Measuring the Contribution of Knowledge*

A thesis by

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The author gratefully acknowledges financial support from ESRC (Grant ES/J035781/1) and the UK NESTA Innovation Index project. This work contains statistical data from ONS which is Crown copyright and reproduced with the permission of the controller of HMSO and Queen's Printer for Scotland. The use of ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. All errors are of course my own.
Abstract

This thesis attempts to contribute to the growing literature on knowledge (or intangible) capital, considering innovation in the context of its contribution to growth and using an extension to the national accounting framework first outlined in Nakamura (1999) and Corrado, Hulten and Sichel (2005). Chapter 1 presents the underlying framework, set out in the context of previous literature and used to confront measurement issues encountered when knowledge capital is incorporated into a national accounts setting. The second chapter confronts measurement of knowledge investment, in the context of UK ‘artistic originals’. The chapter evaluates official estimates and presents new estimates using a variety of methods and new data. The third chapter confronts estimation of the price of knowledge acquisition, with an application to own-account software. In 2009 the UK market sector invested £13.5bn in own-account software, more than ICT hardware (£12.3bn), making estimation of its price a first order issue for productivity analysts. The chapter describes official methodologies and presents new estimates that explicitly consider technical progress in production. The fourth chapter brings together more elements of the broader work programme, presenting data on investment in, and contributions to growth from, the full range of intangibles discussed in Chapter 1. These data are used to estimate the contribution of innovation to UK growth at both the industry and aggregate level. The fifth chapter considers the potential for knowledge capital to generate social returns in excess of the private returns measured in Chapter 4. It uses the dataset developed in that chapter and searches for evidence of spillovers from R&D and other intangibles. The final chapter uses new estimates of telecommunications equipment prices to re-estimate the contribution of telecommunications capital both directly, via growth accounting, and indirectly, using econometrics to search for evidence of network effects. Appendices include papers on related work.
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Introduction to thesis

This thesis attempts to contribute to the growing literature on knowledge (or intangible) capital. In particular it will focus on the measurement of knowledge capital in the context of a conventional national accounting framework, and the integration of those measures into a neoclassical sources of growth framework. In doing so, the measurement of investment in knowledge, the price of those investments and their contributions to growth are all considered. In the latter case, evidence on social contributions in excess of the private contribution of intangible capital is also sought.

The first chapter aims to review some of the primary techniques used by economists in accounting for growth, in both theory and measurement. The first chapter therefore serves two purposes. First, it sets out the framework that underlies the analysis undertaken in the following chapters. Second, it is intended as a contribution in its own right, providing a full exposition of the framework and relevant theory in the context of the previous literature. It therefore draws on the work of Corrado, Hulten and Sichel (2005), who provided the first full exposition of how to account for the role of intangible capital in a conventional measurement setting. The chapter: discusses the role of knowledge and its use in the production of output; considers the measurement of knowledge investment and capital in the context of national accounts and traditional capital theory; discusses alternative methodologies that aim to estimate the volume of innovative or “creative” activity; and responds to actual and potential criticisms of the framework.

The subject of the second chapter is measurement of investment in knowledge assets. The application is to measurement of UK investment in ‘artistic originals’, a form of artistic asset formally protected by copyright, already treated as capital in current official national accounting convention. The chapter therefore reviews the measurement framework and evaluates official estimates of investment in artistic originals as recorded in the UK National Accounts in light of that framework. It then proceeds to present new estimates of gross fixed capital formation in this asset type using improved methods and new data. Bringing these new data to bear suggests an upward revision to UK investment in artistic originals in 2008 of approximately £1.4bn. As it turns out, the ONS has adopted the procedures and data set out in this chapter in a recent revision to the National Accounts (ONS 2013).

The third chapter confronts the issue of estimating the price of investment in knowledge assets. The problem at hand is that most investment in intangibles is undertaken on the firms’ own-account. That is, the asset is produced in-house and no market transaction takes place, so no market price is recorded. An implicit price does exist however. Therefore the underlying framework is used to evaluate the official UK methodology and form new estimates of the price of own-account software investment in the UK. Estimated at £22.6bn in

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Of that £22.6bn, almost 60% (£13.5bn) is in own-account, or in-house, software creation. In recent years there has been considerable progress in the estimation of prices and volumes for hardware and purchased software, which has meant that technical progress in their production is better accounted for. However, the current measurement convention for own-account software is to assume zero or very low productivity growth in its creation. This chapter sets out a framework to: a) describe the current methodologies used in estimating own-account software price indices, and b) exploit the ubiquity of own-account software investment in the UK market sector to form a new price index that explicitly considers estimated technical progress in its creation. The result is an index that falls on average at a rate of -1.85% p.a. over the period 1970 to 2009, compared to an average rise of +6.5% in the official price index. Applying this new deflator has a significant impact on estimates of real investment and growth in capital services, and incorporating those new measures into a growth-accounting analysis more than doubles the contribution of software to UK growth in the last decade.

The fourth chapter brings together more elements of the broader work programme that underlies the work presented in this thesis, presenting a growth accounting application that considers the full range of tangible and intangible capital employed in UK market sector production. The chapter documents investment in the full range of intangible assets discussed in the first chapter, and measures the contribution of knowledge and more broadly innovation in the UK economy, at both the industry and aggregate market sector level. Regarding investment in knowledge/intangibles, we find (a) this is now 34% greater than tangible investment, at £124.2bn and £92.7bn respectively in 2009; (b) that R&D is about 11% of total intangible investment, software 18%, design 12%, and training and organizational capital 21% each; (d) the most intangible-intensive industry is manufacturing (where intangible investment is 17% of value added) and (e) treating intangible expenditure as investment raises market sector value added growth in the 1990s due to the ICT investment boom, but has less impact on aggregate measures of growth in the 2000s. Regarding the contribution to growth, for 2000-09, (a) intangible capital deepening accounts for 26% of labour productivity growth, against computer hardware and telecommunications equipment combined (16%) and TFP (-0.4%); (b) adding intangibles to growth accounting lowers TFP growth by about 18 percentage points (c) capitalising R&D adds 0.04% to input growth and reduces ΔlnTFP by 0.02% and (d) manufacturing accounts for 47% of intangible capital deepening plus TFP.

The fifth chapter goes beyond the previous chapter by considering the potential for knowledge capital to provide returns to society in excess of the private contributions measured in Chapter 4. Many agree that evidence exists consistent with spillovers from R&D. But is there any evidence of spillovers from a broader range of knowledge/intangible investments, such as software, design or training? This chapter uses the industry-level dataset developed and described in the previous chapter and searches for evidence of
spillovers from R&D and the wider range of intangible assets. The method used is common, see Griliches (1973) for an example, with estimated growth in external knowledge regressed on industry TFP. The former is estimated as weighted growth in knowledge in outside industries, where the weights are proxies for industry “closeness” based on matrices for flows of (a) intermediate consumption and (b) workers. The unique contribution lies in the nature of the dataset used, with this being, so far as I am aware, the first study that has sought to estimate social returns for a full range of intangible assets. Our main new result is that we find (controlling for time and industry effects) statistically significant correlations between (future) TFP growth and knowledge stock growth in (a) external R&D and (b) total intangibles. We expand our framework to allow for imperfect competition and non-constant returns and show our results are robust; likewise they are robust to including UK public R&D, foreign private R&D, and other controls, and various lags.

The final chapter includes similar themes to Chapters 4 and 5. Part of the ICT revolution has been the advances in communications technology, the “C” in ICT. However these advances are not reflected in official UK data for telecommunications equipment prices. Using new data on telecommunications equipment prices based on Corrado (2011) we estimate two effects of “C” on UK productivity growth: the direct effect from growth accounting and the indirect effect via network effects. We find: (a) official “C” price data substantially understate quality-adjusted telecoms equipment prices; (b) using new price data doubles the growth accounting contribution of “C” to productivity growth; (c) using new price data also yields some evidence of spillover effects from investment in C capital.

The submitted appendices are papers on related work. Appendix A (Goodridge 2012) uses the framework applied in this thesis to review measurement of the “creative economy”; and produce new measures using what is argued is a more appropriate method that overcomes the limitations of other approaches reviewed. Appendix B (Corrado, Goodridge and Haskel 2011) tackles the issue of estimating a price deflator for UK R&D. It is therefore related to Chapter 3, which confronts the same issue but in the context of own-account software using a complementary approach. Appendix C (Goodridge, Haskel and Wallis 2013) is complementary to Chapter 4 and explores what has happened to intangible investment in the recent recession and whether such investments can potentially explain part of the so-called UK productivity puzzle.
Chapter 1: Accounting for growth and innovation in theory and measurement
Peter Goodridge

Abstract
This chapter aims to review some of the primary techniques used by economists in accounting for growth, in both theory and measurement. In particular it discusses an extension to the conventional national accounting framework, first outlined in Nakamura (1999) and Corrado, Hulten and Sichel (2005), that considers the role of innovation by accounting for the contribution of intangible (or knowledge) assets, often not considered as capital goods in current official national accounting convention. The chapter includes discussion of the role of knowledge assets in production; an exposition of how capitalisation of knowledge assets affects measurement practice; a response to common criticisms of the outlined framework; discussion of alternative methodologies that aim to estimate the volume of innovative or “creative” activity; and discussion of the measurement of knowledge capital in the context of traditional capital theory.
1.1. Introduction

Naturally some of the issues economists are most keen to understand, and the questions they are often called upon to answer, surround growth in real living standards and the drivers of growth. On the latter, the roles of innovation, technology, and knowledge are universally accepted. However, whilst fundamental and implicit throughout economics, the role of knowledge is often taken as given. The argument underlying this survey is that measurement ought to adjust to properly reflect the role of knowledge and allow an improved understanding of the contribution of particular sectors or activities, such as, for example, the “creative sector”, which is growing in terms of size and the attention it receives, but is often quantified using techniques that are flawed in both concept and practice.

An illustration of the way the role of knowledge is sometimes neglected in economic theory is provided by Hayek (1945), who noted that standard microeconomic production theory assumes that firms have access to the latest technology and are subject to a representative production function. That is, access to knowledge is assumed common and costless. Whilst largely for convenience, it is revealing that such a common abstraction omits firm processes that include the developments in knowledge and technology that ultimately drive progress. In reality, knowledge is both an input to production and an output that firms themselves produce, although Hayek would no doubt have objected to the notion that such activity can be readily accounted for in economic statistics.

Despite discussion of knowledge in the context of human capital extending back as far as Smith (1776), similar can be said of macroeconomic theory. The macroeconomic sources of growth (SOG) framework, often attributed to Solow (1956), but with major contributions from Jorgenson, Hall, Griliches (Jorgenson (1963); Hall and Jorgenson (1967); Jorgenson and Griliches (1967)), Domar (1961) and Hulten (1978), allows growth in output to be decomposed into contributions from inputs and total factor productivity (TFP). In the neoclassical growth models (Solow-Swan ((1956); (1956)); Ramsey-Cass-Koopmans ((1928); (1965); (1965)), growth in technology, although a crucial parameter, is determined exogenously as a function of time, thus somewhat disregarding the role of knowledge as an endogenous factor of production. This remained the case until the emergence of endogenous growth models, for example, Romer ((1986); (1991)), Lucas (1988), Aghion and Howitt (1992) and Grossman and Helpman (1991), which allowed for the role of investment in knowledge in the explanation of technical progress and economic growth.

The view of innovation as an endogenous process driven by investment in knowledge lead to greater attention being paid to the exclusion of such investments from national accounting procedure, although the focus of earlier attention was R&D (e.g. Griliches (1973)). Jorgenson and Griliches (1967) and Hulten (1979) provided a reminder that savings and investment are a means of sacrificing current consumption in order to increase future consumption, making the appropriate definition of economic investment the devotion
of current resources to the pursuit of future returns (Weitzman (1976); Hulten (1979)). Consistent application of that definition immediately makes clear that whether expenditure is on a building or a new product design for long-term use does not matter to the question of what ought to be classified as investment. Other prominent authors in the growth literature (e.g. Schankerman (1981); Griliches (1998a)) also recognised that because R&D is not recorded as an investment good in national accounting procedure, its returns are subsumed into estimated ‘costless advance’ or Total Factor Productivity (TFP). But where technical advance requires the devotion of resources, it is clearly not costless. Since then, the (private and social) returns to R&D have been heavily researched, but largely as a distinct topic in the econometric literature, rather than an integrated part of growth analyses (Hulten 2001). The returns to other forms of knowledge capital are less well-studied.

However, national accounting practice has not kept pace with these developments in economic theory. Among the reasons for slow progress are that, first, radical changes to a long-standing system are controversial and naturally subject to resistance, and second, measurement of knowledge acquisition poses conceptual and practical difficulties not faced in the measurement of tangible capital accumulation. Some progress in measurement has however been made. For instance, the 1993 and 2008 revisions to the System of National Accounts (SNA) (United Nations (1993); (2008)) incorporated software, artistic originals, mineral exploration and R&D into official asset definitions, with R&D capitalisation due to be implemented in the UK in 2014.

The framework to be described below helps both define the conceptual and practical problems in question and outline the means to overcome them. It draws heavily on Corrado, Hulten and Sichel ((2005); (2006)), hereafter CHS, which was the first literature to identify a comprehensive range of knowledge capital and provide an exposition of how to integrate such measures into a national accounting system. That framework is in the unusual position of being largely accepted, to the extent that the recent SNA revisions are aimed at remedying some of the defects it highlights, yet still remaining controversial. The rationale is simple: the asset categories used in the SNA are far narrower than the true range of assets invested in by firms in the expectation of generating future returns. Failure to identify and estimate those investments introduces error into the measurement of output and input. For productivity analysis to be informative, measurement ought to adjust to reduce, or eliminate, those errors as far as possible.

However, incorporating knowledge investment into national accounting and productivity measurement involves far more than estimation of the nominal value of resources devoted to the acquisition of knowledge. Full integration of knowledge capital into a productivity framework requires: i) identification of how much is (long-lived) investment and (short-lived) consumption; ii) a decomposition of values into prices and quantities, that is, estimation of the price of knowledge as implicitly or explicitly faced by investors; iii) an understanding of how the efficiency of knowledge capital changes with age, and differs across vintages; and
iv) correct adjustment of nominal and real, output, income, and input, at aggregate- and industry-level, in a consistent way that avoids double-counting. The result is a dataset more appropriate for the analysis of productivity and other matters, such as the role of innovation and the presence of externalities. This survey reviews the literature relevant to these tasks.

The remainder of this chapter is set out as follows. Section two reviews the literature on the role of knowledge or “intangible” capital. Section three reviews national accounting practice and the adjustments necessary for the incorporation of knowledge capital, drawing heavily on CHS ((2005); (2006)). Section four introduces knowledge capital into a growth-accounting framework, and addresses some of the criticisms that have been made of doing so. Section five reviews other methods, common in the literature, for estimating innovative and creative activity. Section six reviews capital theory, in particular its application to intangible capital. Section seven discusses the practical implementation of the framework. Section eight briefly discusses the intangibles literature in the context of spillovers and externalities that may arise from the creation and diffusion of knowledge capital. Finally, section nine concludes.

1.2. Knowledge, or “intangibles”, as capital

The fundamental role of knowledge as an input to production is implicit throughout the economics literature, with early recognition as far back as Marshall (1890) and his discussion of non-material goods that include business skill and ability (Hill 1999), usually termed “organisational capital” in the modern literature. Abramovitz (1956) discussed expenditures on research, health, education and training, as part of a broader range of capital accumulation designed to improve productivity. As far as I am aware, the earliest literature to comprehensively consider knowledge as capital is Machlup (1962), which discusses knowledge in a variety of forms, in the context of production, distribution and use. The concept of knowledge as capital was the foundation of endogenous growth theories, developed some years later.

As stated concisely in Hulten (1979), investment is the devotion of current resources to acquiring future returns. The key questions therefore are, first: does knowledge acquired by firms using costly resources, function as an asset that generates future returns? Secondly, if it does, why is it not measured as such? On the first question, Machlup (1962) makes a simple but crucial point: if expenditures on knowledge acquisition had no value, there would be no incentive for them to occur. Second, he notes that although statisticians and economists have focused on large leaps in technology, hence the attention paid to R&D, smaller incremental advances have almost certainly accumulated to much larger changes in productivity and living standards than more rare, revolutionary changes. Furthermore, Machlup correctly argues that there is much more to knowledge investment than just R&D; rather R&D, engineering and design should be considered separate stages of the innovation process, a foundation of the modern intangibles literature.
Attempts to hive off a narrow definition of scientific research from wider knowledge production have inhibited understanding of the innovation process.

One possible reason for the neglect of the role of knowledge capital in official measurement practice may be that, due to its intangible nature, some have associated it with “immaterial goods” (Marshall 1890), or services in modern nomenclature. Hill (1999) refutes this, noting that the defining feature of a service is that it is produced and consumed almost simultaneously, whereas intangibles are: durable, transportable/transmittable goods, with ownership (rights) that can be exchanged. Hill argued that if a good is used repeatedly in production, or in the creation of multiple copies for consumption, then surely it is an asset. Additionally, where a copy is used repeatedly in production (e.g. software), then that must also be an asset.

With a slight exception in the case of software, Hill makes clear the crucial distinction between the asset and means of distribution (i.e. copies). To use a literary example, the asset is the underlying work, not a copy that it is printed in. The copy is a consumption good, and one of the inputs to its production is the use of the original, for which a royalty is paid to its owners (usually the author and publisher). The original was not “used up” in production as an intermediate good would be, instead it is re-used in the production of copies over multiple accounting periods. Furthermore, the asset can be used in the production of other goods, including other assets, besides copies, for instance films, television programs, merchandise, sequels and other goods. Intangible goods that are not necessarily used to create copies, but are instead employed repeatedly by their owners in production, are also assets, for example, a blueprint that is used and re-used in the construction of buildings. To meet asset criteria, what matters is use in production over a period greater than one year.

Hill also noted the conceptual inconsistency introduced in the 1993 revision of the SNA, which recognised artistic originals and software as assets, but not scientific originals produced from R&D. Hill argued that this stance was inconsistent, and denied the important contribution R&D makes to growth. The 2008 revision of the SNA rectified this, but note that: a) the current definition of “scientific R&D” as used by NSIs is often interpreted narrowly, and as such is more applicable to the manufacturing sector, thus dismissing long-lived developments in other sectors; and b) Hill’s argument of course also applies to other forms of knowledge capital, and the SNA continues to treat different forms of capital inconsistently.

The case for the official capitalisation of knowledge assets, to improve measurement and ensure consistency between tangible and intangible assets, was also made by Nakamura ((1999);(2001)), and CHS ((2005); (2006)). Nakamura noted that some expenditures on intangibles are connected with intellectual property rights (IPRs) already explicitly recognised in legal systems, including copyright and patents, but stressed that it is the underlying knowledge that is the productive asset, not the IPR, just as a building is an asset rather
than the deeds of ownership. Nakamura also noted that firms invest in other intangibles not necessarily protected by IPRs, including process improvement, design and reputation. Brynjolfsson, Hitt and Yang ([Brynjolfsson and Yang 1999]; (Brynjolfsson, Hitt et al. 2000); (Brynjolfsson, Hitt et al. 2002)) have highlighted the strong complementarities between ICT and intangibles, also noted in Machlup (1962). Their results provide evidence that ICT investments require complementary investments in knowledge in order to generate productivity improvements. If ICT expenditures are investments, it is inconsistent for the necessary co-investments to not be counted as such also.

In his early call for the measurement of knowledge production, Machlup also made reference to an inconsistency in national accounting practice. Final output, or gross domestic product (GDP) can be measured in numerous ways. The method considered most robust at the aggregate level, is the expenditure approach, which can be written using the following common notation:

\[ Y = C + I + G + (X - M) \]  

Where Y is final output, C is final consumption, I is private investment, G is government expenditure (consumption or investment) and (X-M) is exports less imports. Machlup correctly noted that publicly funded research and education appear in final output as part of government expenditure, regardless of whether they are considered consumption or investment. However, similar private expenditures do not, because they are not defined as investments, resulting in asymmetrical treatment of knowledge production in the market and non-market sectors.

In considering the consequences that arise from the omission of intangible capital from official measurement practice, researchers have noted paradoxes in the measured data, such as the relatively low growth rates of economies where technical progress is highly apparent in everyday life (Nakamura 2001). To support this point, Nakamura noted that we would expect measured growth to have increased substantially in recent years, as a consequence of the market provision of what used to be unmeasured household production (e.g. domestic services, care etc.). This, coupled with rapid technical change, ought to have resulted in much faster measured growth, but in fact, measured growth rates have been similar or even slightly lower than in past decades. Webster (1999) and Nakamura (2001) also both suggested that the growing importance of intangible capital could help explain the apparently low savings rates of developed economies. If the full range of capital were accounted for, measured rates of saving/investment would be higher and more informative of actual activity. Similarly, Nakamura and others have argued that intangible assets help explain the divergence between stock market capitalisation values and measured capital stocks. Machlup (1962) and Nakamura (2001) both conceded that when intangibles made up a small proportion of productive capital then their exclusion could be justified as pragmatic, but each argued that their ever growing share in
output and investment makes that position untenable. Note that Machlup took this stance in 1962, when the consequences of omission were far smaller than today, and that the consequences for measurement are growing worse over time, with their magnitude depending on the respective real growth rates of knowledge and other final output, and the nominal share of knowledge investment in aggregate output.

