0.38	0.23	0.15	0.25	0.60	0.15	0.32	0.38
6	Financial Intermediation and Business Services	0.08	4.73	0.34	0.21	0.14	0.22	0.72	0.16	0.30	0.28
	Sum	0.26	-	1.15	0.52	0.63	0.74	-	0.52	1.00	1.00

Including All Intangibles

		Capital Deepening: Total Capital: Capital Weight	Capital Deepening: Total Capital: Capital Growth	Capital Deepening: Total Capital: Contrib. to Aggregate Capital	Capital Deepening: Contrib. to Aggregate ICT Tangible Capital	Capital Deepening: Contrib. to Aggregate Non-ICT Tangible Capital	Capital Deepening: Contrib. to Aggregate Intangible Capital	Labour Quality: Labour Weight	Labour Quality: Labour Quality Growth	Labour Quality: Contrib. to Aggregate Labour Quality	Capital + Labour Weight	Employm. (% of total employm.)
1	Agriculture, Fishing and Mining	0.03	3.68	0.11	0.00	0.09	0.01	0.01	0.67	0.01	0.04	0.03
2	Manufacturing	0.08	9.04	0.73	0.06	0.13	0.54	0.15	1.06	0.16	0.23	0.20
3	Electricity, Gas and Water Supply	0.02	3.72	0.06	0.01	0.03	0.02	0.01	0.27	0.00	0.03	0.01
4	Construction	0.02	8.19	0.13	0.00	0.05	0.08	0.06	0.17	0.01	0.08	0.11
5	Trade, Hotels & Rest., Transport & Comm.	0.10	6.32	0.65	0.21	0.16	0.29	0.21	0.60	0.13	0.31	0.38
6	Financial Intermediation and Business Services	0.12	4.95	0.55	0.18	0.12	0.25	0.19	0.72	0.14	0.31	0.28
	Sum	0.37	-	2.23	0.46	0.58	1.19	0.63	-	0.45	1.00	1.01

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. Employment is the share of the industry's hours worked over total hours worked by persons engaged. Panel entitled "excluding software" excludes software and other intangibles, other panel includes software and all intangibles.

Table 8: Industry contributions to aggregate value-added and TFP growth, 2000-2005

		Excluding Software					
		Value-Added per Hours Worked			Total Factor Productivity		
		Value-Added Weight	Value-Added Growth	Contribution to Aggregate Value-Added	Domar Weight	TFP Growth	Contribution to Aggregate TFP
1	Agriculture, Fishing and Mining	0.04	-1.96	-0.08	0.08	-2.51	-0.20
2	Manufacturing	0.22	4.31	0.93	0.64	0.89	0.55
3	Electricity, Gas and Water Supply	0.02	2.19	0.05	0.08	0.01	0.00
4	Construction	0.08	1.35	0.12	0.23	0.13	0.03
5	Trade, Hotels and Restaurants, Transport and Communications	0.32	2.90	0.94	0.68	0.61	0.41
6	Financial Intermediation and Business Services	0.30	2.55	0.77	0.65	0.41	0.27
	Sum	1.00	-	2.74	2.35	-	1.07

		Including All Intangibles					
		Value-Added per Hours Worked			Total Factor Productivity		
		Value-Added Weight	Value-Added Growth	Contribution to Aggregate Value-Added	Domar Weight	TFP Growth	Contribution to Aggregate TFP
1	Agriculture, Fishing and Mining	0.04	-1.98	-0.07	0.07	-2.76	-0.19
2	Manufacturing	0.23	4.70	1.07	0.55	0.37	0.18
3	Electricity, Gas and Water Supply	0.02	2.01	0.05	0.07	-0.28	-0.02
4	Construction	0.08	1.44	0.12	0.19	-0.13	-0.02
5	Trade, Hotels and Restaurants, Transport and Communications	0.32	3.05	0.96	0.58	0.32	0.18
6	Financial Intermediation and Business Services	0.31	1.97	0.61	0.56	-0.17	-0.08
	Sum	1.00	-	2.74	2.02	-	0.05

Note: All figures are annual averages. Value-added weights are the share of industry value-added in aggregate value-added. Domar weights are the share of gross output in aggregate value-added. A contribution is defined as the product of the corresponding share and the growth rate. Panel entitled "excluding software" excludes software and other intangibles, other panel includes software and all intangibles.

Table 9: Innovation Index

		Contribution of Intangible Capital Deepening	Contribution of Aggregate TFP	Total
	All industries	**1.19**	**0.05**	**1.24**
1	Agriculture, Fishing and Mining	0.01	-0.19	-0.18
2	Manufacturing	0.54	0.18	0.72
3	Electricity, Gas and Water Supply	0.02	-0.02	0.00
4	Construction	0.08	-0.02	0.06
5	Trade, Hotels & Rest., Transport & Comm.	0.29	0.18	0.47
6	Financial Intermediation and Business Services	0.25	-0.08	0.17
	% of column totals			
1	*Agriculture, Fishing and Mining*	*1%*		*-15%*
2	*Manufacturing*	*45%*		*58%*
3	*Electricity, Gas and Water Supply*	*2%*		*0%*
4	*Construction*	*7%*		*5%*
5	*Trade, Hotels & Rest., Transport & Comm.*	*24%*		*38%*
6	*Financial Intermediation and Business Services*	*21%*		*14%*
6	***Total***	***100%***		***100%***

Notes: upper panel is in pppa, 2000-2005. Lower panel is fraction of the first row. Data are not reported for lower panel TFP fractions since some numbers are negative. For additional role of labour composition deepening, see text.