Machlup also noted implications for international studies and cross-country comparisons of productivity. Because advanced economies devote a greater share of resources to the production of intangibles, comparisons with economies that predominantly invest in tangible assets are problematic, and increasingly so as resources continue to grow. Therefore, not only are the links between knowledge accumulation and growth not properly understood, neither are the reverse links between productivity and knowledge discovery. As pointed out in Corrado, Haskel et al. (2011), international differences in productivity are often attributed to technology ((Prescott 1998); (Hall and Jones 1999)). Better measurement of innovative activity and knowledge production is key to understanding those differences.

It is easy to think of other ways in which the interpretation of economic data is made problematic by the omission of intangibles from measures of output. Consider the observed low productivity growth rates in services, often referred to as “Baumol’s Disease” (Baumol 1967), with some service industries even exhibiting persistently negative productivity growth. Continued and growing devotion of resources to unproductive activity is contrary to economic theory. One possible explanation for this paradox is measurement error stemming from failure to record: a) improved quality (and therefore increased volume) in service sector output; and b) the investments made in making those improvements. Measurement failure could thus be misinforming the continued notion that non-material output is somehow of less value than material output, which goes back as far as the proposition of “unproductive labour” in Smith (1776). To understand any inherent differences in industry productivity, it is first necessary to accurately measure real output and input.

It is clear that, throughout the literature, investment is defined as the devotion of resources to future returns. SNA investment criteria have the same interpretation, but national accounting practice is not fully consistent with them ((Robbins, Streitwieser et al. 2010); (Van Rooijen-Horsten, van den Bergen et al. 2008)). Of course, not all knowledge is capital and not all knowledge acquisition is investment, but if its acquisition contributes to production for more than one accounting period, it ought to be treated as investment. The concept of productivity as a measure of output per unit of input is simple, but if data for output and input are deliberately mismeasured, that simple concept loses value and meaning.

**Alternative approaches to the evaluation of intangible activity**

As briefly summarised in Barnes and McClure (2009), most of the literature evaluates the importance of intangibles using two broad approaches: a) financial market valuation; b) direct measurement of investment.
Examples of the first approach include Griliches (1981), Hall ((Hall 2001); (Hall and Hall 1993)) and Webster (1999), with the premise that equity values have become increasingly disconnected from observed profits, investment and asset book values, as each are under-recorded if intangible assets are not defined as capital (Nakamura 2001). Brynjolfsson, Hitt and Yang ((Brynjolfsson and Yang 1999); (Brynjolfsson, Hitt et al. 2000); (Brynjolfsson, Hitt et al. 2002)) have found that each dollar of ICT hardware represented five to ten dollars of market value, and considered the difference to reflect the intangible capital stock held by firms. A second approach to estimation is to directly measure investment, as advocated by Machlup (1962), Nakamura ((1999); (2001)), Lev (2001), and most famously, CHS ((2005);(2006)). Each of these authors discussed some of the measurement implications of treating knowledge output as capital, but CHS provided the first complete exposition in national, and growth, accounting frameworks. As noted by Schreyer (2007), of all the approaches, the CHS method is the most practical for regular estimation using NSI data.

1.3. National accounting framework, with and without intangibles

This section will outline the CHS framework and how the incorporation of intangible investment affects the measurement of output and input. For clarity, it is helpful to first review conventional measures before extending them to include intangibles. A warning against estimating the returns to knowledge capital without adjusting the underlying data was made by Schankerman (1981), who noted that since R&D output is not part of GDP, not only is the level of output biased, but so are real measures of growth and the estimated elasticities of output to labour and capital, including R&D capital.

1.3.1. Measuring output: conventional method, without intangibles

Consider a closed economy\(^2\) consisting of three broad sectors: the first (I) produces tangible assets used in production over more than one accounting period (one year); the second (C) produces final household consumption goods, consumed in the accounting period; the third (M) produces intermediates, used up in production over the period.\(^1\) Assuming competitive markets, so the marginal productivities of each unit of input equal the price, the production functions and accounting identities are:

\[
\begin{align*}
I_i &= F^I (L_i^I, K_i^I, M_i^I, t); & P^I I &= P^K P^I + P^K M^I \\
C_i &= F^C (L_i^C, K_i^C, M_i^C, t); & P^C C &= P^K P^C + P^K M^C \\
M_i &= F^M (L_i^M, K_i^M, S_i^M, t); & P^M M &= P^K P^M \\
\end{align*}
\]

\(^2\) This is solely for simplicity. International trade can easily be incorporated. Permanent, exclusive, sale of assets (rights) to non-domestic agents are exports, and are not part of domestic investment. Imports of permanent, exclusive rights are domestic investment. Royalties to domestic owners of intangible capital are part of domestic capital compensation. Royalties to non-domestic owners of intangible capital are part of imported intermediate consumption. Of course, in practice it can be difficult to distinguish between production fees; full asset sales; partial asset sales; temporary licences; multi-period licences paid for up-front, exclusive rights; non-exclusive rights; bundled goods etc. in international payments.

\(^1\) For simplicity inventories of intermediates are ignored.
The $I$, sector produces tangible investment goods of value $P^I I^I$, using labour ($L$), tangible capital ($K$), and materials ($M$); the $C$, sector produces consumer goods, $P^C C^C$, with the same inputs; and the $M$, sector produces intermediates, $P^M M^M$, using labour, capital and freely available raw materials ($S^M$). $P^L$, $P^K$ and $P^M$ denote the prices per unit of input, and the payments to each input equal their marginal products. Costless technical advance is incorporated with $t$. Tangible capital accumulates into a stock ($K$), and generates income ($P^K K$) through its use in production.

GDP can be calculated using three equivalent approaches. On the: i) “production-side”, as the sum of sectoral value-added (gross output less intermediate consumption); ii) “expenditure-side”, as the sum of gross output in the consumption and investment (but not intermediate) sectors; iii) “income-side”, as the sum of factor incomes in each sector: In theory, provided intermediates and capital are correctly identified, each will provide the same result.

\[
\begin{align*}
(i) & \quad P^V = (P^I I - P^M M^I) + (P^C C - P^M M^C) + (P^M M) \\
(ii) & \quad P^V = P^I I + P^C C \\
(iii) & \quad P^V = P^L L + P^K K
\end{align*}
\]

Where:
\[
\begin{align*}
P^L L &= P^L L^I + P^L L^C + P^L L^M \\
P^K K &= P^K K^I + P^K K^C + P^K K^M \\
P^M M &= P^M M^I + P^M M^C
\end{align*}
\]

In practice, capital income flows are unobserved, and due to conceptual differences between “operating surplus” ($P^K K$) in national accounts, and profits in company accounts; the former is largely estimated residually, as expenditure-based value-added less labour compensation ($P^L L$). This is important as it is partly this calculation that introduces error into estimated operating surplus.

---

4 In practice, measurement error will mean that there is some discrepancy between the three approaches.
5 Corporate profits are sales less expenses, where the latter include interest payments and depreciation allowances to write off capital. These expenses form part of the cost of capital and are implicitly within operating surplus.
6 Data on profits are used to inform the income-side measure of GDP, but in the balancing process where all three measures are confronted, estimates using the income and production approaches are reconciled to equal that from the expenditure approach.
In the main, purchases of intangibles are treated as intermediate consumption in current measurement convention. Let us introduce a new sector \((N_i)\) that produces intangibles, \(P^N N\), using labour, tangible capital, materials, and freely available knowledge \(R^N_t\), where the latter is determined outside the model, from universities say. Treating the output of the \(N_i\) sector as intermediates:

\[
I_i = F^I_i (L^I_i, K^I_i, M^I_i, N^I_i, t) ; \quad P^I I_i = P^I L^I_i + P^K K^I_i + P^N N^I_i + P^M M^I_i,
\]

\[
C_i = F^C_i (L^C_i, K^C_i, M^C_i, N^C_i, t) ; \quad P^C C_i = P^I L^C_i + P^K K^C_i + P^N N^C_i + P^M M^C_i,
\]

\[
M_i = F^M_i (L^M_i, K^M_i, N^M_i, S^M_i, t) ; \quad P^M M_i = P^I L^M_i + P^K K^M_i + P^N N^M_i,
\]

\[
N_i = F^N_i (L^N_i, K^N_i, M^N_i, R^N_i, t) ; \quad P^N N_i = P^I L^N_i + P^K K^N_i + P^M M^N_i.
\]

Where:

\[
P^I L = P^I L^I + P^I L^C + P^I L^M + P^I L^N,
\]

\[
P^K K = P^K K^I + P^K K^C + P^K K^M + P^K K^N,
\]

\[
P^M M = P^M M^I + P^M M^C + P^M M^N,
\]

\[
P^N N = P^N N^I + P^N N^C + P^N N^M.
\]

In the measurement of final output, if intangibles are intermediates, they are subtracted from production in (i) and do not enter final expenditure in (ii). Since operating surplus is determined residually, estimated GDP income includes only the compensation earned by labour and tangible assets:

\[
(i) \quad P^V = (P^I I - P^M M^I - P^N N^I) + (P^C C - P^M M^C - P^N N^C) + (P^M M - P^N N^M) + (P^N N - P^M M^N)
\]

\[
(ii) \quad P^V = P^I I + P^C C
\]

\[
(iii) \quad P^V = P^I L + P^K K
\]

But the characteristics of intangibles include: repeated use in the production of final goods; non-rivalry; and being impervious to physical “wear and tear”. Therefore accounting for such goods as intermediates cannot be correct.

---

The only intangibles capitalised in the SNA are software, artistic originals and mineral exploration. Most of this investment takes place on own-account and so is unobserved output. Purchases of intangibles are treated as intermediate payments. In the case of those intangibles already capitalised, sales of full asset rights do take place, but it is important not to confuse them with licence payments for use, or the sale of non-exclusive rights. The sale of some permanent exclusive rights, can be thought of as a partial sale. Purchases of software licences for use are treated as investment provided they are for longer than one year.
1.3.2. Measuring output: with intangibles as capital goods

If intangibles are not “used up” in production, they should not be subtracted in (7)(i), and they should be included in final expenditure in (7)(ii). Value-added, \( P^V V \), is thus under-estimated by the amount \( P^V N \).

As assets, intangibles also earn compensation, to be incorporated in (iii). Treating intangibles as assets, the production functions and accounting identities become:

\[
\begin{align*}
I_i &= F^I (L_i^I, K_i^I, R_i^I, M_i^I, t); & P^I I &= P^K K_i^I + P^R R_i^I + P^M M_i^I \\
C_i &= F^C (L_i^C, K_i^C, R_i^C, M_i^C, t); & P^C C &= P^K K_i^C + P^R R_i^C + P^M M_i^C \\
N_i &= F^N (L_i^N, K_i^N, R_i^N, M_i^N, t); & P^N N &= P^K K_i^N + P^R R_i^N + P^M M_i^N \\
M_i &= F^M (L_i^M, K_i^M, R_i^M, S_i^M, t); & P^M M &= P^K K_i^M + P^R R_i^M
\end{align*}
\]

(8)

Where \( N_i \) are real intangible investments that accumulate into a stock, \((R_i)\), and earn capital compensation \((P^R R)\), and:

\[
\begin{align*}
P^K L &= P^K L_i^I + P^K L_i^C + P^K L_i^M + P^K L_i^N \\
P^K K &= P^K K_i^I + P^K K_i^C + P^K K_i^M + P^K K_i^N \\
P^K M &= P^K M_i^I + P^K M_i^C + P^K M_i^M \\
P^K R &= P^K R_i^I + P^K R_i^C + P^K R_i^M
\end{align*}
\]

(9)

Intangibles that are not long-lived are re-allocated to the intermediate sector \((M_i)\). What happens to value-added? (Note, here value-added is written as \( P^V V' \) to distinguish it from value-added in the previous section, where intangibles were not capitalised)?

\[
\begin{align*}
(i) \quad P^V V' &= (P^I I - P^M M_i^I) + (P^C C - P^M M_i^C) + (P^N N - P^M M_i^N) + (P^M M) \\
(ii) \quad P^V V' &= P^I I + P^C C + P^N N \\
(iii) P^V V' &= P^K K + P^K R
\end{align*}
\]

(10)

On the expenditure and production side, there has been a level increase to final GDP, equivalent to the output of the knowledge-producing sector \((P^V N)\). On the income side, the level change is equal to the total cost of using intangible capital \((P^K K + P^K R)\) in that accounting period. In golden rule steady-state, defined as the maximisation of intertemporal consumption as a constant proportion of output, these two terms are equivalent and the capital income share is equal to the investment share (Jorgenson 1966). In practice this will not be the case, but since capital compensation is determined residually, the estimate of operating surplus will implicitly incorporate the returns to both tangible and intangible assets \((P^K K + P^K R)\). Note
that even if operating surplus is not estimated residually and is instead informed with data on corporate profits, the returns to intangible capital are missing from the corporate data too because intangible investments are largely expensed in corporate accounts. The dependence of observed corporate profits on the treatment of assets by the tax system, and corporate accounting practice, is one reason that operating surplus is typically estimated residually.

For clarity, all production has been modelled in four distinct sectors. From here on it will be helpful to refer to the knowledge-producing sector \( (N_t) \) as the upstream, and the knowledge using sectors as the downstream. As noted in Romer (1991), upstream activity often takes place in-house, so no output transaction is recorded. The predominant measurement problem for tangible capital is that transactions refer to the purchases of capital goods, rather than for their annual capital services. For intangible capital, the measurement problem is greater still, as often not even the purchase is observed. As noted by Griliches (1973), this causes issues in estimating the stock\(^8\) and the stream of income it generates.

1.3.3. Non-rivalry: platforms and versions

At this point it is worth considering how the non-rival nature of intangibles has implications for measurement. The following discussion is based on a scenario set out in Corrado, Goodridge and Haskel (2011).

A sceptic of the above adjustments may make some related points. First, the above model does not account for the use of commercial knowledge, \( R_t \), in the upstream, instead it only uses the free resource of \( R_t^N \), which may not seem realistic; second, if downstream purchases of knowledge are actually of “licences for use” of one year or less, then they should be counted as intermediates; and third, as knowledge is non-rival it could be sold an infinite number of times.

This is correct. The reason the upstream is modelled as not using \( R_t \) is first, for clarity of notation, and second, because if both the upstream and downstream are renting from the same stock then we have a measurement issue as the knowledge is being paid for twice. It is therefore necessary to assume, and also surely correct, that the knowledge used in upstream production is somehow different to that used in the downstream.

Let us apply the scenario where the downstream purchases licences for the use of \( R_t \) via intermediate payments. Those payments, made by different users over multiple years, are for the use of some long-lived knowledge that exists in the upstream. The argument therefore implicitly acknowledges that there is some

---

\(^8\) In the case of tangible assets, statistical agencies can undertake Fixed Asset Surveys to inform estimates of the capital stock. Observation of intangible stocks is less straightforward.
form of capital good in the upstream that has not been accounted for. It is not reasonable to assume that
capital was created costlessly; therefore the term for its use (in producing the licenced goods) is missing from
the \( N_t \) accounting identity in (5) and (8). Measurement therefore ought to adjust to account for that. So if it
is the case that the payments made by the downstream are not investments, then it must be accepted that the
upstream has invested in some knowledge capital that it licences to the downstream, and that investment
should be measured.

This scenario illustrates the common distinction between “breakthrough” and “incremental” innovation in
the literature (basic knowledge vs. applied knowledge, is another similar distinction). The underlying stock
of knowledge in the upstream \( R_t \) is a platform used to produce reduced-form versions that are leased to the
downstream (think of Microsoft Office and the release of versions for 2009, 2010 etc.). Because \( R_t \) is non-
rival, the leasing of versions helps the upstream producer maintain sole access to the underlying platform.

Some part of the platform is inherent in the versions however, so the licence payments act as a return to the
platform, which could be denoted \( \delta P^N R_t \) where \( \delta \) is some rate, and \( P^N \) the price paid per unit of \( R_t \). The
upstream did not obtain \( R_t \) costlessly, it had to be created using paid for resources, so there is an implicit
cost to its use, which also acts as a return to the platform. Call that cost (or return) \( r P^N R_t \), where \( r \) is
again some rate. The total return is therefore:

\[
(r + \delta) P^N R_t = P^R R_t
\]

(11)

Where \((r + \delta)\) is a gross rate of return. The downstream does not have to pay the full cost of using \( R_t \) as it
is only renting a reduced form version. So in the scenario where the downstream buys short term licences to
versions, they should be counted as intermediates. But in that case upstream output must incorporate the
total return to the platform used in production \( (P^R R_t) \), showing that upstream output in (5) is clearly under-
estimated. GDP expenditure and production should therefore incorporate the investment in the platform and
GDP income the return to the platform, \( P^R R_t \). The precise interpretation of (11) and the rates \( r \) and \( \delta \) will
become clear in sections that follow.

**Own account and purchased knowledge investments**

Whether intangibles are purchased or produced on own-account also has implications for measurement. For
purchases, although capitalisation results in a level increase to value-added, there is no change to gross
output since the acquisition is simply re-allocated from intermediate consumption to investment. For own-
account investment, there is a change to both gross output and value-added, since in-house production is recorded as previously unmeasured output. So in the case of say, a retailer that develops some long-lived software on its own-account, the retailer is counted as producing software output as well as distributive trade output. The implications for certain firms/industries are significant: Hulten (2010) shows that most Microsoft employees are actually engaged in upstream activity, generating long-lived knowledge assets for future use in generating final output.

1.4. Growth-accounting

1.4.1. Conventional measures

There is a considerable literature on growth-accounting, with major contributions from Solow ((1956);(1957)) and Jorgenson and Griliches (1967). Hulten (2001) provides a concise review of the method and the major developments within it.

Consider a production function, where final output is produced using factors, labour (L) and capital (K). Intermediates can be ignored at the aggregate level since they are used up in the generation of value-added. In the neoclassical models ((Solow 1956); (Cass 1965); (Koopmans 1965)) current consumption is sacrificed in order to increase future consumption, via savings and investment, thus accumulating capital and maximising intertemporal utility. The accumulated capital stock provides a flow of services in the production of final output. Increases in factor services increase output via movements along the production function (i.e. duplication), and changes in technology increase output via shifts in the function, represented as increases in A(t).

\[ Y = A(t).F(K, L) \]  \hspace{1cm} (12)

Differentiating with respect to time:

\[ \frac{Y}{Y} - \frac{\partial K}{\partial K} - \frac{Y}{Y} + \frac{L}{L} - \frac{L}{L} + \frac{A}{A} \]  \hspace{1cm} (13)

Where growth in real output is equal to weighted growth in factor inputs and growth in the shift parameter, A. The weights are the elasticities of output to the factor inputs. Assuming competitive markets, firms will employ labour and capital up to the point where the factor price equals its marginal productivity. Therefore, at the margin, the elasticity of output to labour (capital) is equal to the relative price of labour (capital) and output, and factor payments will equal the factors marginal product. The shares of the factor incomes in total income can therefore be used as weights in the growth-accounting decomposition:
If constant returns to scale are assumed, $s^K$ and $s^L$ sum to one, as enforced in the residual calculation of $P^K Y_s$. The estimated weights should be those for a superlative index, such as the Tornqvist or Fisher, with the superlative index being the most suitable index form for approximation to a continuous function. Tornqvist weights are most common, where the annual weights are the averages of the income shares in the current and previous periods. As shown in Diewert (1976), if the true production function is of translog form, discrete time estimation using superlative indices is exact.

$$\bar{s} = \left(\frac{s_t + s_{t-1}}{2}\right)$$

Combining the income shares with data on growth in real output and real inputs, $\Delta \ln TFP$ can be estimated residually:

$$\Delta \ln TFP = \Delta \ln Y - s^K \Delta \ln K - s^L \Delta \ln L$$

$$s^K = \frac{P^K Y_t}{P^Y Y_t}$$

$$s^L = \frac{P^L L_t}{P^Y Y_t}$$

### 1.4.2. Growth-accounting, with intangibles

Incorporating intangible capital introduces a third factor to the production function, the quantity of knowledge capital services ($R_i$). Nominal income and output must therefore be adjusted as described above. Growth in real value-added must also incorporate previously uncounted real intangible output:

$$\Delta \ln Q_t = \bar{s}_i^{\ell} \Delta \ln Y_t + \bar{s}_i^N \Delta \ln N_t$$

$$\bar{s}_i^{\ell} = \left(\frac{P^Y Y_t + P^Y Y_{t-1}}{2P^i Q_t + P^i Q_{t-1}}\right), \bar{s}_i^N = \left(\frac{P^N N_t + P^N N_{t-1}}{2P^i Q_t + P^i Q_{t-1}}\right)$$

Where $Y$ refers to measured output that does not incorporate intangibles, $Q$ to adjusted output, and the output shares are Tornqvist weights. Since this estimation requires a series for real intangible output, we
must also consider its price, reviewed in a later section. Using the adjusted nominal data, the labour income share can be re-estimated, and the residual for capital compensation will implicitly incorporate income generated by intangible capital. The growth decomposition becomes:

$$
\begin{align*}
\Delta \ln \text{TFP}'_i &= \Delta \ln Q_i - \bar{s}^K_i \Delta \ln K_i - \bar{s}^{L'}_i \Delta \ln L_i - \bar{s}^R_i \Delta \ln R_i \\
\bar{s}^K_i &= \frac{P^K}{P^Q} K_i \\
\bar{s}^{L'}_i &= \frac{P^L}{P^Q} L_i \\
\bar{s}^R_i &= \frac{P^R}{P^Q} R_i
\end{align*}
$$

Where the income shares and ΔlnTFP differ from those in (16) and are therefore denoted using ′. The main data requirements not yet discussed are therefore the measurement of asset-level real capital services (Δ ln K and Δ ln R) and capital compensation (P^K K and P^R R), each discussed below in a review of the theory of capital measurement. However, before introducing capital theory, it is worth addressing any perceived or actual limitations in the above methodology.

1.5. The intangibles framework: common objections; strengths compared to standard approaches

1.5.1. Criticisms of national accounting adjustments

Revisions to incorporate software, artistic originals and mineral exploration as assets in the SNA have affected measurement practice in the ways described above, but not all theorists and practitioners are supportive, mainly due to concerns surrounding double-counting. Below is a response to some of the common objections. Many are inter-related, so some repetition is inevitable, but it is important all are addressed to satisfy genuine concern. Machlup (1962) noted that complementarities between knowledge and: a) other forms of knowledge; and b) ICT, make double-counting an easy trap to fall into when estimating knowledge production. For example, consider the software used in R&D, the R&D in software creation, and how these activities can be almost simultaneous. The discussion below emphasises the need for a consistent framework to explain how each factor cost or income enters measurement, which is the outstanding contribution of CHS (2006).

1.5.1.1. Too hard to measure

The most common objection to the capitalisation of intangible assets is that because intangibles are so much more difficult to measure than tangible goods, it is preferable to exclude them from estimation. This view is even held among statisticians and economists who have a full understanding of asset criteria and the concepts of investment, consumption and output, in national accounting. Although an advocate of the

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9 The subject of Chapter 3 is the estimation of the price of intangible assets, with an application to own-account software. Appendix B presents work on the estimation of the price of R&D (Corrado, Goodridge and Haskel 2011).
measurement of knowledge production, a similar reticence is even present in Machlup (1962), who argued that some knowledge production ought not be counted as investment as it simply cannot be measured. Even where knowledge output can be measured, some argue it should not be treated as capital expenditure as there is no way of verifying the stock. It is worth pointing out that although it is possible to verify tangible stocks using fixed asset surveys, this is rare due to high costs in surveying and the response burden for firms. Also, what matters for growth analysis is that the estimated stock is proportional to the real input of capital, which does not require a precise estimate for the level of the stock.

There are two obvious responses to this objection. First, it is not possible to improve measurement unless there is a concerted effort to do so. Second, to use a famous quote from Read (1898), sometimes attributed to Keynes: “it is better to be vaguely right than exactly wrong”. Practical difficulties do not justify a decision to not seek to improve current practice. What matters is whether intangibles meet capital criteria, not whether they are “hard to measure”.

1.5.1.2. Double-counting of output
A second objection made is that capitalisation of intangibles results in double-counting, as the costs of knowledge investment are already embedded in measured output. Such confusion is also present in the otherwise insightful work of Machlup (1962), when he states that while some knowledge production ought to be re-classified as investment, other parts need not, as the costs are already covered from the sales of final goods. Therefore, shortly after recognising that organisational, reputational, engineering and design capital make long-lived contributions to production, Machlup states they need not be classified as assets.

But this is a misleading proposition. As noted in Corrado, Haskel et al. (2011), of course sales revenue must cover payments to inputs; the issue is that current methods do not measure those inputs correctly. The argument that investment in intangibles should not be estimated as it is already implicit in value-added suggests that: a) investment in tangible capital used to create other tangible assets (i.e. “machines that make machines”) should not be counted (Corrado, Haskel et al. 2011); and b) investment in tangible capital used to create consumption goods, should also not be counted. Obviously neither is correct, and application would leave no role for capital in measured production.

This response can be re-expressed using the output identities in (10). First consider the expenditure approach. In a closed economy, value-added is the sum of final consumption and investment. The argument that investment in tangible assets need not be counted as it is already embedded in the value of consumption goods is one that is never made, so it is not clear how it applies to intangibles. Second, consider the income-side, where value-added equals the factor incomes of capital and labour. There is no basis for a subjective decision to only count income from some assets and not others. Third, consider the production-side, where
value-added is gross output less intermediate consumption. If intangibles are not used up in production, they should not be subtracted as intermediates.

Prior to some confusion on which categories of knowledge production ought to be considered investments, Machlup (1962) correctly notes that: a) the defining feature of investment is the devotion of current resources to future productivity gain and; b) that investment as measured in business accounts is determined by tax policy and accounting practice, and is largely irrelevant to the correct measurement of economic investment, output and productivity. Unfortunately this reasoning is not always applied consistently, perhaps due to excessive deliberation on the value of knowledge used for intellectual purposes compared to, say, entertainment purposes, thus losing previous focus on the above criterion.

For practical purposes, it is worth noting here that if the sale of a tangible good, say a building, included a payment for the exclusive purchase of the design \((P^i I + P^N N)\), with ownership transferred, then the total payment should either be: a) split into the two implicit components; or b) if that is not possible, counted as investment in buildings, with the design component excluded from intangible investment. But this is a problem for measurement to overcome; not a reason to not undertake measurement. The far more likely scenario is that the payment for the building \((P^i I)\) included an implicit payment for the use of a design \((P^R R)\), just as it included implicit payments to the tangible capital \((P^K K)\) and labour \((P^L L)\) used on the construction site. That design can then be re-used in the construction of other buildings in future accounting periods, earning additional capital compensation. Current official methods subsume the contribution of the design into \(\Delta \ln TFP\).

1.5.1.3. Own-account investment: double-counting of labour

A third criticism is aimed at the inclusion of own-account investment, which causes most issues with sceptics of the literature. But if market transactions in knowledge assets do not occur, the only appropriate measure available is data on the factor costs of its production (Machlup 1962). Some argue that this double-counts labour and tangible capital income, as they are already within GDP, but that is not the case. Rather, intangible capital income is excluded from GDP, and the measurement of own-account investment seeks to rectify that.

As no asset sale is observed, own-account investment can instead be incorporated on the expenditure side using data on factor costs, usually based on labour income. But that does not mean we are moving a term from the income identity to the expenditure identity. Rather we are estimating an (unobserved) output
measure for the left-hand side of the third identity in (8), $P^N N$, using the input terms from the right-hand-side as a proxy, and they are equivalent provided market conditions are competitive.\textsuperscript{10}

\[ P^N N = P^L L^N + P^K K^N + P^M M^N \]  \hfill (19)

One way to illustrate the error in this (and the previous) objection is to consider the own-account production of a \textit{tangible} capital good. Consider first a closed economy made up of two firms: one produces investment goods (I) using labour and free raw materials; the other, consumption goods (C) using labour and the capital good produced in I. For clarity, it is helpful to attach number to each term:

\[ P^I I = P^I L^I \]
\[ 40 \quad = 40 \]
\[ P^C C = P^I L^C + P^K K^C \]
\[ 45 \quad = 30 + 15 \]  \hfill (20)

Value-added can be estimated in the usual ways:

\[ P^I V = P^I I + P^C C = P^I L + P^K K \]
\[ 85 \quad = 40 + 45 = (40 + 30) + 15 \]  \hfill (21)

Where:

\[ P^I L = P^I L^I + P^I L^C \]
\[ 70 \quad = 40 + 30 \]  \hfill (22)

In practice the estimate for capital compensation ($P^K K$) is calculated residually as:

\[ P^K K = P^I V - P^I L = P^I I + P^C C - P^I L \]
\[ 15 \quad = 85 - 70 = 40 + 45 - 70 \]  \hfill (23)

Now suppose that, for whatever reason, the investment by the C sector, or put another way the output of the I sector, cannot be observed. For example, the firm in the C sector produces its own capital goods to use in production. In doing so it employs the workers previously allocated to the I sector. Since there is no market transaction, investment is not observed, and if measurement makes no allowance for this, then on the expenditure side:

\textsuperscript{10} Of course, as noted in Romer (1991) and other studies, innovators invest in knowledge to acquire a market advantage. In the case of successful knowledge investments, and on average, factor costs will be lower than the value of output. The estimate based on factor costs can therefore be seen as a lower bound for the value of investment. Following sections and chapters will consider the effect of upstream market power on measurements.
\[ P^V V = P^C C \]
\[ = 45 \quad (24) \]

Measured output is therefore lower by the amount, \( P^V I = 40 \) even though the economy is generating exactly the same output as before. On the income-side, labour income is as previously, but all labour is employed in the C sector. Since capital compensation is estimated residually, and \( P^V V = P^C C \):

\[ P^K K = P^V V - P^L L \]
\[ = 25 = 45 - 70 \quad (25) \]

Thus measured operating surplus is negative, implying that the marginal product of capital is negative and there is no rational incentive to use the capital good. Whilst the marginal product of capital can turn negative, due to say an unforeseen fall in demand, in this example the demand conditions are exactly the same in each scenario. The only difference between the two scenarios is in the acquisition of the capital good, that is whether it is purchased or produced on own-account. Failure to measure own-account investment has resulted in mismeasurement of output and capital compensation, and a measure of labour compensation that is greater than value-added, so the expenditure- and income-side measures do not balance as they ought to.

Now suppose the statistical agency notices that a capital good is being used in production over multiple accounting periods. There is no market transaction to observe so instead they measure the in-house inputs used to create it (the labour payments in the first identity of (20)). Using those payments to proxy the value of the capital good, measured GDP returns to the correct estimate in (21), incorporating own-account investment on the expenditure side and the return to capital on the income side. This has not double-counted labour income in GDP, rather labour income is being used to proxy for previously unobserved investment, thus correcting the error that occurred when own-account production went unrecorded.\(^\text{11}\)

The capitalisation of own-account intangibles is directly analogous to the example above. Since it is not possible to observe the value of knowledge produced through an asset sale, it is estimated using data on the

\(^\text{11}\) Note also that if own-account investment is uncounted, gross output is also mismeasured. In this example, there were no intermediates so gross output equals value-added. Incorporation of own-account investment meant previously uncounted output was added to both gross output and value-added, so the firm that produced consumer goods was also considered as a producer of capital goods. In the context of intangibles, this shows that: a) investors are also counted as creators of intangible capital, thus increasing the levels of gross output and value-added; and b) the exact adjustment depends on whether investment is purchased or on own-account. In the case of purchased, gross output is unchanged, as intermediate consumption is simply re-allocated to investment, but value-added is increased. In the case of own-account, the levels of gross output and value-added both increase by the amount of newly observed output.
resources that went into its production. Consider R&D. The wages of scientists are already in GDP income, that is definitely true, but GDP income includes no measure of the income earned by R&D assets.\textsuperscript{12} If scientists produce long-lived output to be used in future production, conceptually and practically that output ought to be counted as capital, even if it is not sold in a market transaction.

Sometimes the same argument is applied to the tangible capital input to producing own-account intangibles, that is, that it should not be used in the estimate of own-account investment as it is already part of value-added. Jorgenson and Griliches (1967) also pointed out that the returns to the capital and labour input used in R&D are already within value-added. But as was argued above in the context of labour, the factor costs on the right-hand side are only used as a proxy because the output value on the left-hand-side is not revealed in a sale. Therefore the best measure available of that output is a full estimate of the factor costs of production. The above example highlighted the error introduced if own-account production is not (fully) measured. As a practical matter it is worth adding a cautionary note. We do not observe the true input of tangible capital to own-account intangibles, we can only estimate it. If tangible capital is not utilised as intensively as estimated, that could result in an overestimate of tangible capital input to own-account knowledge production.

1.5.1.4. In the long-run, all output is consumption

A fourth objection that is made is that even if correct, these adjustments are ultimately futile. This draws on the observations of Weitzman (1976): that investment goods are intermediates in a multi-period system; and Smith (1776): “the whole annual produce of the land of every country is, no doubt, ultimately destined for supplying the consumption of its inhabitants”. The argument is that the only reason intangibles can be considered capital is due to the arbitrary choice of one year as the accounting period. If the accounting period was, say, one hundred years, and no non-labour inputs were “left over” at the end of that period, all (tangible and intangible) capital would be treated as an intermediate, all output would be final consumption, and all income would flow to labour.

Given the strict and unrealistic assumption that no inputs are carried over to the next period, this is true, but the proposition is misleading. National Accounts are constructed with a one-year accounting period, and asset criteria ought to be applied on that basis. If the accounting period changed, the asset boundary would change for tangibles and intangibles. Evidence suggests that life-lengths for most intangibles are around five years (Awano, Franklin et al. 2010a), similar to ICT, and longer for R&D ((Peleg 2008); (Pakes and Schankerman 1984)). This argument does not justify asymmetric treatment of capital, in a framework designed to be consistent.

\textsuperscript{12} At the time of writing, R&D is not considered an asset in national accounting practice. This is due to change following the most recent revision of the SNA (2008), with R&D due to be capitalised in the UK and other European countries in 2014.
The underlying crux of the argument is really that GDP is an inappropriate measure of welfare, and that net domestic product (NDP) provides a more appropriate measure. As outlined in Oulton (2004), this is a valid argument, but for the purposes of measuring output and productivity, GDP remains the preferred measure, with output incorporating investment to account for the positive impact of capital on future consumption.

The following three period example, presented in Table 1.1, illustrates that whilst capitalisation raises the level of GDP, and does change the allocation of NDP between periods, capitalisation has no effect on total multi-period NDP, as at the end of all periods all output must be consumed. The example uses a three-sector model. In each period, the materials sector transforms freely available raw materials into materials using labour. The ICT sector produces ICT goods, using materials and labour, in period two. The consumer goods sector produces final consumption goods for households using materials and labour, and also ICT goods in periods two and three. GDP is estimated as described above using each of the three approaches. NDP is estimated as output less intermediate consumption less capital “used up” in production in each period. GDP and NDP are calculated for each period and, in the final column, as a total of all periods.

In the first panel, scenario A, the ICT goods used in the production of final consumer goods are counted as intermediates, not capital goods; in scenario B (second panel) they are counted as capital goods as they contribute to production over more than one period. Therefore in scenario A, ICT is not capitalised and the purchase of ICT is instead counted as intermediate consumption in the period in which the transaction took place.

In period 1, summing across the three sectors, GDP on the output side is: (60 minus 10) from the consumer goods sector; plus zero from the ICT goods sector; plus 10 from the materials sector; summing to 60. GDP on the expenditure side is just consumer sales, which are 60, since there are no investment goods. GDP on the income side is the sum of factor incomes, which is just labour income since there are no capital goods. Estimating capital compensation residually shows it to be zero. GDP on the income side is therefore 50 plus 10 equals 60, from the wage payments in the consumer goods and materials sector respectively. NDP is gross output minus intermediate consumption minus capital consumption, and so is 60 plus 10 (consumer goods plus materials) minus 10 (intermediate consumption in the consumer goods sector) equals 60.

In period 2, the ICT producer produces ICT goods which are used as an input in the consumer goods sector. On the output side GDP is (95 minus 40 minus 5) from the consumer goods sector; plus (40 minus 5) from the ICT goods sector; plus 10 from the materials sector. Period 2 GDP is therefore 95. NDP is also 95. The reason GDP and NDP are equal is because the ICT good is treated as an intermediate. Similar calculations
for period 3 show GDP and NDP to equal 60. Summing across the periods, total multi-period GDP and NDP both equal 215.

In scenario B, ICT is treated as a capital asset so its purchase by the consumer goods sector is counted as an investment transaction. The estimation of GDP and NDP is affected as follows. In period 1, GDP and NDP equal 60 as in scenario A, as the ICT good is not produced or used in period 1. In period 2, on the output side, GDP is (95 minus 5) from the consumer goods sector (note the purchase of the ICT good is no longer deducted as an intermediate); plus (40 minus 5) from the ICT producing sector; plus 10 from the materials sector. Period 2 GDP therefore equals 135. Estimating from the expenditure side yields the same result – as the purchase of the ICT good is counted as an investment transaction, GDP (95 plus 40) equals 135.

NDP is gross output less intermediate consumption less capital consumption. Therefore in scenario B, period 2, NDP is (95 plus 40 plus 10) minus (20 plus 5 plus 5) equals 115, where the 20 is consumption of ICT capital. ICT capital consumption is 20 as the value of the good is 40 and it is assumed to last two periods. Therefore, at 115, NDP is estimated as higher than in scenario A, where it was 95.

In period 3, GDP is estimated as 60, as it was in scenario A, as there is no investment transaction in period 3. NDP is (60 plus 10) minus (20 plus 10) equals 40, where the 20 again equals consumption of ICT capital. So NDP is estimated as lower than in scenario A. Looking at the total across periods, total GDP is estimated as higher than in scenario A, at 255 compared to 215. However, total NDP is the same in each scenario, at 215.

Therefore the treatment of the ICT good as a capital asset has the effect of raising the level of GDP in period 2, with no impact on the level in periods 1 and 3. The allocation of NDP differs from scenario A as the use of ICT is allocated between periods 2 and 3, whereas in A it was implicitly assumed the ICT good was fully used up in period 2. However, across periods, total NDP in scenario B is the same as it was in scenario A. In contrast, across periods GDP is higher in scenario B, as measurement has accounted for the increase in productive capacity that occurred with the ICT investment in period 2.

GDP is therefore a measure of productive output that equals the value of current consumption plus the value of goods produced that will add to future consumption. NDP only counts the value of current consumption. Intermediate consumption and capital goods “consumed” or “used up” are subtracted in each accounting period, leaving multi-period NDP unaffected as to whether a good is treated as capital or an intermediate. Therefore whilst NDP is often rightly considered a more appropriate welfare measure, GDP is seen as the preferred measure for estimating output and productivity. To highlight why GDP is preferred, say we were comparing two different economies, or the same economy at two different points in time. Economy A consumes 100 units and invests zero. Economy B also consumes 100 units but invests in ten units of capital goods that will contribute to future production/consumption. If investment in future output is not counted as
part of current output (as it is in GDP), then the performance of each economy would be interpreted as identical, even though the situation in economy B is clearly preferable.

Table 1.1: Impact of capitalisation, GDP and NDP

<table>
<thead>
<tr>
<th>Scenario A: ICT treated as an intermediate</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials producer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Sales of Materials</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td><strong>ICT producer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Wages</td>
<td>0</td>
<td>35</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Sales of ICT goods</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td><strong>Consumer goods sector</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate consumption (materials)</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Intermediate consumption (ICT goods)</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Wages</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Final consumer sales</td>
<td>60</td>
<td>95</td>
<td>60</td>
<td>215</td>
</tr>
</tbody>
</table>

\[
\text{GDP (Output side: gross output less intermediate consumption)} = (60-10)+(0-0)+(10-0) = (95-40-5)+(40-5)+(10-0) = (60-0-10)+(0-0)+(10-0)
\]

\[
\text{GDP (Expenditure side: final consumption plus investment)} = 60 = 95 = 60 = 215
\]

\[
\text{GDP (Income side: labour compensation plus capital compensation (latter estimated residually))} = (50+0+10)+(60-50-0-10) = (95+35+10)+(95-50-35-10) = (50+0+10)+(60-50-0-10)
\]

\[
\text{NDP (gross output less intermediate consumption and use of capital)} = (60+0+10)-(0+10+0) = (95+40+10)-(40+5+5) = (60+0+10)-(0+10+0)
\]

<table>
<thead>
<tr>
<th>Scenario B: ICT treated as a capital good</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials producer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Sales of Materials</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td><strong>ICT producer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Wages</td>
<td>0</td>
<td>35</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Sales of ICT goods</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td><strong>Consumer goods sector</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermediate consumption (materials)</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>ICT Investment</td>
<td>0</td>
<td>40</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Consumption of ICT capital</td>
<td>0</td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Wages</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Final consumer sales</td>
<td>60</td>
<td>95</td>
<td>60</td>
<td>215</td>
</tr>
</tbody>
</table>

\[
\text{GDP (Output side: gross output less intermediate consumption)} = (60-10)+(0-0)+(10-0) = (95-5)+(40-5)+(10-0) = (60-10)+(0-0)+(10-0)
\]

\[
\text{GDP (Expenditure side: final consumption plus investment)} = 60 = 95+40 = 60 = 255
\]

\[
\text{GDP (Income side: labour compensation plus capital compensation (latter estimated residually))} = (50+0+10)+(60-50-0-10) = (95+35+10)+(135-50-35-10) = (50+0+10)+(60-50-0-10)
\]

\[
\text{NDP (gross output less intermediate consumption and use of capital)} = (60+0+10)-(0+10+0) = (95+40+10)-(20+5+5) = (60+0+10)-(20+0+10)
\]

\[
\begin{align*}
\text{GDP (Output side: gross output less intermediate consumption)} & = (60-10)+(0-0)+(10-0) = (95-5)+(40-5)+(10-0) = (60-10)+(0-0)+(10-0) \\
\text{GDP (Expenditure side: final consumption plus investment)} & = 60 = 95+40 = 60 = 255 \\
\text{GDP (Income side: labour compensation plus capital compensation (latter estimated residually))} & = (50+0+10)+(60-50-0-10) = (95+35+10)+(135-50-35-10) = (50+0+10)+(60-50-0-10) \\
\text{NDP (gross output less intermediate consumption and use of capital)} & = (60+0+10)-(0+10+0) = (95+40+10)-(20+5+5) = (60+0+10)-(20+0+10) \\
\end{align*}
\]
1.5.1.5. Where have the extra “profits” come from?

A fifth objection, already somewhat addressed but worth noting as it causes discomfort, is the implied increase to capital compensation not observed in measured corporate profits. This is for two reasons. First, corporate profits are determined by asset definitions used in corporate accounting convention, in turn determined by tax law. If tax policy allows investment in say, design, to be expensed, then it is deducted from profits. Second, although in theory GDP can be estimated using all three approaches, in practice, the expenditure-side measure is considered more robust, and capital compensation on the income-side is largely determined residually.

1.5.1.6. Double-counting of intangibles themselves: “the software argument”

A sixth criticism of intangible capitalisation again refers to double counting. Consider again (8). The upstream produces knowledge output, and the accumulated stock of knowledge earns a return, \( P^R R \). Applying this model to software, some have argued that the investment and knowledge stock accumulation occurs in the software upstream, and payments to use software are licence payments that provide a return to the upstream knowledge stock. This much is correct, it is the platform/versions distinction introduced above.

The difficulty is that, due to the non-rival nature of intangibles, non-exclusive, permanent licences for the use of copies can be sold, without causing a transfer of ownership of the original. Whether those purchases should be counted as investment is disputed. Some argue that since ownership has not transferred, only the investment made by the upstream in producing the original should be counted, and that capitalising the expenditures by downstream users would be double-counting. This is a valid concern, but, where licences are for longer than one year and are repeatedly used in production, the consensus among much of the literature (e.g. Hill (1999)) and the practical resolution of the OECD (2010), is that it is an “investment in use”, distinct from the investments made in the original platform, and those expenditures should be capitalised.

1.5.1.7. Double-counting of human capital: training and labour composition

Growth analyses frequently incorporate a quality-adjusted measure of labour services, as a better estimate of labour input than a pure hours measure. The principles of measurement are the same as those applied in the estimation of capital services. Hours worked are estimated for different “types” or categories of labour, using data on characteristics considered to be determinants (or proxies of determinants) of productivity. Labour services are then estimated as a share-weighted sum of hours for the different categories, where the weights used are income shares for each category in total labour compensation. Adjusted labour services thus incorporate volume (hours) and any additional labour input that derives from the skill, composition or quality of the workforce.
It is sometimes argued that including investment in firm-provided training, and using a measure of labour adjusted for composition, double-counts the contribution of human capital. In theory, this is not so. Following Becker (1962), the returns to general human capital and higher marginal productivity accrue to labour, via wages (assuming labour markets are competitive). However, the returns to firm-provided training are not appropriated by labour, but by the firm, which extracts additional capital compensation from its acquired productivity gain. If the returns accrued to labour, the firm would not be incentivised to invest in the provision of training in the first instance.

1.5.1.8. Further remarks
As well as providing a response to some common objections of this part of the literature, the above discussion also highlights the value of a framework that allows every activity to be identified in terms of output, factor cost and the implicit income flows between sectors. The CHS model (2006) provides an incredibly rich tool for understanding these relationships. A determined sceptic might argue that for it to hold, the goods in question must be long-lived. Of course they are right, the purpose is to count the purchases, and own-account production, of assets. If a purchase is short-lived, it should be deducted as an intermediate. If a short-lived good is produced on own-account, then it need not be estimated as it is used up in generating value-added (although strictly it should be part of gross output). The justification for capitalisation should be made and challenged on a case-by-case basis. However, all of the intangible categories used in the modern literature have been identified as assets employed by firms in production for more than one year (Awano, Franklin et al. 2010a).

1.5.2. Interpretation of growth-accounting analyses incorporating intangible capital
1.5.2.1. Limitations of growth-accounting, with and without intangibles
The popularity of growth accounting techniques has wavered and been volatile at times, and their use in the intangibles framework is a concern to some. It is true that some of their limitations are highlighted in the context of intangibles, but growth decompositions which incorporate intangible capital offer a far richer analysis than those that do not. This section discusses some of the main limitations of growth-accounting techniques, as noted in Hulten (2001) and other literature, but is not comprehensive.

The most popular criticism of the SOG literature is its reliance on assumptions of constant returns to scale and competitive markets. It is true that constant returns to scale are usually assumed, but it is worth noting this is not a necessity. Decomposition of the production function only relies on the assumption of constant returns if the factor income shares are forced to sum to unity, with the capital share estimated residually. The primary intent of this restriction is to allow endogenous estimation of the rate of return, but if exogenous estimates of the rate of return and capital compensation are applied, analyses can be conducted without imposing constant returns to scale (Hulten 2001).
The criticism of reliance on competitive markets is more valid, as it is this which allows factor prices to be interpreted as marginal productivities, and factor payments as marginal products. There is no way around this, but it is worth saying that provided competitive markets are the norm even if not universal, analysis for most sectors and at the aggregate level ought to provide a valid approximation. Some have argued that it is even less appropriate to model the role of intangible capital in this framework, because the market power of innovators, increasing returns to scale, and the importance of knowledge diffusion and externalities, do not sit well in SOG analyses. However, it can also be argued that the incorporation of intangibles actually serves to reduce this problem rather than exacerbate it.

The identified problem is that, as in Romer (1991), there is a divergence between the value of knowledge output and its factor cost, due to the market power of innovators. In order for the estimated elasticity of output to knowledge, and the contribution of knowledge capital to output, to be unbiased measures, estimated knowledge services must be truly representative of the input of knowledge capital to production. There are few points to make on this. First, whether or not intangibles are incorporated into measurement, their role in production is part of reality, so the impact of distortions that result from increasing returns and market power, are already inherent in measured data. Revenues from final goods must cover the payments to inputs. The fact that intangible capital exists introduces a bias to the estimated factor shares, even if intangibles are not incorporated in the model. Incorporating intangible capital into estimation serves to reduce, rather than increase, that bias. Second, it is correct that the income share of intangible capital is a biased estimate of the elasticity if it does not incorporate the additional returns earned from the use of unique knowledge. If some information exists on the degree of that market power, such as in data on revenues that knowledge assets earn, that can be incorporated into the analysis to reduce that bias. As discussed above, the renting of assets via licences and such like is more common for intangible capital than it is for tangible. If all capital were rented, then actual capital services from all (tangible and intangible) assets could be explicitly observed, and factor income shares would be estimated perfectly. Therefore, data on intangibles can offer some guide as to the impact of imperfect competition, and more hope for reducing bias by observing the true rental cost, than conventional data that excludes intangibles. The impact of varying degrees of market power among innovators can therefore be explicitly considered in the model.

On the potential presence of non-constant returns to scale and imperfect competition, it is worth noting that Basu, Fernald et al. (2004) find returns-to-scale estimates very close to one (1.07 for durable manufacturing; 0.89 for non-durable manufacturing; and 1.10 for non-manufacturing). They therefore find little evidence of increasing returns, suggesting the potential bias to the factor shares in SOG analyses is minimal.

Another limitation of SOG analyses that is often cited is that TFP implicitly includes a host other effects besides shifts in the production function, such as measurement error, factor utilisation and cyclicality, with the residual famously described by Abramovitz (1956) as a “measure of our ignorance.” Measurement error
will always be present but that is not a sensible reason to: a) not seek to improve measurement; or b) deliberately mis-specify the production function. Abramovitz also noted that among the effects that TFP includes are the returns to expenditures aimed at improving productivity, such as those on education and research. Accounting for intangible capital only serves to reduce the degree of ignorance of the true production function. Similarly, Jorgenson and Griliches (1967) pointed out that if changes in inputs go unmeasured, their impact is incorrectly attributed to TFP. They also went so far as to suggest that the residual ought to disappear altogether if inputs were measured perfectly, but that would imply that costless advances, perhaps spilling over from costly advances made elsewhere in other firms/sectors, are minimal. Growth accounts also provide a useful diagnostic of the underlying data, and incorporation of the full range of capital improves that application, due to improvements in specification. On the impact of factor utilisation and cyclicality, it is worth noting that if constant returns to scale are assumed, ex-post estimation of the rate of return results in estimates of capital compensation that reflect the actual marginal product of capital, removing some cyclical effects from the TFP residual (Berndt and Fuss, 1986). However, since capital stocks are not adjusted to account for scrapping, mothballing and market entry/exit, and the intensity of labour utilisation cannot be directly observed, some cyclical and utilisation effects remain present in TFP.

On the point regarding factor utilisation, it is worth noting again the work of Basu, Fernald et al. (2004). They show that for a cost-minimising firm optimising on all margins, changes in unobserved labour (effort) and capital utilisation can be proxied by changes in observed hours per worker. Using data for US industries, and controlling for factor utilisation, non-constant returns to scale and imperfect competition, their measure of technology change varies about half as much as TFP and is countercyclical. Their method therefore offers the means to: a) more fully account for factor utilisation; and b) remove the cyclical and other effects from TFP that critics sometimes point to.

Analyses that omit intangible assets have another fundamental limitation. NSI practice has increasingly moved toward the measurement of output in quality-adjusted (or efficiency) units, particularly for goods where quality change is rapid (e.g. ICT), and it is unlikely this trend will be reversed. Therefore, measured productivity includes the effects of both product and process innovation, and it is therefore only consistent to measure the investments made in improving the quality of output, such as those in design and market research. Failure to do so incorrectly assigns the increase to “costless advance”, but examples of product innovation without cost are surely rare.

1.5.3. Common methods used to evaluate the contribution of the knowledge economy

Even though growth accounts have limitations and are not accepted by all, the above framework provides a better means for monitoring innovation and the “knowledge (creative) economy” than other techniques commonly used. The following section will review some of these other techniques and their limitations,
based on the arguments set out in Goodridge (2012). It is argued that these limitations can be neatly overcome using the intangibles framework reviewed in this survey.

In assessing the economic contribution of innovative activities, two approaches are particularly common. The first is to compile a set of indicators, often weighted together to form a composite, and assess them over time, e.g. the European Innovation Scoreboard (2008). The problems with this approach are that: a) interpretation of a composite index made up of subjectively chosen, correlated, indicators is problematic; b) the choice of weights is often subjective; and c) a change in the weighting scheme can produce different results. A second approach often undertaken is to aggregate output across chosen industries, as in: the annual report on the UK creative sector (DCMS 2011) and the WIPO (2003) framework for estimating the contribution of the copyright industries. For want of a better term this will be referred to as the “aggregation method”. It is commonly used and has perceived credibility due to its “economic” approach and the use of official data. To discuss some of its flaws, the DCMS application will often be referred to, but the same points can be made of other instances. The sectoral framework presented in (8) illustrates why the method does not measure what it is intended to.

1.5.3.1. Subjectivity in application: industry does not equate to activity

If the chosen approach is to aggregate output, the first task is to identify across which industries. DCMS define creative industries as those “which have their origin in individual creativity, skill and talent and which have a potential for wealth and job creation through the generation and exploitation of intellectual property”, which is ambiguous in terms of practical application. The latest DCMS report (2011) provides an example of the implicit judgements that are required: “This release has had two key changes from the 2010 release. SIC07 codes 62.01 and 62.01/1 have been removed from the Software/Electronic Publishing sector and the scaling factor that was previously applied to the GVA estimates has been dropped (see page 10). The impact of these has caused a considerable reduction in the estimate of GVA, but these changes make the estimates in this release a more accurate representation of the Creative Industries.”

“Computer consultancy activities” and “Business and domestic software development” were excluded as they were considered “more related to business software than to creative software” (DCMS 2011). But it is not clear why business software does not meet the DCMS definition for creative industries given above. Even if some threshold of creative activity were used to select industries, there is: a) subjectivity in setting the level of the threshold; and b) implicit disregard of the cumulative activity in industries that fall below it, which is often substantial. Furthermore, industries as defined by the SIC do not neatly equate to economic activity, so there is no clear boundary between creative and non-creative activity.

The DCMS definition of creative industries includes advertising, architecture, and design. But this directly implies that the output of say, a web designer in the design industry is “creative”, but that of a web designer
working for, say, a manufacturer, is not. Why should this be the case? The very value of “creative output” is that each unit is often in some sense unique, and to retain that value, firms often produce creative output in-house, rather than contract it out. Continuing with the example of design, most design is actually undertaken on own-account by firms outside the design industry itself Galindo-Rueda, Haskel et al. (2008). Conversely, it is also valid to ask, why should the incomes of say, administrative workers or the owners of buildings in the DCMS list of industries, count as creative output? Many might say they should not.

Both the DCMS (2011) and WIPO (2003) reports include recognition that: a) industries normally assigned to the creative sector also engage in non-creative activity; and b) excluded industries also produce creative output. In attempting to circumvent this problem, WIPO classify industries as ‘core’, ‘partial’, ‘interdependent’ and ‘non-dedicated support’, depending on the prevalence of creative activity in business processes. But to maintain the ability to fully appropriate revenues from unique outputs, there is often a considerable degree of vertical integration in firms and industries that produce and use creative outputs, making it difficult to separate “core” processes from other activities and introducing a further element of subjectivity into the methodology.

For the same reason, DCMS also disaggregate estimates of creative sector employment into: i) those with a creative job, working in the Creative Industries; ii) those with a non-creative job, working in the Creative Industries (support employees); iii) those with a creative job, not working in the Creative Industries. The DCMS also attempt to remove “support activity” from the GVA estimate, using the factors in the third column of Table 1.2, with the report stating:

“In certain sectors the SIC codes do not map directly to the Creative Industries. This is generally due to either the SIC code capturing non-creative elements (e.g. designer fashion SIC codes includes the manufacture of the clothes) or where elements of other non-creative industries are captured by the code (e.g. photographic activities SIC codes include elements such as ‘passport photos’). Proportions are applied to the SIC group so that only the creative elements are included” (DCMS 2011)

But despite such adjustments, by only counting creative output from the pre-defined list of creative industries, the majority of creative output is missed and a host of non-creative output is erroneously included. Furthermore, as will be shown below in the context of the music industry, application of this method actually results in the unintended inclusion of additional non-creative output. Because industries defined by the SIC differ greatly in degrees of vertical integration, and therefore the extent to which they produce, distribute and use creative output, aggregation across industries results in all three activities being treated identically, which is not appropriate. For example, the publishing industry either fully or partly includes all of the following functions: i) the creation of artistic/literary/musical works; ii) their distribution; and iii) their use.
To illustrate the inherent flaw of the approach, consider the music industry. The Standard Industrial Classification (SIC) does not classify “music” as a distinct industry, instead components are dotted around the SIC, in publishing, the live entertainment industry, artistic creation, and so on. DCMS estimate “Music GVA” by summing value-added across the industries in Table 1.2, likewise with “Creative GVA” and the larger industry list.

Table 1.2: Mapping from the SIC to music as a creative industry

<table>
<thead>
<tr>
<th>SIC 2007</th>
<th>Description</th>
<th>% applied</th>
<th>Including:</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.20</td>
<td>Sound recording and music publishing activities</td>
<td>100%</td>
<td>Production of master recordings; releasing, promoting and distributing to wholesalers, retailers or directly to the public; production of (non-live) radio programming; music publishing (acquisition and registration of musical copyrights, promotion, and authorisation of use); publishing of books/sheet music</td>
</tr>
<tr>
<td>18.20/1</td>
<td>Reproduction of sound recording</td>
<td>25%</td>
<td>Reproduction from master copies of sound recordings</td>
</tr>
<tr>
<td>90.01</td>
<td>Performing arts</td>
<td>100%</td>
<td>Live performance: theatre, concerts, opera, dance, circuses, orchestra, bands, actors, dancers, musicians, speakers</td>
</tr>
<tr>
<td>90.02</td>
<td>Support activities to performing arts</td>
<td>100%</td>
<td>Activities of directors, producers, set designers, lighting engineers etc. and producers/entrepreneurs of live events</td>
</tr>
<tr>
<td>90.03</td>
<td>Artistic creation</td>
<td>100%</td>
<td>Activities of artists (sculptors, painters, cartoonists, engravers, etc.), authors/writers, independent journalists, restorers of art</td>
</tr>
<tr>
<td>90.04</td>
<td>Operation of arts facilities</td>
<td>100%</td>
<td>Operation of concert and theatre halls</td>
</tr>
<tr>
<td>78.10/1</td>
<td>Motion picture, television and other theatrical casting</td>
<td>0.07%</td>
<td>Activities of casting agencies</td>
</tr>
</tbody>
</table>

Source: “Creative Industries Economic Estimates” (ONS 2009b; 2011), Annex A, Table 6; and Standard Industrial Classification 2007 (ONS 2009b)

Note that “Music GVA” includes value-added in the “Operation of Arts facilities” i.e. live venues. What does this value-added equate to? At industry-level, it is only appropriate to consider the production- or income-side measures (the expenditure-side can only be used at the aggregate level). On the production-side, value-added is sales less intermediates. On the income side, it is the sum of incomes of industry employees (including managers, administrators, security guards etc.) and capital owners (including those of buildings, set equipment etc.). Therefore from the production-side, GVA in live venues is gross revenues, largely ticket sales, less payments, including those made to the musicians that reside in “Performing Arts” and “Artistic Creation”.

So the element that acts as a return to creative output (in this case live music) is actually subtracted from GVA in live venues. What remains is used to compensate industry labour and capital, including
administrators, security guards, and the owners of venues and set equipment. This would not appear to meet the definition of what most would call “creative output”. The income earned by say, the owner of the venue, is simply a return to tangible capital (the building and the capital that resides within it), rather than a return to creativity. The returns to creative output appear in the incomes of artists and musicians, and also of record labels and publishers who also own some share of the creative good. All of these agents reside outside the “Operation of Arts facilities”.

Likewise the DCMS estimate of “Music GVA” includes 25% of value-added in “Reproduction of sound recording”. But not all of the value-added in music publishing is a return to creativity, and in the case of reproduction, what is being counted are the incomes earned by factory buildings, plant and machinery and employees that manufacture CDs. The subtracted intermediates include rentals paid for the right to produce copies, which act as a return to music and flow to the owners of rights (record labels, artists, publishers) that reside in other industries.

This misidentification of creative production and the use of creative capital, occurs throughout the DCMS analysis. For instance, creative output is defined to include the production of film and also film projection i.e. cinemas. Value-added in cinemas is sales (e.g. tickets and popcorn) less intermediates. Payments for the right to project are an intermediate subtracted from value-added in projection, and those payments act as a return to film originals owned by studios and production companies. What remains are the incomes earned by cinema employees and the owners of cinema capital, including the popcorn machine. It is difficult to accept that the margins earned on film projection and popcorn sales represent genuine creative activity. Equally it does not seem appropriate to consider cinema ushers and ticket hall attendants as generating creative output. Therefore, by aggregating value-added in industries in which creation takes place, with that in industries which use creative output, the DCMS method explicitly includes additional non-creative output, the very outcome it intended to avoid.

1.5.3.2. Classification issues

The DCMS method allocates firms to the creative sector according to the SIC. As well described in Hellebrandt and Davies (2008), the industrial classification of firms is based on their primary activity of engagement. The first point to note is that economic activity is surveyed on a reporting unit (RU) basis. Often an entire firm or enterprise is classified as a single RU even if it has several sites. Suppose an enterprise that is a single RU actually operates from two separate sites or local units (LUs). Site 1 is a factory say, whilst site 2 undertakes all design activity. If site 1 is larger, the entire enterprise and its output are classified in manufacturing, even though a proportion of output is actually design. This is the ‘dominance rule’. In this scenario, none of the output produced on site 2 will feature in estimated creative sector GVA.
Now suppose the firm contracts out all design to a firm in the design industry. That same output will now fall within the DCMS definition of the creative sector, even though it is exactly the same in nature to that excluded in the previous scenario. Of course design is a specific example, the function could be any form of creative activity.

1.5.3.3. Impact of firm size on classification

For the purposes of data collection, larger enterprises are sometimes broken up into several RUs. If the two sites described above were treated as distinct RUs, RU1 and its output would be allocated to manufacturing, and RU2 to design. But this shows that the aggregation method is more likely to capture creative activity undertaken in large firms, making the result dependent on: a) the sizes of firms that produce creative output; b) the structure of individual firms; and c) classification decisions taken by the statistical office; all of which can change over time. Small and medium sized enterprises (SMEs) make up the majority of the UK market sector and are considered important in the context of creative activity. However, the creative output of SMEs is not well accounted for in this methodology.

1.5.3.4. Granularity and bias in the SIC

Further classification issues arise from the greater granularity of the manufacturing breakdown compared to that for services. Let us extend the example so that a single RU operates out of three LUs. Two are plants dedicated to the manufacture of distinct products in the SIC, and the third designs both products. Employment on each site is:

<table>
<thead>
<tr>
<th>Local Unit / Site</th>
<th>Industry (SIC)</th>
<th>SIC code</th>
<th>No. of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU1</td>
<td>Manufacture of basic metals</td>
<td>SIC 24</td>
<td>50</td>
</tr>
<tr>
<td>LU2</td>
<td>Manufacture of fabricated metal products</td>
<td>SIC 25</td>
<td>30</td>
</tr>
<tr>
<td>LU3</td>
<td>Specialised design activities</td>
<td>SIC 74.1</td>
<td>55</td>
</tr>
</tbody>
</table>

Source: authors example

As classification is conducted at the two-digit SIC level, even though the majority of employees are engaged in manufacturing (80 compared to 55 in design), the entire RU would be classified in the design industry (as 55>50>30). A slight adjustment of the employment numbers would result in it being classified as SIC24, even though the manufacture of SIC 25 and design form large parts of firm activity. Now suppose the manufacture of basic and fabricated metals were classified in the same two-digit industry in the SIC. Then the firm would be allocated to manufacturing, even though it undertakes a considerable amount of design.
Classification is partly a product of the differential level of detail across the SIC, and measuring the creative sector using SICs is affected by this.

1.5.3.5. The growing servitisation of the manufacturing sector
Some of the limitations of the aggregation method arise from the fact that the nature and composition of manufacturing output is changing, and can include design, consulting and other services, that may or may not be bundled with manufactured products. Rolls-Royce is a commonly cited example of this, see for example Neely (2008) and Hellebrandt and Davies (2008), with the latter noting the statement on the Rolls-Royce website that 53 per cent of global annual revenues derive from the sale of services. Other firms traditionally viewed as part of the production sector that offer a range of services include Dell, IBM, BP and Shell. Firms in manufacturing and other sectors also produce a range of “creative outputs” for use in the production of final goods. This is particularly true of manufacturing sectors in advanced economies such as the UK.

1.5.3.6. Potential for double-counting
Although not inevitable, the aggregation method also introduces great potential for double-counting. Methods that seek to isolate specific activities without proper consideration of how they integrate into wider measures of output, can be easily misinterpreted. As stated in the DCMS report (2011): “There is considerable overlap between the Digital Industries and the Creative Industries. Therefore any estimates that attempt to measure the Digital Industries should not be compared to or aggregated with estimates of the Creative Industries”.

With regard to the digital economy, in “The Connected Kingdom” report, Boston Consulting Group (Kalapesi, Willersdorf et al. 2010) sought to measure the contribution of the Internet to UK GDP using a variant of the aggregation method. GDP can be estimated using data from the production-side, the income side (both described above), and the expenditure side. Ignoring international trade, GDP expenditure equates to final household consumption plus business investment plus government expenditure. Summing across data for final consumption mediated by e-commerce and private/public ICT investment due to the Internet, BCG concluded that: a) £100bn, 7.2 per cent of UK GDP, was due to the Internet; and b) were the Internet an industry it would be the fifth largest in the UK.

There are many problems with this interpretation and the result actually says very little about the contribution of the Internet to UK GDP. Were we to discover that consumers spent £100bn after catching a bus to their local high street, then by adding that to the money spent on bus fares, and investments in buses themselves in the transport services industry, we could estimate the contribution of buses to GDP in a similar way. But most would recognise it would not be sensible to do so.
Furthermore, there is inherent double-counting in the BCG method. First, treatment of the Internet as a separate industry, with say Amazon implicitly part of both the retail and Internet sectors, is pure double-counting. Second, a large part of retail revenues flow back to original producers. Only the margins earned by online retailers ought to count as value-added in what BCG term the Internet sector. Again, this is double-counting.

The real question is whether the Internet has increased the volume of consumption or efficacy of production. If the Internet has increased the quantity or quality (and therefore volume) of goods and services consumed, or reduced the cost of their production, then it has made a positive contribution to GDP. The framework described in this chapter can be applied to estimate the contribution of both: a) the telecommunications capital used to deliver Internet services; and b) the creative capital such as music, film and design, used to generate output; in a way that is consistent with the measurement of GDP and with no double-counting.

1.5.3.7. International trade

A final limitation of the DCMS approach is the inadequate consideration of international trade. If the aim is to estimate the economic contribution of the UK creative sector, appropriate treatment of international payments is crucial. Consider again the production and projection of film. The output of UK film production has two broad components: the first produces UK (part-owned)13 films which generate UK revenues over multiple accounting periods via payment for the rights to project, distribute on DVD, broadcast on television, use on merchandise etc.; the second produces non-UK owned films, for a one-off fee for the ‘Rest of the World’ sector.

The first is the production of a UK asset and the second is an export. By using the value-added of film production in estimation, the DCMS method makes inadequate consideration of UK asset creation (investment), implicitly treating it as equivalent to production of an asset not owned in the UK. If we are interested in the magnitude of the UK creative sector, UK ownership of creative assets surely matters.

Furthermore, UK (and worldwide) projection uses both UK- and non-UK films as inputs. As we know, payments for the right to project are subtracted from value-added in projection. What matters from the perspective of UK creative activity is the value of payments to project/distribute/broadcast/use, which flow to UK (part-)owners (investors) from both UK and non-UK sources.

13 As is the case for many forms of artistic originals, rights are split into various categories and asset ownership is often split between multiple agents, sometimes across international borders.
1.5.4. *Advantage of using the intangibles and growth-accounting frameworks*

The inherent flaws of the aggregation method can be summarised as follows. First, the same output is treated inconsistently depending on firm classification. As a result, a large proportion of the activity in question is missed. Large proportions of design, software and other intangible outputs are produced outside of those industries (see for example, Galindo-Rueda, Haskel et al. (2008) and Chamberlin, Clayton et al. (2007)). Second, it fails to distinguish between the processes of production, distribution and use, with all treated identically.

The precise advantage of the framework reviewed in this chapter is that it avoids these downfalls: 1) identification of investment provides a measure of production by asset or activity rather than industry; 2) estimated contributions are consistent with measured investment and output; and 3) all estimation is conducted within a consistent framework with no double-counting. Rather than subjective value judgements having to be made, the values used are those assigned by the market, and present in the estimated returns to intangible investment activity. This is essentially a Schumpeterian view of innovation as the increased productivity derived from the commercialisation of knowledge, rather than the knowledge discovery itself. Machlup (1962) was correct to point out that a superior approach to using industry data is to identify upstream activity, using occupational data. In addition, he proposed the measurement of “knowledge-produced per worker” and argued this would be an appropriate metric for innovation. This is conceptually similar to the integrated intangibles-growth accounting model, which incorporates the estimated contribution of knowledge capital per hour worked.

1.6. Capital theory

Growth-accounting analysis requires estimation of the capital services that flow from both tangible and intangible assets. This section provides a review of capital theory, largely in the context of tangible capital as that is the subject of much of the literature. Specific reference to intangible capital is made where appropriate, to highlight any difference in application or interpretation. However, broadly speaking, “the accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation” (Jorgenson and Griliches 1967).

1.6.1. Asset Valuation

1.6.1.1. Tangible capital

The seminal studies in developing capital theory into its modern form are: Jorgenson (1963), Hall and Jorgenson (1967), and Jorgenson and Griliches (1967). Their findings are implicit in the methodologies applied by national statisticians and researchers, for example Oulton and Srinivasan (2003), and described in the OECD Manual (2001a). The fundamental identity is given in Hall and Jorgenson (1967). The value of
an investment good, at the time of purchase or some other point in its working life, is equal to the expected net present value (NPV) of the future income it earns:

$$P^I I_{t,i} = \sum_{t=1}^{T} \left( \frac{P^K K_{t,i}}{(1+r)^t} \right)$$  \hspace{1cm} (26)$$

Where \(t\) refers to the accounting period (\(t=1, 2, \ldots, T\)) and \(i\) to the asset. \(P^I I\) is the nominal asset value, \(P^I\) the price, and \(I\) the real quantity. \(P^K K_{t,i}\) is the nominal value of capital services produced in a given period, with \(P^K\) the unit price of those services (the “user cost of capital”) and \(K\) the real quantity. \(r\) is a discount rate, and plays an important role in valuation, the investment decision and estimation. Investment will only occur if capital services are sufficient to provide a rate of return at least as high as available elsewhere. Assuming competitive markets, via arbitrage (26) will hold across assets with each asset generating an equivalent net rate of return. An asset that earned a higher net rate would experience increased demand, increasing the asset price and reducing the implied rate back to equilibrium.

1.6.1.2. Intangible capital

As in Romer (1991), the same condition can be applied in the context of knowledge capital, where \(P^K N\) is the asset value and \(P^K R\) the value of its services in \(t=1, \ldots, T\). However, as also noted in Romer, the owner of unique knowledge acquires market power so the income generated, \(P^K R\), and the asset value itself, implicitly includes additional returns appropriated by the innovator, regardless of whether it is earned explicitly (as rental payments) or implicitly (through use by the owner in generating final output).

$$P^K N = \sum_{t=1}^{T} \left( \frac{P^K R}{(1+r)^t} \right)$$  \hspace{1cm} (27)$$

1.6.2. Depreciation

In order to account for capital input, it is also necessary to understand how asset values change with age (the age-price profile). This is the concept of economic depreciation, thoroughly discussed in the context of tangibles in Hulten and Wykoff (1981a) and Triplett (1997). Less is written on depreciation (and related concepts) for intangibles, where the meaning and application changes slightly.

The asset value to the investor is equal to the (expected) NPV of capital services, as in (26) and (27). As the asset ages and its remaining service life diminishes, its value will decline or depreciate. Furthermore, its services may also decline, that is, it may get less efficient as it ages. Even if it does not, it is difficult to imagine an asset that increases in efficiency with age. The age-price profile is therefore clearly downward
sloping, even for an asset that does not lose efficiency as it ages. The decline in value in each period is the amount of depreciation (D) that has occurred:

$$D_{i,t} = P^t I_{i,t} - P^{t-1} I_{i,t-1}$$  \hspace{1cm} (28)$$

Depreciation is a price or value concept, and thus incorporates three distinct effects: first, the decline in value due to the reduction in service life; second, a decline in efficiency with age (deterioration or ‘wear and tear’); and third, obsolescence, where the suitability of the asset to production processes decreases, perhaps due to a change in processes themselves or the introduction of new vintages of assets of greater quality.

Application of depreciation in capital measurement requires knowledge of the shape or elasticity of the age-price profile. The rate of depreciation will vary across assets, but is also likely to vary with age. A straight-line would imply that the asset value ($P^t I_t$) declines in equal increments ($D_{i,t}$) in each period, meaning that the rate of depreciation increases as the asset nears the end of its service life. For example, an asset which had an original value of £100, and a life-length of five years, would depreciate by £20 each period, which would represent a greater proportion of the remaining asset value in year four than in year two. In the special case where the rate of depreciation is constant (or geometric), absolute declines in asset value are in reducing increments each period. With the exception of Hulten and Wykoff (1981a) and a few other studies, little empirical work has been done on the shape of age-price profiles. Instead the depreciation rate is usually assumed. The three profiles typically used are: straight-line and geometric, described above; and hyperbolic, where both absolute, and the rate of, depreciation is less in earlier years and increases with ages.
The straight-line and geometric functions are those most commonly assumed. Straight-line depreciation can be estimated as:

$$D_{i,t} = \frac{P^t I_{i,t}}{T}$$  \hspace{1cm} (29)

Where $T$ is an estimate of the asset service life. Geometric depreciation can be estimated as follows, where $d$ is a constant rate (between zero and one):

$$D_{i,t} = d.P^t I_{i,t}$$  \hspace{1cm} (30)

A feature of geometric depreciation is the infinite tail to the asset value. Therefore a decision is required on the rate that the value should diminish and how much of the original value should remain after $T$ periods. This is done by applying the following formula:

$$d = \frac{R}{T} = \frac{2}{T}$$  \hspace{1cm} (31)

Where $R$ is the declining balance rate. One popular option is the double-declining balance rate (where $R=2$). Applying $d$ the asset value declines at a constant rate and the remaining asset value at the end of the assumed service life is a small amount that continuously decreases over time.
The most prominent empirical work on depreciation (Hulten and Wykoff 1981a) found that price data for new and used assets did not provide concrete support for any of the profiles given in Figure 1.1 and their work suggested that true age-price profiles are in fact more convex than the geometric, and follow a more complex path. However the implication of their work is that if one had to choose between these alternatives, the geometric profile provides the closest fit to the data. One reason for the lack of empirical work on rates of depreciation is that estimation is made complicated by inflation and obsolescence. Inflation distorts price observations, although its effects can be removed. Obsolescence occurs due to innovation and the quality of vintages improving over time. Improvement in the characteristics and marginal productivity of assets therefore adds a premium to the value of new vintages, with the most dramatic example being ICT hardware. One means of accounting for this is to incorporate the effect of quality change into the measurement of prices using, for example, hedonic techniques (see Triplett (1989)) which seek to decompose the price change into that due to improved quality, and that which would have occurred had there been no improvement.

1.6.2.1. Depreciation: intangible capital

The concept of depreciation in the context of intangibles is similar to that in tangibles, with one important difference. Depreciation is a value concept, and value will incorporate any decline in asset efficiency due to age (deterioration). However, as discussed below, it has been argued by some that intangible assets do not exhibit a decline in efficiency with age.

1.6.3. Deterioration and capital accumulation

The definition of depreciation as a value or price concept is one most economists would recognise. Unfortunately, as noted in Triplett (1997), the term has also been used for a related but distinct quantity concept: the decline in asset efficiency due to age. Following Triplett’s nomenclature, this will largely be referred to as deterioration in what follows, as below in (32) and (33). The distinction matters because applied rates of deterioration and depreciation have different purposes in capital measurement.

The aim in modelling capital input is to estimate the real flow of capital services in production. Just as labour input is thought of in terms of hours worked, capital services can be thought of in terms such as “machine-hours”. Since assets are usually owned by the user, observed market transactions for capital services are rare. Instead they must be inferred from the estimated stock. What matters for productivity therefore is the efficiency of the stock in producing services, that is, the “productive capital stock” (Triplet 1997), or the stock measured in “standard efficiency units” (OECD 2001a). To account for efficiency we apply a rate of deterioration, a stock constructed using the rate of depreciation is a wealth measure rather than a measure of the productive stock. As clarified in Triplett (1997), there are three components to deterioration: i) output decay, where an asset produces less services with age; ii) input decay, where an asset
requires maintenance to keep producing the same amount of services; iii) retirement or discard, the final loss of asset efficiency at the end of its service life.

As with depreciation, due to the difficulty in observing actual age-efficiency profiles, applied rates of deterioration are largely based on assumption. Again there are three popular models. The one-hoss-shay describes an asset that produces a constant amount of services over its lifespan, with no deterioration until services drop to zero at the end of its service life. This model is popular with some researchers but unrealistic. The light bulb is often used as an example of a one-hoss-shay age-efficiency profile, but it is difficult to conceive of an actual asset that would produce services in this way. One suggestion has been infrastructure, but as pointed out in Triplett (1997), deterioration incorporates input decay, meaning that an asset with a true one-hoss-shay profile would require no maintenance. The interpretations of the straight-line and geometric profiles are clear from the above discussion of depreciation.

The age-price and age-efficiency profiles are obviously related, since one element of depreciation is the decline in value due to a loss of efficiency. This relationship has caused confusion in the literature and misuse of the term depreciation. The rates are different except in one special case. For one-hoss-shay decay, the corresponding age-price profile is hyperbolic or concave. For straight-line decay, the age-price profile is convex, but not geometric. In terms of Figure 1.1, it would be a convex curve that lies between the straight-line and geometric profiles. In the special case of geometric decay, the corresponding age-price profile is also geometric, and the implied rates of depreciation and deterioration are the same. This property may be a reason why use of the term depreciation in the literature is occasionally careless. Geometric rates have convenient properties for empirical work, and Hulten and Wykoff (1981a) show that geometric age-price profiles provide a closer fit than other assumed profiles. Geometric rates thus reduce complexity in capital measurement, but it is important to bear in mind the distinction between depreciation and deterioration.
Applying a geometric rate of deterioration, and assuming all assets of each type are perfect substitutes (Jorgenson, 1963), estimates of the productive stock can be derived using the standard perpetual inventory method (PIM):

\[ K_{i,t} = I_{i,t} + (1 - \delta_i)K_{i,t-1} \]  

(32)

Where \( i \) is the asset type, \( I \) is real investment, \( K \) the real productive stock, and \( \delta \) a geometric rate of deterioration. As vintages are aggregated in efficiency units, the estimated stock is directly proportional to the real quantity of capital services it is capable of producing. As illustrated in Triplett (1997), if the stock is made up of five vintages from five successive periods, the real services it is capable of producing (\( \Lambda \)) is

\[
\Lambda = I_1(1 - \delta_1) + \\
I_2(1 - \delta_1)(1 - \delta_2) + \\
I_3(1 - \delta_1)(1 - \delta_2)(1 - \delta_3) + \\
I_4(1 - \delta_1)(1 - \delta_2)(1 - \delta_3)(1 - \delta_4) + \\
I_5(1 - \delta_1)(1 - \delta_2)(1 - \delta_3)(1 - \delta_4)(1 - \delta_5)
\]

(33)

Where \( t = 1,2,..,5 \) refers to the asset vintage; \( \delta_1 \) to the proportion of deterioration in a 1-year old asset compared to a new asset, \( \delta_2 \) to the proportion of deterioration in a 2-year old asset compared to a new asset, and so on. Thus \( \Lambda \) accounts for the marginal productivity of each vintage, and changes in real capital.
services and the estimated productive stock are equivalent. Since growth analyses are by definition concerned with flows, estimation of the productive stock is sufficient for estimating changes in capital input.

The use of assumed deterioration rates in accounting for capital input is sometimes criticised, but unfortunately little real-world information exists. Empirical estimation of deterioration would require the observation of capital services, but if we could observe capital services we would not need to infer them from the stock, and the applied rate of deterioration would be entirely redundant (Triplett 1997). Some earlier literature also provides support for assuming geometric rates. Jorgenson (1963) considered investment as comprised of two components: (i) new investments to increase the stock; and (ii) replacement investments to make up for deterioration. Since replacement is recurrent, then as $t$ tends towards infinity, the rate of replacement must approach a constant ($\delta$).

The above discussion focused on efficiency decay, but deterioration also incorporates retirement or discard, and strictly speaking, a decay function should be used in conjunction with a discard function. The discard function considered most realistic is the bell-shaped function, where retirements are assumed to not start occurring until sometime after the start of the asset life, peaking around the average service life, before tapering off. Therefore further support for the use of a geometric deterioration profile is provided by the observation that a straight-line decay function, combined with a bell-shaped retirement function, results in a rate of deterioration that approximates to geometric (OECD 2001a). Note also that if it is assumed all retirements occur when assets fully decay and not before, the deterioration profile is the same as decay profile (Hulten 1991).

1.6.3.1. Intangible capital: depreciation, deterioration and capital accumulation

To model the input of knowledge capital, it is therefore necessary to consider how it deteriorates, but the concepts of depreciation and deterioration differ slightly in the context of intangible assets. Discussion in the literature has largely been in the context of R&D. As noted by numerous authors, (e.g. Hill (1999); Peleg (2008)), it could be argued that since there is no “wear and tear” to R&D, and since to some extent most R&D is based on past R&D, knowledge assets have infinite lives with no decline in efficiency as they age. If this is so, the appropriate profile is a one-hoss-shay, with no retirement. In that case, the R&D productive stock is equivalent to a gross stock with no deductions for deterioration. However, deterioration incorporates both input and output decay. Whilst output decay may not be relevant to knowledge assets, it seems likely that intangibles require some form of “maintenance” or modification to keep generating a constant amount of services. Also, most consider that knowledge assets do have finite lives as they either gradually, or suddenly, become obsolete. For R&D, some have argued this occurs at patent expiry, when the knowledge becomes freely available to other potential users (Peleg 2008).
Due to their non-material and non-rival nature, intangibles do not physically decay with age; however the profile of revenues they earn \( (P^\delta R) \), does. This decline is usually explained using ideas of obsolescence or “creative destruction”, with new innovations making past assets either less useful or redundant. Therefore their efficiency in generating income does decline with age. It is clear from the above discussion that it is this rate of decline that is relevant to estimating the productive stock of intangible assets. This insight was made in Pakes and Schankerman (1984), who produced the first empirical estimates of R&D deterioration. Previous work ((Mansfield 1968); (Griliches 1980)) had applied rates in the range of 0.04 to 0.07, similar to those for certain tangible assets. Pakes and Schankerman (1984) argued such rates seriously under-estimated the rate of decay in R&D capital, with one reason being that the very use of R&D assists its diffusion, revealing knowledge to others and reducing the ability of the owner to appropriate revenues.

Using data on patent renewals across several countries, Pakes and Schankerman found evidence of a convex R&D decay profile, and estimated the rate of decay at 0.25, far higher than assumed in prior studies. They noted that since they only considered patented R&D, their result may incorporate a downward bias if patenting protects the ability to appropriate revenues. The same study also included a survey of R&D performers and the results showed that, although there was variation between fields and between product and process R&D, most R&D performers had life-length expectations in line with those implied by the patent study. Many other empirical studies have also concluded that the appropriate rate of R&D deterioration lies in the range of 0.1 to 0.2 (e.g. Nadiri and Prucha (1997); Bosworth and Jobome (2003); Lev and Sougiannis (1996)) and similar rates are applied by NSIs in R&D satellite accounts (e.g. Galindo-Rueda (2007)).

As important as the estimated rate for R&D was the finding of a convex decay profile, and this is supported in the work of Soloveichik ((2010c); (2010b); (2010a)) on artistic originals. Evidence suggests that intangible deterioration profiles are highly convex due to rapid revenue decay and early discard (due to high failure rates and the degree of “riskiness”). As with tangible assets, this suggests geometric rates are a reasonable approximation, and maybe even more appropriate in the context of intangibles. This is in line with intuition as it is reasonable to consider the process of knowledge discovery and innovation to be itself innovative and productive, with a high degree of obsolescence. The geometric property of an infinite tail to the asset value also resonates nicely with the idea that past vintages are inherent in new knowledge assets.

Despite this evidence, the idea that the appropriate efficiency profile for intangibles is one-hoss-shay, or highly concave, is persistent. As noted above, deterioration incorporates both decay and discard. Intangible investments are often described as “risky” due to the high rate of failure. That high rate of failure ought to be reflected in the discard function. Using the reasoning in a series of papers from Hulten and Wykoff (e.g.(1981b)), combining a function with a high rate of early discard, with a concave decay function, and aggregating across the distribution of age cohorts, results in a convex deterioration profile similar to the
geometric (Corrado, Haskel et al. 2011). Therefore even if it is considered that the decay function resembles
the one-hoss-shay, a convex deterioration profile can still be justified if early discard is also incorporated.

The stock of intangible capital can therefore be modelled as accumulating in the same way as tangible capital:

\[ R_{i,t} = N_{i,t} + (1 - \delta^R_i)R_{i,t-1} \]  

(34)

Where \( i \) is the asset type, \( R_i \) is the accumulated stock, \( N_i \) is real knowledge investment, and \( \delta^R_i \) the rate of deterioration. On \( \delta^R_i \), in reality, each individual knowledge asset is unique, with its own specific rate. Applied rates for each asset type should therefore be thought of as (weighted) averages of those for each individual asset. Additionally, the nature of intangible investment (or assets) can differ greatly by product/industry (e.g. consider the type of R&D in pharma compared to that in aerospace), as supported in Peleg (2008) who reports expected R&D life-lengths of five and eight years in software and semiconductors, and sixty years for major developments in chemicals. Therefore \( \delta^R_i \) should be applied at the most detailed level possible, as illustrated by the use of industry-specific rates for R&D in the Bureau of Economic Analysis (BEA) satellite account (Mead 2007).

As well as surveying the expected benefit lives for R&D, the UK “Investment in Intangible Assets Survey” (IIAS) incorporates questions on expected life-lengths for the full range of knowledge capital considered in the intangibles literature. Awano, Franklin et al. (2010a) present evidence of expected benefit lives of longer than 2 years for: training; software; reputational capital; R&D; design; and process improvement, with the shortest expected lives being for training and reputational capital, at 2.7 and 2.8 years respectively, and the longest being for R&D at 4.6 years. Note that after incorporating estimated times for development and implementation, the result for R&D suggests a total R&D life-length of 8.6 years, consistent with a geometric rates of 0.23 if the double-declining balance model is used. For other intangibles, the implied geometric rate is in the order of 0.4.

1.6.4. Real Investment

Capital stocks are estimated in real terms. To estimate real investment, \( I_i \) or \( N_i \), an asset price index \( P^I \) or \( P^N \) is applied to the nominal series, so all investment values are expressed in terms of the base year of the index. Whilst it is not possible to provide a review of asset price measurement here for reasons of space, it is worth making two points.
First, TFP is frequently interpreted as ‘disembodied technical change’. Technical change already embodied in capital goods should be incorporated into their measurement. Johansen (1959), Salter (1960) and Solow (1960) all observed that obsolescence means that asset vintages differ in terms of their marginal productivities. Therefore the volume of capital services generated depends on the composition of the stock and the vintages within it. Deflation of investment provides a means to account for these differences between vintages. Any change in quality ought to be reflected in the volume of $I_t$ or $N_t$, and therefore $K_t$ or $R_t$. In other words, a new vintage that generates, say, twice the services of a previous vintage, should be measured as double the volume. Popular techniques to adjust for the quality of new vintages include hedonics, mentioned above, and matched models. These techniques are typically only applied where quality change is rapid, as in the case of ICT. In reality the quality of all assets will improve in gradual increments over time. Full accuracy would therefore require all estimates of real investment and capital stocks be quality adjusted to reflect changes in their marginal product.

Second, most intangible investment occurs through in-house production, so market prices for knowledge assets are typically not observed. This presents a serious problem for measurement as implied prices must be derived instead. The previous point makes clear that appropriate estimates of intangible asset prices should consider the roles of obsolescence and also technology and productivity in the asset creation process. Chapter 3 of this thesis applies the framework presented in this chapter to form estimates of the implied price of own-account software in the UK in a way that explicitly accounts for productivity in its creation.

1.6.5. The price of capital services

Estimation of capital services also requires estimation of their price, and the method for doing so is set out in Jorgenson (1963), and Jorgenson and Griliches (1967). Prior to then, growth analyses had largely been from the primal (or quantities) perspective. These two studies investigated the dual relationships between prices. Using the condition that in competitive markets elasticities equal relative prices and marginal productivities, Jorgenson (1963) derived a formula for the implicit price per unit of capital services: the “user cost of capital”:

$$P^k = P^I \left[ \frac{1-u.w}{1-u} r + \frac{1-u.v}{1-u} d \right]$$

(35)

Where $P^k$ is the price per unit of capital services; $P^I$ the asset price; $u$ the rate of taxation on taxable income (corporation tax rate); $v$ and $w$ the proportions of investment (capital allowances) and interest payments that can be deducted from taxable income; $d$ the rate of depreciation; and $r$ the interest rate. (Recall that in the case of geometric rates, the rate of depreciation used in estimating the price of capital...
services (d) and the rate of deterioration used in estimating the capital stock (δ) are equivalent). If holding the asset generates capital gains/losses (π), the relation becomes:

\[
P^K = P^d \left[ 1 - u, w \frac{1 - u, w}{1 - u} \right] + \frac{1 - u, x}{1 - u, x} \]  

(36)

Where x is the proportion of capital gains included in taxable income and:

\[
\pi = \frac{P^d_{t-1} - P^d_t}{P^d_t} \]  

(37)

A holding gain (so that π is positive) thus reduces the price of capital services. Increases in the interest rate, asset purchase price and rate of depreciation raise the price of capital services. Ignoring taxation and capital gains, (36) reduces to the common user cost relation:

\[
P^K = P^d (r + d) \]  

(38)

The implicit payment for using capital (or its compensation, \( P^K K \)) therefore equals the interest (or opportunity) cost (\( r . P^d K \)), plus the value of capital “used up” (d. \( P^d K \)), less capital gains (\( \pi . P^d K \)). Assuming \( w = v = x \), the impact of taxation can be represented as:

\[
\tau = \frac{1 - u, w}{1 - u} \]  

(39)

\[
P^K = P^d (r + d) \tau \]  

(40)

This highlights an occasional misunderstanding in the discussion of income flows: depreciation is only one element of the cost of using capital. The full cost incorporates the net return, taxation and holding gains/losses. An alternative way to derive the user cost relation (OECD 2001a) is to use the asset value equation in (26), re-written as:

\[
P^d I_{j,t} = \frac{P^K K_{i,t}}{(1 + r)} + \frac{P^K K_{i,t+1}}{(1 + r)^2} + \frac{P^K K_{i,t+2}}{(1 + r)^3} + \ldots + \frac{P^K K_{i,t+T-1}}{(1 + r)^T} \]  

(41)

In period t+1:
Dividing (42) by \((1+r)\):

\[
P^I_{i,t+1} = \frac{P^K K_{i,t+1}}{(1+r)} + \frac{P^K K_{i,t+2}}{(1+r)^2} + \frac{P^K K_{i,t+3}}{(1+r)^3} + \ldots + \frac{P^K K_{i,T-1}}{(1+r)^{T-1}}
\]  \hspace{1cm} (43)

Subtracting (43) from (41):

\[
P^I_{i,t} - \frac{P^I_{i,t+1}}{(1+r)} = \frac{P^K K_{i,t}}{(1+r)}
\]  \hspace{1cm} (44)

Multiplying (44) by \((1+r)\) and re-arranging:

\[
P^K K_{i,t} = P^I_{i,t} - P^I_{i,t+1} + r.P^I_{i,t}
\]  \hspace{1cm} (45)

Substituting in the expression for depreciation given in (28):

\[
P^K K_{i,t} = D_{i,t} + r.P^I_{i,t}
\]  \hspace{1cm} (46)

So in this example where the stock is made up of just one asset, the rental can be written as:

\[
P^K K_{i,t} = P^I K_{i,t}(r+d)
\]  \hspace{1cm} (47)

Note that the above equations hold for both the: a) explicit renting of services, where the asset is owned in the leasing industry; and b) implicit rental, where the asset is owned by the final user. In the first case, the net rate of return is a profit rate. In the second, the rate of return can be viewed as an interest cost of purchasing the asset, or a rate of opportunity cost if it was purchased outright. Assuming competitive markets, these rates are equivalent (Triplett 1997).

The means to estimate user costs was a crucial development in capital measurement, as it enables the appropriate (dis)aggregation of capital, incorporating differences in marginal product, where the (dis)aggregation can be extended to include intangible assets. In terms of estimation, the main difference in the context of intangibles is that they are often treated differently by the tax system. For example, capital allowances or credits for intangibles are rare, with exceptions in the UK including R&D and film production.
1.6.6. The rate of return to capital

A further insight made in Jorgenson and Griliches (1967) was that the rate of return could be estimated endogenously. Prior to then, exogenous rates were applied. Assuming constant returns, so total capital compensation\(^\text{14}\) \((\Sigma K_r K_j)\) can be derived residually, and combining it with data on real productive stocks (\(K_j\)), and user costs (\(P^K_j\)), the value of services (\((P^K_j K_j)\)) can be estimated, by asset, such that the rate of return (\(r\)) exhausts total capital compensation.\(^\text{15}\) The reasoning is that arbitrage equalises the net rate of return to each asset. Gross ex-post rates of return \(((r + d - \pi)\tau)\) differ across assets due to differences in depreciation rates and taxes, and unanticipated holding gains. If holding gains are foreseen they are built into expectations. Assuming that there are just two types of asset, i and j:

\[
r = \frac{\Sigma P^K K - \left(\left([-\pi_i + (1 + \pi_i)d_i]\right)P^K_i K_j \tau_j - \left([-\pi_j + (1 + \pi_j)d_j]\right)P^K_j K_i \tau_i\right)}{(P^K_i K_j \tau_i + P^K_j K_i \tau_j)}
\]

Note that the endogenous calculation of the net rate of return also helps to partly account for changes in capital utilisation. We would expect utilisation to vary with the business cycle and that is reflected in the data for “operating surplus”. As shown in Berndt and Fuss (1986), by assuming constant returns to scale and ensuring the net rate of return is estimated such that operating surplus is exhausted, user costs estimated ex-post reflect the actual marginal product of capital. However, in reality the actual flow of capital services also depend on utilisation of the stock. Since the productive capital stock is an estimate of potential input, rather than actual input, utilisation is not fully accounted for. The impact of unforeseen market exit, under-utilisation and idle capital will therefore introduce a bias to TFP due to partly unmeasured changes in utilisation (Jorgenson and Griliches 1967).

Intangibles can be incorporated into estimation using data for adjusted output and therefore adjusted operating surplus, and asset-specific information on stocks, deterioration, depreciation, holding gains, and tax allowances. The net rate of return is thus equalised for all assets, tangible and intangible.

1.6.7. Aggregate capital services

Using the proportional equivalence between real capital services and the real productive stock, and the user cost relation, nominal capital income flows can be estimated by asset (\(P^K_j K_j\)). Assuming the real quantity of capital services from each asset contributes to the aggregate real quantity through a translog function \(g\):

\[\text{In practice value-added also includes “mixed income” which is the return to the labour and capital of the self-employed. Mixed income can be allocated to labour and capital using data on “Operating Surplus” and “Compensation of Employees.”}\]

\[\text{The terms used here are those for tangible capital for simplicity of notation, but of course the definition of capital compensation can be extended to incorporate intangible capital in the way described earlier in this chapter.}\]
Then real aggregate capital services can be estimated as:

\[ K = g(k_i, k_2, ..., k_{i-1}, k_i) \]  

(49)

\[ \Pi \left( \frac{K_{i,t}}{K_{i,t-1}} \right)^{w_{i,t}} \]  

(50)

Where the weights are asset-level nominal incomes as shares of total operating surplus. The applied weights should be Tornqvist weights for reasons already given. Intangible capital services can be aggregated in the exact same way, with user costs for tangible and intangible capital summing to total adjusted operating surplus.

1.7. Implementation of the framework

The first step in implementation of the framework set out in this chapter is to identify intangibles that meet asset criteria and estimate investment in those assets. In practice, a large proportion of these investments are undertaken in the form of in-house production, so a method for measuring this activity is also required.

1.7.1. Which intangibles should be counted as capital goods?

The role of knowledge as a factor of production has long been a feature of the economic literature. On the practical implications for measuring investment in knowledge, Machlup (1962) correctly identified the standard investment definition as the appropriate criteria for capitalisation, but backed away from its full implications and only finally proposed the capitalisation of education and R&D. In addition to these two activities, Abramovitz (1956) also identified expenditure on health and training as among those designed to enhance productivity. Due to his stance on education, it might be expected that Machlup (1962) would take a similar view of firm-training, but instead he argued it ought to be counted as an intermediate good, due to high labour turnover. Whilst labour turnover does almost certainly reduce the service life of firm-provided training, it seems unlikely that benefits to firms last less than one year. Awano, Franklin et al. (2010a) find that on average, firms expect to benefit from training for 2 to 3.5 years, and staff turnover will have been considered in forming those expectations. The appropriate way to account for labour turnover in estimation is in the application of service lives and the rates of deterioration, depreciation and discard.

Regardless of which form of knowledge is being considered, if the decision is taken that the good in question meets capital criteria, it is important that all investment is recorded, not just that which is successful. The correct way to account for failure is in the estimation of the rates of discard and deterioration. Consider mineral exploration, the full costs of a discovery also include the cost of past failed exploration. Measurement of only successful investments would result in over-estimation of their returns. As an example
of this, Machlup (1962) cited a study by Ewell (1955) which estimated rates of return to R&D of 100-200% p.a., due to the exclusion of failed or discarded investments.

The case for capitalising R&D has been made by many authors, culminating in the incorporation of R&D as an asset in the 2008 SNA. The 1993 revision had also incorporated software (purchased and own-account), artistic originals and mineral exploration as assets, following which, Chamberlin, Clayton et al. (2007) identified under recording of UK own-account software investment and Soloveichik ((2010c); (2010b); (2010a)) worked to rectify the exclusion of artistic originals from the US National Accounts. Other authors have made the case for capitalising a wider range of intangibles, for instance Nakamura ((1999);(2001)), identified business process improvement, reputation, product development and design, as productive assets invested in by firms. The first comprehensive evaluation of intangibles that meet asset criteria was made by CHS ((2005); (2006)) who presented the following three broad categories to use in identification:

Table 1.4: Intangible asset categories, CHS (2006)

<table>
<thead>
<tr>
<th>Computerised information</th>
<th>Innovative Property</th>
<th>Economic Competencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer software</td>
<td>Scientific R&amp;D</td>
<td>Firm-specific training</td>
</tr>
<tr>
<td>Computerised databases</td>
<td>Non-scientific R&amp;D</td>
<td>Reputation (Advertising and Market Research)</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Organisational Capital</td>
</tr>
<tr>
<td></td>
<td>New financial product development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Artistic Originals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mineral Exploration</td>
<td></td>
</tr>
</tbody>
</table>

Investments in innovative property can be regarded as the investment in innovation itself, and those in economic competencies as the co-investments necessary to successfully undertake and commercialise the innovation, and appropriate revenue. CHS noted that knowledge assets can be purchased or produced in-house, and both need to be measured, although in-house creation of assets to be sold should not be counted twice. Due to the literatures focus on R&D, predominantly undertaken in-house, purchases of intangible assets had received less consideration up to this point, although Machlup (1962) observed the growing role of knowledge purchased from business service industries such as management consultancy and market research. Machlup also noted that it may be difficult to accurately identify such knowledge purchases if they are bundled in with other goods and services in market transactions.

1.7.2. Methods for estimating investment in intangible goods

In general, purchased investments in knowledge are easier to identify since they are recorded in the official data for intermediate consumption, although distinguishing between asset purchases and short-lived services is more challenging, as is recognising genuine purchases from licence payments. Therefore, much of the

---

16Work to produce new and improved estimates of UK investment in artistic originals is presented in Chapter 2 of this thesis. At the time of writing these estimates have recently been incorporated in a revision to the UK National Accounts.
literature has focused on developing methods for estimating own-account investment, where no asset sale is observed. OECD (2010) provides a useful survey of NSI methods of estimating own-account investments in particular intangible assets. Machlup (1962) noted that the task of estimating knowledge production is made much easier if separate departments or occupations can be identified as knowledge producers, and this is exploited in the methodologies used by NSIs and in the wider literature.

The two predominant approaches to estimation can be explained using the framework already discussed. The first uses data on upstream input costs, as set out in (19), and applied by NSIs in estimating R&D investment (see for example Galindo-Rueda (2007)), using data on labour, capital and material inputs as reported in R&D surveys. Chamberlin, Clayton et al. (2007) use the same principles to measure own-account software investment, identifying the cost of upstream labour input using firm-level microdata, and adjusting those costs to: a) exclude maintenance of software and other short-lived activity; and b) account for the additional input of capital and materials in own-account software production.

The second method exploits the asset value equation in (27), but estimation requires data on the revenues that assets earn through explicit rental. Therefore the most common application of this method is to artistic originals as in Soloveichik (2010a). For instance, films earn revenue from payments by cinemas, DVD producers, TV broadcasters etc. Likewise for books and music, where royalties are paid for sales of copies, audio-visual rights, performance etc. Chapter 2 of this thesis concerns the estimation of UK investment in artistic originals, which includes applications of both methods described here.

1.7.3. The prices of intangibles

The adjustment of data for real output and the construction of intangible capital stocks, requires data on real intangible investment meaning that we need some estimates of the prices of intangibles. This clearly presents a problem in the case of own-account investment where no asset sale occurs. Therefore the standard method of estimation is again based on a model of the upstream, with output prices estimated as share weighted averages of input prices, as in (51). This method been applied to estimating the price of R&D by researchers (e.g. Cameron (1996)) and NSIs (e.g. Galindo-Rueda (2007) and Copeland, Medeiros et al. (2007)). A similar approach is taken to estimate the price of own-account software in the UK (see Chamberlin, Clayton et al. (2007)). Note that as written (51) does not allow for productivity change in the upstream. Improvements in upstream productivity increase the volume of upstream output and reduce its implicit price. The true model therefore ought to incorporate a term (with a negative sign) for upstream total factor productivity. On some occasions a productivity adjustment is applied. For example, in work to estimate the price of R&D in the US, Fixler (2009) subtracts an estimate of TFP based on observed data for the R&D services industry. In the UK, the official method for estimating the price of own-account software is to subtract a labour productivity growth (LPG) term for the service sector, as a proxy for upstream TFP (Chamberlin, Clayton et al. (2007)). However, if it is thought that the upstream is an innovative, productive
sector, a LPG figure for services, inherently under-estimated for reasons discussed previously, is unlikely to be appropriate. Chapter 3 of this thesis presents new estimates for the price of UK own-account software that incorporate estimates of upstream TFP.

\[
\Delta \ln P^N = s^L_N \Delta \ln P^L + s^K_N \Delta \ln P^K + s^M_N \Delta \ln P^M
\]

(51)

\[
s^L_N = \frac{P^L N^N}{P^N N}; \quad s^K_N = \frac{P^K N^N}{P^N N}; \quad s^M_N = \frac{P^M N^N}{P^N N}
\]

A related method to this upstream approach is used in Copeland and Fixler (2012), who model in-house R&D using data for the R&D services industry. Proxying real quantities using volume indicators for output (patents) and input (scientists), and combining them with nominal data on sales and costs, they back out an implied estimate of R&D prices, and assume those prices also reflect those for in-house R&D. The main limitation of the method is that numbers of patents and scientists are imperfect proxies of real output and input.

A second approach to estimation is to use data on final output prices. The most common application of this is the use of the GDP deflator, but a more specific application in Copeland, Medeiros et al. (2007) estimates R&D prices as a weighted average of output prices in R&D intensive industries, where the weights are industry shares of total R&D investment. It is therefore assumed that the predominant input in these industries is R&D, so that the output price is primarily driven by the implicit price of R&D:

\[
\Delta \ln P^N = \sum \omega_j \Delta \ln P^y_j
\]

(52)

A novel approach to estimating the price of knowledge, based on a decomposition of final output prices, can be found in Corrado, Goodridge and Haskel (2011). Those authors exploit data on measured outputs and inputs in the downstream (final goods) sector, and back out the implicit input price for R&D which incorporates estimated upstream TFP (\(\Delta \ln TFP^Y\)). That paper is submitted as an appendix to this thesis.

1.8. Externalities from knowledge diffusion

Another reason knowledge assets are of importance in the context of economic growth is the potential for additional social returns which derive from the diffusion of knowledge. The potential for externalities is an important part of the justification for measurement of intangible capital. Consider for example the externalities that have arisen from publicly funded R&D, including that on ICT products and the internet, with the latter originating in academia and the military. Whilst investors can reduce knowledge diffusion
somewhat via secrecy or formal IPRs (otherwise if they could not protect their investments they would not be incentivised to undertake them), the key question is whether there is under-investment from the perspective of the social optimum. Although there has been a great deal of research on externalities from private and public R&D, there has been little that has considered a broader range of knowledge capital. One exception to this is Goodridge, Haskel and Wallis (2013) who explore whether there is evidence of inter-industry spillovers arising from the diffusion of R&D and other forms of knowledge capital.

Published research provides evidence that the total social returns to R&D are indeed large, for example, Griliches (1958) estimated total returns in agriculture of up to 700%. However, much of that research has been based on data that has not been appropriately adjusted for the treatment of knowledge as capital. First, if the premise is that knowledge generates excess returns beyond private returns appropriated by investors, then if it is not treated as capital in the underlying data, part of any effect uncovered will include the private returns not incorporated into measured income. But it is already known that a private return must exist as investments have been observed and used in the analysis. Second, if the production function is misspecified, estimates of output, income, growth and factor shares (elasticities) are all biased, and the analysis is undertaken using flawed data.

The literature on R&D externalities is vast, and cannot be reviewed here. The main estimation problem is that, as pointed out by Griliches (1973), it is not possible to observe knowledge flows directly. Therefore typical methods (e.g. Schmookler (1966); Griliches (1973); Griliches and Lichtenberg (1984); Scherer (1982)), involve constructing a measure of external knowledge, weighted in a way that might correspond to knowledge diffusion, and seeking a correlation with TFP. A series of papers have used this approach, see Hall, Mairesse et al. (2009) for a survey. In particular, Griliches (1973) and Griliches and Lichtenberg (1984) constructed weights using intermediate consumption matrices. An application of this approach to UK data, that also looks for evidence of externalities from other intangible assets can be found in Goodridge, Haskel and Wallis (2013), also presented in Chapter 5 of this thesis. Chapter 6 also seeks evidence of spillovers from knowledge (and complementary) assets using aggregate market sector data, this time from publically funded scientific research and telecommunications capital.

1.9. Conclusions

This chapter has reviewed the modern literature that considers the role of intangible capital in explaining economic growth. In doing so the national accounting framework and prior literature on capital measurement and sources of growth analysis that underpin the intangibles framework were also reviewed. The review also incorporated some explanation of the advantages offered by the intangibles framework over other techniques, and argued that incorporation of intangible capital into theory and measurement is important for understanding economic growth as it plays an increasing role in real world production,
particularly in more advanced economies. It is therefore crucial that theory and measurement accounts for this. This chapter surveys the latest developments in attempts to do so.
Chapter 2: Film, Television & Radio, Books, Music and Art:
Estimating UK Investment in Artistic Originals*
Peter Goodridge

ABSTRACT
This chapter evaluates official estimates of investment in artistic originals as recorded in the UK National Accounts. It lays out a framework for measuring investment in the creation of knowledge assets and proceeds to estimate gross fixed capital formation in this asset type using a variety of methods, including new data. Bringing these new data to bear suggests an upward revision to UK investment in artistic originals in 2008 of approximately £1.4bn. The data and procedures used in this chapter have recently been adopted in a revision to the UK National Accounts.

* I am very grateful for financial support for this research from the UK Intellectual Property Office and ESRC (Grant ES/I035781/1). I also wish to thank all those that provided me with data or insights into the workings of industries studied. In particular: Rachel Soloveichik (BEA); Shaun Day (BBC); Nicholas Maine (UKFC); Steve Gettings (OFCOM); Bruce Nash (the-numbers.com); Ben White (British Library), representatives of publishing houses and collecting societies led by Sarah Faulder (PLS); and Will Page and Chris Carey (PRSforMusic). This work contains statistical data from ONS which is Crown copyright and reproduced with the permission of the controller of HMSO and Queen's Printer for Scotland. The use of ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. All errors are of course my own.
2.1. Introduction

This chapter features work that is part of a broader project aimed at measuring investment in intangible or knowledge assets, and the contribution of those assets to growth. It also aims to contribute to the discussion on the contribution of the ‘creative sector’ to the UK economy. In this chapter the specific focus is on investment in long-lived artistic assets formally protected by copyright, defined as artistic originals in the System of National Accounts (SNA).

As discussed extensively in Goodridge (2012), the standard approach taken in measuring the creative sector is to select industries from the Standard Industrial Classification (SIC) that are considered ‘creative’, collate measures of their output and present it as a fraction of aggregate output. Some examples are numerous analyses by the Department of Culture, Media and Sport (e.g. DCMS (2011)) and a report by the World Intellectual Property Organisation (WIPO 2003). However, there are a number of issues with this approach. First, there is considerable debate on which industries should be considered ‘creative’. These industries and sub-industries are discussed in more detail in the WIPO report, which introduces definitions such as ‘core’, ‘interdependent’, ‘partial’, and ‘non-dedicated support’ according to the extent and way in which industry activity (as defined by the SIC) is based on copyright. Second, measuring the economic size of the creative industries is inadequate for measuring creative activity or the input of creative workers, as it takes no account of creative activity in outside industries. For instance consider investment in design. Data for 2006 show that around half of investment in design was undertaken on the own-account of firms outside the design industry (Galindo-Rueda, Haskel et al. 2008). A simple measure of output for the design industry could miss as much as half of actual activity. Such an approach also measures all industry output, some of which is non-creative. For instance, expenditure on staff or equipment for administration or other non-creative business processes.

Therefore, rather than seeking to define which industries should be considered part of the creative sector, the plan of this chapter is to set out a framework to identify and measure UK investment in long-lived creative assets formally protected by copyright. It proceeds as follows. Section two presents a general overview and compares official UK data with that from the US. Section three sets out a framework for analysing artistic sector output and investment in artistic originals. Section four evaluates current ONS measurement practice in the context of that framework, highlighting some of the measurement issues that require consideration in measuring investment and a number of ways to build on official data, by asset type. Section five presents new estimates of investment for each individual asset, making explicit use of the framework set out previously. As a result estimates for: i) Film are revised upward using data on a broader range of UK productions; ii) TV & Radio are revised downward due to adjustments in data and methodology; iii) both

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17 This refers to ONS practice at the time of writing. Since then the ONS have incorporated the outcomes of this work in a recent revision to the National Accounts, based on the findings in the original report.
Books and Music are revised upward using new data and methodologies; v) miscellaneous artwork, not included in official data, are estimated as substantial. Section six concludes.

2.2. Definitions and general overview

Investment in Artistic Originals, sometimes referred to as “copyrighted assets” and more formally as ‘Entertainment, Literary and Artistic Originals’, is one of the few categories of intangible investment already officially capitalised in the National Accounts along with software and mineral exploration, and soon R&D\(^\text{18}\).

To get an idea of current estimates, Table 2.1 compares official estimates of gross fixed capital formation (GFCF) in artistic originals as a percentage of Gross National Product (GNP) for European Economic Area (EEA) countries in 1995 and 2001. UK estimates are among the highest of those presented for EEA states. US data for 2002, based on estimates outlined in Soloveichik (2010a), are included for comparison. The disparity suggests there may be some undercapitalisation in EEA countries including the UK.

<table>
<thead>
<tr>
<th>% of GNP</th>
<th>1995</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Germany</td>
<td>0.16</td>
<td>0.18</td>
</tr>
<tr>
<td>Spain</td>
<td>0.1</td>
<td>0.07</td>
</tr>
<tr>
<td>Finland</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>France</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>Italy</td>
<td>0.07</td>
<td>0.1</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Portugal</td>
<td>0.17</td>
<td>0.22</td>
</tr>
<tr>
<td>UK</td>
<td>0.21</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Note to Table: Data for European countries taken from a report for the Eurostat GNI Committee, First meeting, 5-6\(^\text{th}\) November 2003: ‘Report of the Task Force on Entertainment, Literary and Artistic Originals’ (2003). Since artistic originals are not currently capitalised in the US Accounts, US data are based on developmental BEA estimates (Soloveichik 2010c). Additionally they are presented as a % of GDP rather than GNP, and refer to 2002 rather than 2001.

From Table 2.1 it can be seen that US estimates are considerably higher as a share of GDP than those for the UK or other EEA countries. Table 2.2 makes a direct comparison between UK and BEA estimates, by asset category. Since only four of the five assets covered by the BEA are currently capitalised in the UK, column 4 adjusts the US data so it can be compared with the UK on a like-for-like basis. That is, miscellaneous artwork is excluded from US investment, and the percentages are re-calculated.

\(^{18}\)Software, mineral exploration and artistic originals were officially capitalised in the 1993 revision of the SNA. R&D was officially capitalised in the 2008 revision of the SNA, and is due to be treated as an asset in the UK National Accounts from 2014.
### Table 2.2: Investment in Artistic Originals, % breakdown (2002)

<table>
<thead>
<tr>
<th>Asset</th>
<th>US ($bn) (Soloveichik)</th>
<th>UK (£bn)</th>
<th>US ($bn) approx, using UK breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>$65.1bn</td>
<td>£2.14bn</td>
<td>$60.1bn</td>
</tr>
<tr>
<td>% of GDP</td>
<td>0.62%</td>
<td>0.20%</td>
<td>0.57%</td>
</tr>
<tr>
<td>(1) Movies</td>
<td>$9.8bn</td>
<td>£0.02bn</td>
<td>$9.8bn</td>
</tr>
<tr>
<td>% of Artistic Originals</td>
<td>15.10%</td>
<td>0.94%</td>
<td>16.31%</td>
</tr>
<tr>
<td>% of GDP</td>
<td>0.09%</td>
<td>0.002%</td>
<td>0.09%</td>
</tr>
<tr>
<td>(2) Music</td>
<td>$7.6bn</td>
<td>£0.13bn</td>
<td>$7.6bn</td>
</tr>
<tr>
<td>% of Artistic Originals</td>
<td>11.70%</td>
<td>6.07%</td>
<td>12.65%</td>
</tr>
<tr>
<td>% of GDP</td>
<td>0.11%</td>
<td>0.012%</td>
<td>0.07%</td>
</tr>
<tr>
<td>(3) Books</td>
<td>$7.1bn</td>
<td>£0.21bn</td>
<td>$7.1bn</td>
</tr>
<tr>
<td>% of Artistic Originals</td>
<td>10.90%</td>
<td>9.81%</td>
<td>11.81%</td>
</tr>
<tr>
<td>% of GDP</td>
<td>0.07%</td>
<td>0.020%</td>
<td>0.07%</td>
</tr>
<tr>
<td>(4) TV</td>
<td>$35.6bn</td>
<td>£1.78bn</td>
<td>$35.6bn</td>
</tr>
<tr>
<td>% of Artistic Originals</td>
<td>54.70%</td>
<td>83.17%</td>
<td>59.24%</td>
</tr>
<tr>
<td>% of GDP</td>
<td>0.34%</td>
<td>0.165%</td>
<td>0.34%</td>
</tr>
<tr>
<td>(5) Misc</td>
<td>$5bn</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>% of Artistic Originals</td>
<td>7.70%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>% of GDP</td>
<td>0.05%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note to table: Artistic Originals are not currently capitalised in the US National Accounts. Therefore, as a % of GDP, the above data are not quite on a like-for-like basis, with originals implicitly part of UK GDP but not US GDP. For Column 4, the data have been adjusted to account for the differing coverage of originals in the UK and US i.e. since miscellaneous artwork is not capitalised in the UK, $5bn is subtracted from the US aggregates, and the percentages are re-calculated accordingly.

Inspection of investment in each category as a percentage of GDP reveals that UK data for Film, Books and Music in particular are considerably lower than US estimates and gives some indication of potential “missing” investment in the UK data. In particular the UK seems to record very little investment in Film relative to the US. This could reflect the central role of Hollywood in both the funding and production of motion pictures, mis-measurement of UK asset production, or both.

#### 2.2.1. What assets should be counted as “Artistic Originals”?

Before identifying alternative approaches for measurement, one has to define just what assets to consider. Eurostat and the OECD have opined on this issue. The following discussion includes a summary of recommendations for National Statistical Institutes (NSIs) outlined in a Eurostat Taskforce report (2003) and further clarification issued by the GNI Committee (2004).

The Taskforce set four criteria for identifying investment in artistic originals. The item:

1) Must be covered by copyright
2) Should have primary artistic intent i.e. where the original is the end product in itself, and not an interim part of the production process for another good
3) Must satisfy capital criteria i.e. have a useful service life of more than one year
4) Should not be covered elsewhere in the National Accounts. Therefore software and valuables should be excluded
On the first criterion, there may appear to be an inconsistency with the treatment of say R&D, also recognised as a fixed asset in SNA 2008. That is, it is not necessary for R&D to be protected by patent in order to qualify as investment. The reason much R&D is not formally protected by IPRs is that firms can still exploit the asset without such protection and they often prefer not to make the acquired knowledge public in any way. In contrast, in order to commercially exploit an artistic original, it must be protected by copyright. Also, copyright protection is automatic whereas patents are registered rights that must be applied for.

On the second criterion, this does not mean the final asset cannot be used as an input in the production of final goods. It simply means that a component of the final asset should not be counted separately e.g. un-edited or animated images should not be counted separately to the final film/TV original they are a part of. A potential grey area is the treatment of film or television scripts, which can be covered by a separate copyright, and a case can be made for considering them separately.

The fourth criterion explicitly recommends the exclusion of ‘valuables’, which are goods held as stores of value as alternatives to financial assets, and typically include items such as fine art or jewellery. Valuables appear as a transaction item in the National Accounts within Gross Capital Formation (GCF), termed ‘acquisitions less disposals of valuables’. Note that GCF differs from GFCF, since the latter refers only to productive fixed capital.

\[
\text{GCF} = \text{GFCF} + \Delta \text{inventories} + \Delta \text{valuables}
\]

The Eurostat Taskforce considered that because items such as paintings, sculptures and fine art may be present in valuables, then they should be excluded from estimates for artistic originals. However, provided the data on valuables correctly pertains to alternatives to financial assets, and data on GFCF correctly pertains to fixed productive assets, it should be possible to avoid double-counting. According to the data, valuables are largely held by the insurance and pension industries. The values for acquisitions less disposals are typically relatively small, but volatile, presumably because such assets tend to be held rather than frequently bought or sold. SNA (2008) states that valuables include, but are not restricted to: precious metals and stones, antiques and other art objects, where the latter can include collections of stamps, coins, china, books and jewellery.

However, GFCF in artistic originals ought to include investment in artistic assets that are part of the productive capital stock. That is, assets that can be exploited by their owner in generating final output. If an asset is produced, but then sold to an owner that intends to hold it as a store of value rather than employ it as
productive capital, the transaction should be recorded as negative GFCF for the innovator and positive acquisition of valuables and therefore GCF\textsuperscript{19} for the new owner. At no point has the investment been counted twice and there is no reason to not record the initial investment in creation, or to not consider the role of the asset in production before it was sold.

More importantly, note that valuables refer to some copy, not the original asset itself and crucially not the rights to commercially exploit the original asset. Just because, say a piece of fine art is held as a store of value, that does not mean that the original has been removed from the stock of productive assets. Prints of the asset can still be produced and images of the asset can still be used in the production of final output. Likewise for book collections. If an investor has decided to purchase a copy of the very first print of an original as a valuable, because they expect it to maintain its value or achieve a capital gain, then that purchase does not mean that we should exclude the investment made in the creation of that original, as the original can still be used in the generation of final output. The purchaser has not bought the asset rights, they have simply purchased a piece of final output that the original was used to produce.

Therefore the composition of the data on valuables means that the potential for double-counting between ‘artistic originals’ and ‘valuables’ seems limited. Although not necessary, rather than excluding investment in a large portion of artistic originals, a more appropriate treatment would be to estimate investment in remaining types of artistic capital and subtract the measured data on valuables. This would guarantee no double-counting of assets, and avoid the exclusion of a potentially significant area of investment.

The following headings outline the asset categories considered by the Eurostat Taskforce as potential items for inclusion in artistic originals, their final recommendations on which types of originals should be capitalised in the National Accounts, and additional information considered relevant to the discussion. The recommendations of the Taskforce are summarised in Table 2.3 and discussed in more detail below.

\textsuperscript{19}Note again the conceptual difference between investment in productive capital (GFCF) and investment in monetary alternatives (GCF).
### Table 2.3: Summary of Eurostat Taskforce recommendations, by category

<table>
<thead>
<tr>
<th>Category/Asset</th>
<th>Taskforce Recommendation (✓/X)</th>
<th>Further considerations noted by Taskforce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Films</td>
<td>✓</td>
<td>Only the final version should be capitalised, and not interim versions, so as not to double count. Estimation of investment requires information on residency of production company.</td>
</tr>
<tr>
<td>TV &amp; Radio</td>
<td>✓</td>
<td>Only “stock” programmes should be capitalised (i.e. those with service lives of more than 1 year).</td>
</tr>
<tr>
<td>Books</td>
<td>✓</td>
<td>Magazines and newspapers should not be capitalised, since they generally have service lives of less than 1 year.</td>
</tr>
<tr>
<td>Music</td>
<td>✓</td>
<td>Only the final version should be capitalised, so as not to double count. Advertising jingles should be excluded as they are not considered long-lived.</td>
</tr>
<tr>
<td>Images</td>
<td>✓</td>
<td>Should be capitalised provided they are covered by copyright</td>
</tr>
<tr>
<td>Maps</td>
<td>✓</td>
<td>Should be capitalised but likely already included under Books</td>
</tr>
<tr>
<td>Branding</td>
<td>X</td>
<td>Should not be capitalised since service life is generally less than 1 year</td>
</tr>
<tr>
<td>Technical Drawings</td>
<td>X</td>
<td>Should not be capitalised since their primary intent is not artistic, but rather they are a component of a different final asset (e.g. buildings)</td>
</tr>
<tr>
<td>Models</td>
<td>X</td>
<td>Should not be capitalised since they are neither ‘original’ nor have primary artistic intent</td>
</tr>
<tr>
<td>Artwork</td>
<td>X</td>
<td>Should not be capitalised to avoid any potential double counting with items already recorded as ‘valuables’</td>
</tr>
</tbody>
</table>

**a) Films**

The Taskforce recommended that GFCF in Film Originals should include the production of all short and long films that satisfy the above four criteria, including translations and re-worked originals, but that only the edited final version should be capitalised, and not interim versions. They also noted that it is important to establish the residency of the production company so investment is allocated to the correct country. However, rather than residency of production what actually matters for the purpose of measuring investment is residency of ownership, that is the country to which future revenues will flow when the asset is commercially exploited. Establishing ownership is particularly important for Film where national tax/subsidy arrangements encourage activity in different locations. This is especially true for the UK where a significant amount of activity is funded by major US studios. In fact a number of the major production companies in the UK are subsidiaries of US producers.²⁰

²⁰According to the ONS Film & Television (FTV) release, in 2007 62% of UK film exports were by UK subsidiaries of major US film companies.
b) **TV & Radio stock programmes (e.g. fiction, documentaries, drama, music, arts, history & education, children’s)**

Only long-lived TV & Radio productions ought to be capitalised. Programmes for broadcast in the television and radio industries are categorised as either ‘Stock’ or ‘Flow’ productions. ‘Stock’ programmes are long-lived, and include the genres listed in the heading above, whilst ‘Flow’ programmes include genres such as news, sport or game shows which are less likely to be repeated or re-produced on alternative formats such as DVD. The stock/flow distinction therefore provides a natural break in meeting capitalisation criteria.

However in some cases the distinction is less clear. Consider sport for example, with DVD releases of major events and re-runs on channels such as ‘ESPN Classic’ long after the original broadcast. The OECD explicitly recognise that some sports broadcasts have service lives of more than one year, but recommend that, due to very fast depreciation rates (on average), sporting rights be excluded from final estimates of GFCF in originals (OECD 2010). Furthermore, the proportion of sports broadcasts that generate long-term revenues is small, with those that are long-lived determined by the special nature of the event or a particular outcome. In the case of game shows, a differing view is taken by Soloveichik (2010a) who argues that although one programme may be short-lived, the format and therefore underlying asset is long-lived. This may be debatable since it could be argued that all formats are long-lived. But surely there has been some investment when a ‘title’ is re-produced either domestically or internationally for several years, even if the one-off programme itself is unlikely to be repeated.\(^{21}\)

c) **Books & Pamphlets (Literary Originals)**

The Taskforce recommended that all investment in the creation of full books regardless of subject or style be included, and that audio or e-books also be included provided they hold a separate copyright. The recommendation for sheet music and scripts is that if they are protected by a distinct copyright they can be recorded as a separate item under literary originals, but should not be included within music or film.

Since newspapers and magazines generally have a service life of less than one year it was recommended they be excluded from final estimates. A potential grey area is the treatment of journals, since their service life is often greater than one year, but data practicalities mean it can be difficult to disentangle them from magazines and similar publications.

d) **Music (Recorded Originals)**

As with Film it was recommended that only the edited final version be recorded as GFCF so as not to introduce double-counting. It was also recommended that all media types be included, including music videos, but that advertising jingles be excluded. On advertising, although the stand taken in this thesis is that

\(^{21}\) Obvious examples of this include numerous reality shows that are re-produced domestically and internationally on an almost annual basis. For instance: ‘The X Factor’, ‘The Apprentice’ or ‘Big Brother’ to name a few.
the intent of some proportion of advertising expenditures is to create long-lived reputational capital, it is considered a distinct category in the intangibles framework and so will not be included in estimates of artistic originals (see for example, Corrado, Hulten et al. (2005) or Goodridge, Haskel et al. (2012)).

e) **Slogans/Brand names**
The Taskforce felt that although protected under Trade Mark, such investments should not be considered as part of GFCF in artistic originals. Again, although part of such expenditure certainly goes towards building brand and reputational capital, it is treated as a separate asset in the intangibles framework (Goodridge, Haskel et al. 2012).

f) **Technical/Architectural Drawings & Models**
The Taskforce felt these items ought not to be considered as artistic originals, even if they have copyright protection, since their primary use is as an input to construction output. Therefore they fail to meet the criterion of primary artistic intent. However, provided such blueprints (or prototypes or scaled models) have a service life of more than one year and are used in the production of final output then it is clear that they should be treated as capital, even if not as artistic originals. Therefore although not considered here in the context of originals, such assets are included in the broader intangibles framework under “Architectural and Engineering Design” (Goodridge, Haskel et al. 2012).

g) **Paintings, sculptures, antiques, fine art & jewellery**
The Taskforce recommended these items be excluded from estimates of investment to avoid double-counting, as according to the fourth capitalisation criterion and the presence of ‘valuables’ in the National Accounts. However, ESA95 does reference portraits, images, reproductions and pictures in its discussion of what should be included as artistic originals. As discussed above, the potential for double-counting and the rationale for exclusion of such assets are not clear.

h) **Photographs & Images (reproductions or copies from books)**
The Taskforce recommended these be included provided they are covered by copyright. Data for such assets are however more limited than that for other asset types.

i) **Maps**
The Taskforce recommended that maps be included, and noted that in any case, it is unlikely they could be separated from other publications.

j) **Summary**
As a minimum therefore, the Taskforce recommended that originals be defined to include Films, TV & Radio stock programmes, literary and musical works, and that other categories such as photography/images
could be included provided they meet the criteria listed above. Broadly in line with these recommendations, this chapter will present new estimates of UK investment in Film, TV & Radio, Books, Music and Miscellaneous Art, where the latter includes assets such as art, photography, images, choreography and maps, where data are available and where they are not counted elsewhere.

2.3. Theory: Review of methodological approaches for estimating investment in artistic originals

2.3.1. Model of the artistic sector

To understand the various measurement methods available, it is worth setting out a simple two sector model, analogous to that used in Corrado, Goodridge and Haskel (2011).

Consider an economy with an innovation (or artistic) sector and a final output sector. The innovation sector, or upstream, produces artistic originals which are used as an input in the final output, or downstream, sector: the film production (upstream) and cinema industry (downstream) for example. In this economy we may then write the value of gross output in the artistic/innovation sector as \( P^N N \). This is equal to factor and intermediate costs in the sector times any mark-up (\( \mu \)) over those costs, where \( \mu \) represents the monopoly power acquired through ownership of a unique asset formally protected with intellectual property rights (IPRs):

\[
P^N N = \mu (P^L L^N + P^K K^N + P^M M^N)
\]

Where \( P^L L^N \), \( P^K K^N \) and \( P^M M^N \) are payments to labour, capital and materials respectively, \( P^X \) their competitive prices, and \( \mu \) the mark-up over competitively priced inputs. Payments for materials can include rental payments for the use of other originals in production e.g. the use of a music original in film production, or even the sampling of a music original in another music original.

Consider next the downstream, which uses the artistic good in generating final output. If the downstream purchases the asset rights (or some component of them) outright, then the cost is (some proportion of) \( P^N N \). If they purchase and use the original, they will pay an implicit annual rental for its use. Alternatively they may rent the asset explicitly e.g. pay a licence fee, \( P^R R \), for T years to the IPR-holding artistic sector. In either case, capital market equilibrium implies that:

\[
P^N N = \sum_{t=1}^{T} \frac{P^R R}{(1 + r)^t}
\]

(3)
Where $r$ is a discount rate and $R$ is the stock of knowledge accumulated from upstream artistic sector output; using the perpetual inventory method (PIM) this stock accumulates as:

$$R_t = N_t + (1 - \delta^R)R_{t-1}$$  \hspace{1cm} (4)

Where $\delta^R$ is the rate of decay in revenues appropriated from artistic assets, the appropriate concept of depreciation for intangible capital, as first noted in Pakes and Schankerman (1984).

Equation (3) says that the asset value must equal the discounted rental payments from the users of the good. This condition is set out in, for example, the classic paper of Romer (1991).

The final output sector, which uses the artistic good in production, produces downstream output, $P^YY$:

$$P^YY = P^LL^Y + P^KK^Y + P^MM^Y + P^RR^Y$$  \hspace{1cm} (5)

Where $P^LL^Y$, $P^KK^Y$ and $P^MM^Y$ are the payments to labour, tangible capital and materials, and $P^RR^Y$ are the payments to the artistic capital used in the downstream but created in the artistic sector. How then are we to measure investment in the creation of artistic originals, $P^YN$? A number of approaches are possible.

a) Input cost based: Upstream Production Costs

The most popular method for estimating investment in intangible assets is to estimate the cost of asset production in the upstream sector, using data on input costs (labour, capital and materials), as in equation (6). This is one of the two primary methods for measurement of GFCF in Artistic Originals, as recommended by both Eurostat (2003) and the OECD (2010). It is also the approach taken in estimating investment in R&D using a survey of R&D performers (BERD).

$$P^NN = P^LL^N + P^KK^N + P^MM^N$$  \hspace{1cm} (6)

In practice, detailed data on capital compensation ($P^KK^N$) and intermediate inputs ($P^MM^N$) in the upstream sector(s) are sometimes not available. Therefore a variant of this approach is to use data on labour input costs and apply some factor ($\gamma > 1$) to cover other costs of production, as in equation (7). This is the

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22 At first it may appear that there could be a measurement issue in the sense that both the upstream and downstream are renting from the artistic stock, as payments in the upstream can also include payments for the use of artistic originals. This is not the case. The upstream is renting a different asset to that which it is producing. For example, the producer of broadcasting assets is renting music assets.
method used to estimate own-account software investment in the UK National Accounts (Chamberlin, Clayton et al. 2007).

\[ P^N N = \gamma P^N L^N \quad (7) \]

There are two issues worth noting in the context of artistic originals. First, the treatment of the use of other artistic goods in the upstream e.g. the use of music as an input to a movie original. It has been argued that including such payments could potentially lead to double counting. However, this would only be so if the measured input payment was the total cost of the musical original, \( P^N N \), that is if it was bought outright with ownership transferred to the film producer. Provided what is being counted is a rental payment for its use, \( P^R R \), then only the capital services from the use of the music original are included, as is appropriate, and there is no double-counting.

Second, note the difference between equations (2) and (6). Theoretically, the output of the upstream implicitly includes \( \mu \), the mark-up earned by the upstream innovator. Use of data on upstream input costs alone implicitly assumes that \( \mu=1 \). Assuming the copyright is enforceable then a mark-up such that \( \mu>1 \) almost certainly exists, but there is little evidence of its magnitude. In reality the mark-up is likely to vary greatly not only by asset type but also by individual asset.\(^2\) It is worth noting that at the time of writing the ONS have introduced a mark-up of 1.15 into the estimation of investment in own-account software.

b) Upstream sector output: asset sales
A second potential approach is to measure the left-hand side of (6), \( P^N N \), using data on the value of sales in the upstream/artistic sector. This method is equivalent to measuring tangible investment by the value of sales in the investment goods industries. Note also that any estimate of \( P^N N \) derived from data on industry revenues will implicitly include \( \mu \). However, there are a number of practical difficulties with this approach.

First, industries as defined by the SIC do not neatly correspond to upstream activity. Just as R&D is often undertaken on the own-account of firms that use that R&D output, artistic originals are often produced and used within the same firm, or at least by firms within the same SIC. Consider for example music, with record labels and publishers involved in both the creation and use of originals, including the production and distribution of copies. Furthermore, the ownership of IPRs can cross industry boundaries and be complex, making it very difficult to identify the upstream from data categorised by the SIC.

\(^2\)The size of the mark-up will be determined by the commercial success of the individual asset. Therefore an estimate for \( \mu \) generated by say, Harry Potter, would differ greatly from that generated by the author of this thesis.
Second, upstream revenues could be received in a number of ways. First, in the case of vertically integrated firms involved in both upstream and downstream activity, the rental earned by originals is implicit and so cannot be observed from direct market transactions. It is therefore extremely difficult to split industry output into revenues that accrue to the asset and those that accrue to other factors. Second, the asset could earn revenues in a number of forms: as an explicit rental for one–off or short term use, for example the right to project a film at a cinema for one month; or a sum of rentals for a longer period, perhaps for the right to manufacture the DVD for the next five years; or a payment for the outright purchase of the asset, or for a component of the asset rights such as a one-off payment to use a movie logo on merchandise for perpetuity. Accurate valuation requires that each payment is treated correctly and not simply summed, that is with each payment correctly discounted over the appropriate period as in (3). In practice, such detail is rarely available.

Third, measurement is further complicated by the fact that there are often numerous downstream industries which in turn may rent from a variety of different upstream owners. For example, a t-shirt manufacturer may rent the rights to use intellectual property from the film industry, but they may also rent similar rights from the music/recording industry. Additionally, those rights may be split across owners, for instance between producers and distributors (studios) in the case of film, or between artists and recording companies in the case of music.

Fourth, this approach could capture industry activity that is not in fact asset creation. For example, in the case of television, industry output will include the production of short-lived goods such as news, which is not an asset in the National Accounts framework. Of course in the case of television industry, output will also include downstream use (broadcast) as well as upstream creation. In the case of film, UK production companies may produce short-lived outputs, say infomercials, other forms of output not considered capital in the SNA such as advertising, and also long-lived outputs destined for export and not funded (or owned) by the UK. None should be recorded as part of UK investment.

Therefore whilst this method can be used to say something about the proportion of output or employment that is in some way linked to ‘creative output’, it cannot be used for an accurate analysis of the value or volume of artistic asset creation. For that we need instead to consider the sector from a broader viewpoint than that provided by the SIC.

---

24 This feature is not unique to artistic originals. Consider a firm such as Ford. The majority of its output is downstream since it represents the sale of final goods (vehicles). However, the firm also includes a significant upstream that the rest of the firm implicitly rents capital from. For example, the lab generates ideas through R&D. Likewise the units that design or brand the final goods are part of the upstream for those particular knowledge assets.

25 In practice, in film the owner (the funding studio) receives rentals as a percentage of revenues generated by the cinema, rather than as a flat fee (Soloveichik, 2010)
c) Rental payments: capital compensation

A third potential method for measurement of investment in artistic originals is to exploit the data on payments for their use. As noted above, data on industry output is insufficiently detailed to observe such payments accurately. However, in cases where rental payments can be observed directly, it is possible to exploit the competitive equilibrium relationship in equation (3), where, at the margin, the owner is prepared to invest up to the point where the value of the investment equals the expected net present value (NPV) of future revenues generated by the asset. Such data is partly held by Collecting Societies, who provide a centralised payments receiving house for particular artistic assets, and distribute those payments to asset owners i.e. to the holders of IPRs.

A true measure of investment constructed using this method would require the allocation of royalties to each individual asset in a full longitudinal analysis, with each royalty correctly discounted according to the type of payment (i.e. the length it refers to), the timing of the payment, and the vintage of each individual asset in question. For reasons of commercial confidentiality and other legal barriers, it was not possible to obtain such data. However, provided some fairly restrictive assumptions are employed, it is also possible to derive an estimate of investment based on the cross-sectional sum of royalties that accrue to all asset vintages.

According to a standard PIM, the stock of originals at different points in discrete time is:

\[
R_t = N_t + (1 - \delta)R_{t-1}
\]

\[
R_{t-1} = N_{t-1} + (1 - \delta)R_{t-2}
\]

\[
R_{t-2} = N_{t-2} + (1 - \delta)R_{t-3}
\]

etc..

Where \( R \) is the real stock, \( N \) is real investment and \( \delta \) is the rate of decay in appropriable revenues. Substitution yields:

\[
R_t = N_t + (1 - \delta)N_{t-1} + (1 - \delta)^2N_{t-2} + (1 - \delta)^3N_{t-3} + \ldots + (1 - \delta)^{T-1}N_{T-1}
\]

Assuming steady-state conditions, real output and investment grow at a constant rate \( g^N \):

\[
g^N = \frac{\Delta N_t}{N_t}
\]

\[
N_t = (1 + g^N)N_{t-1}
\]
\[ R_i = N_i + \frac{(1 - \delta)}{(1 + g^N)} N_i + \frac{(1 - \delta)^2}{(1 + g^N)^2} N_i + \frac{(1 - \delta)^3}{(1 + g^N)^3} N_i + \ldots + \frac{(1 - \delta)^{T-1}}{(1 + g^N)^{T-1}} N_i \]  

(11)

Which reduces to:

\[ R_i = N_i \left[ \frac{1}{1 - \left( \frac{1 - \delta}{1 + g^N} \right)} \right] \]  

(12)

And

\[ R_i = N_i \left[ \frac{(1 + g^N)}{(\delta + g^N)} \right] \]  

(13)

The other key relationship is given by the user costs relation:

\[ P^R_i = P^N_i (r + \delta) \]  

(14)

Where \( P^N \) is the unit price of a finished original (an investment or asset price), \( P^R \) the price of renting a unit of the same original and \( r \) is the net rate of return to capital. For simplicity taxes and capital gains are ignored. Multiplying both sides by \( R \), and then both multiplying and dividing the right-hand side by \( N \):

\[ P^R_i R = P^N_i N (r + \delta) \frac{R}{N} \]  

(15)

Substituting in an expression for \( \frac{R}{N} \) from (13):

\[ P^R_i R = P^N_i N (r + \delta) \left[ \frac{(1 + g^N)}{(\delta + g^N)} \right] \]

\[ P^R_i R = \tau P^N_i N; \quad \text{where} \quad \tau = (r + \delta) \left[ \frac{(1 + g^N)}{(\delta + g^N)} \right] \]  

(16)

In golden rule steady-state, defined as the maximisation of intertemporal consumption as a constant proportion of output, quantities of output and capital grow at the same constant rate (Barro and Sala-i-Martin 2003). In this theoretical state, growth in gross investment is equal to growth in net (of depreciation)
investment and growth in capital compensation, \( g^N \) approaches the economy-wide net rate of return \( r \), and the investment share is equal to the capital income share (Jorgenson 1966; Corrado and Hulten 2012), that is, \( \tau = 1 \). Therefore provided it is assumed that the life-lengths and implied depreciation rates for all individual assets in the asset category are equal, and that the production of originals is in golden-rule steady-state, then the value of annual investment can be approximated using the annual cross-sectional sum of royalties. Clearly this method is only applicable for assets where royalties are readily observed. For this reason it is the method recommended by Eurostat and the OECD in the case of literary and musical originals. Note that an estimate derived in this way will implicitly include \( \mu \) since it is based on the revenues earned by the asset through use.

\[ d) \quad \text{Proportion of downstream revenues} \]

Above it was shown that under certain conditions the annual cross-sectional sum of royalties is an approximation to annual investment. From this a potential variant of that method becomes clear. Licence fees are paid by downstream users and flow to owners of assets in the upstream. Therefore royalties are some component of downstream input costs and output, as shown in equation (17). If it is assumed that some constant proportion of downstream output equates to the payments made for the use of originals, and further assumed that the sum of these payments are a proxy for the value of annual investment using the reasoning above, then GFCF can be estimated in this way:

\[
\begin{align*}
&P^Y Y = P^L L^Y + P^K K^Y + P^M M^Y + P^R R^Y \\
&P^R R^Y = \alpha P^Y Y
\end{align*}
\]  \( (17) \)

Royalty rates can therefore be used to inform an estimate of the proportion of downstream output (\( \alpha \)) that flows to upstream owners of originals. Again, an estimate derived in this way will implicitly include \( \mu \).

2.4. Official UK estimates of investment in artistic originals

The UK National Accounts include estimates of investment in the following types of artistic originals: Film; TV & Radio; Music and Books. The following section provides a brief description of current official data and methods and highlights some of the measurement issues faced for specific assets. Unfortunately not all of the data and its components can be presented as it is considered disclosive and in some cases commercially sensitive. Taking each item in turn:

2.4.1. Film

For Film the ONS use upstream input costs as the basis of estimation. The underlying series is based on funding for UK productions as provided by production companies and funding partners, predominantly FilmFour. The data can be found in Channel 4 Annual Report(s). For example, funding of £39m is recorded
for 2009 (Channel4 2009). Due to a lack of coverage of UK-owned productions, official data and methods considerably understate UK investment in this asset.

There are a number of measurement issues that need to be borne in mind when estimating GFCF in film. The first concerns the distinction between production and ownership.

(a) Performance vs. Ownership

Eurostat and OECD recommendations note that in the case of Film it is important to consider the residency of the production company. However, for the measurement of investment, it is ownership that matters rather than where production took place. Consider UK film production. Only part of the UK film production sector constitutes the UK upstream for film assets. Of the following three elements of film production, only two form part of UK GFCF:

i) UK-located firms that (part-)produce (part-)UK-owned film originals ((part)UK GFCF)

ii) Non-UK located firms that (part-)produce (part-)UK-owned film originals, (imports but part of UK GFCF)

iii) UK-located firms that produce film originals owned by the Rest of the World (exports and not part of UK GFCF)

If a film is produced wholly or partly in the UK, but the final asset is owned by say, a Hollywood studio, then licence fees and royalties for use of the film flow to owners in the US, and the investment is American. Consider a Harry Potter movie for example, and assume all filming took place in the UK, was carried out by a UK production company, and that the majority of the cast and crew were UK residents. However, also assume that the movie is owned by (i.e. the asset rights belong to) a Hollywood studio. In this example, the film is certainly part of UK production/output, since the payments for services from labour and capital all took place in the UK. But if the asset is owned by a US studio then the investment is American. That is, the production is part of UK output as recorded in the National Accounts, but is allocated to exports rather than investment. In practice measurement is less straightforward: it is likely that the UK production company would retain some proportion of asset rights as a production fee, and the US studio would acquire the remaining (larger) proportion. In addition the scriptwriter, and if applicable, the author of the literary work behind it, may be granted some proportion of rights. So continuing with the Harry Potter example, it is likely that some part of production does represent UK GFCF, but estimation is complicated by the fact that 100% ownership of rights is rare, and it is common for rights to be split among the primary funder(s), other investors, the distributor (studio), co-producers, writers, lead actors and directors, in private arrangements that differ case-by-case.
b. Rental of copyrighted assets in the production of new assets i.e. embedded originals

A further issue for measurement is that services from different artistic assets are sometimes rented in the production process. Continuing with the example of Harry Potter, inputs to the film include the book used as the basis of the script and music recordings used in the soundtrack. Therefore production costs also include the royalty payments made to the author, J.K. Rowling, and musical artists, for the use of those assets. This is the correct treatment and not double-counting. Conceptually it is similar to, say, a firm using capital to produce an aeroplane, and a separate firm in the airline industry renting that aeroplane to provide transport services. Therefore, royalties for the use of other pieces of artistic capital should not be excluded from production costs.

c. Scope and divisibility of the final original

Another issue is the treatment of what could be considered components of the original, which could be viewed as distinct assets in their own right. That is, do we consider say scripts or sheet music to have already been counted within the value of the film or recording original, or should they be treated as separate originals? The Eurostat Taskforce recommended that if scripts are covered by a separate copyright then they can be recorded as a distinct component, in the category of literary originals, rather than Film (or Television). Conceptually the correct treatment depends on whether the value of the asset is divisible and a case can be made either way. A sensible general approach would appear to be the following. Where estimates are based on production costs then it is reasonable to assume that it is not possible to accurately decompose the asset value into constituent parts and that the value of, say, the script is already embedded in the value of the final asset. Where data on royalties are available then it should be possible to count payments for distinct categories.

2.4.2. TV & Radio

For TV & Radio the ONS use data on upstream input costs as the basis of estimation. They include components for both the own-account production of originals and those purchased from the independent sector. Costs are adjusted so as to exclude short-lived productions (e.g. news). Data for are also split into those investments made by public corporations and private sector broadcasters. The data for television and radio, and in fact total artistic originals, are dominated by the estimated investments of private sector broadcasters for a reason discussed below. Data for individual components are not presented here but inspections of the data suggested that difficulties in identifying all in-house, purchased and commissioned productions have led to some under-estimation of investment by public corporations. There is also a lack of documentation on the types of programmes covered.

Although estimates for private sector broadcasters are also based on costs of production, there is a significant conceptual difference in the methodology compared to that for other artistic originals and TV and radio originals produced by public corporations. In short, for private sector broadcasters, costs are adjusted using a
factor based on the percentage of downstream revenues earned through the sale of advertising space. The intent of the adjustment appears to be to incorporate the additional value of TV assets in generating commercial revenues, this is essentially an estimate of the factor \( \mu \) discussed above. It is this adjustment that is responsible for this component being by far the largest item in official estimates of artistic originals, with estimates of investment around four times greater than pure production costs for private sector broadcasters.

It is worth making a point here on consistency. It would seem reasonable to argue that estimation and application of \( \mu \) should either be done for all assets, or excluded entirely. So if it is thought that \( \mu \) should be estimated for private sector broadcasting, then for consistency perhaps it should also be estimated for the public broadcasting corporations, which do generate at least part of their revenues on a commercial basis.\(^{26}\) Alternatively, an assumption that \( \mu = 1 \) would achieve consistency with UK measurement of other knowledge assets such as R&D\(^{27}\) and, until recently, own-account software, where investment is measured as the cost of production with no adjustment for value or market power.

Issues surrounding the measurement of GFCF in this asset type include the residency of owners, rental of other copyrighted assets in the production of television assets, and the scope and divisibility of the final original, as already discussed above in the context of film. Another important issue for measurement, particularly in the UK, is the need to consider commissions and the role of the independent sector.

\[ a. \quad \textit{Outsourcing and the independent sector} \]

For television, estimation of investment requires consideration of the increasing trend to outsource production to the independent sector, and final estimates ought to include both direct investments in in-house productions and funding for commissions. In the case of commissions, funding provided by broadcasters may not be entirely sufficient in measuring the investment in those originals, since some proportion of asset rights remain with the independent producer, providing the incentive for additional investments by that party.

2.4.3. \textit{Music}

Official estimates for investment in Music, or recording originals, are estimated as a percentage of annual UK sales (i.e. of downstream revenues, using the method and reasoning described above), which is assumed

\(^{26}\) For instance, BBC Worldwide have the first right to commercial exploitation of any originals produced/owned by the BBC. Although classified as public corporations, Channel 4 and S4C also earn revenues through the sale of advertising space.

\(^{27}\) Mark-ups that account for the market power of innovators are an important conceptual issue relevant to measurement of investment of knowledge assets in general. In the US R&D satellite account, the costs of R&D exchanged between R&D establishments classified in a different industry than the parent/owner firm are marked up (Robbins and Moylan 2007, p.52). The mark-up is estimated using the ratio of net operating surplus to gross output for miscellaneous professional, scientific, and technical services, which for the US averages about 1.20. The ONS have also recently incorporated a mark-up into the measurement of own-account software, set at 1.15, although it is not fully clear whether this mark-up is to account for the additional revenue earned by unique software assets, or for the capital input to their production.
to equate to the cross-sectional sum of royalties. The percentage used is 9.5%, an estimated royalty rate for artists. However, this method results in an under-estimate of UK investment for a number of reasons.

First, ownership rights for music originals are split between a number of parties, namely songwriters, artists, record labels and publishers, with the ownership share for each depending on the specific right in question. The royalty rate used in the official method only considers the share received by artists, with no allowance for the compensation earned by other owners.

Second, the downstream for music consists of more than just the sales of recorded music. Consider for example, merchandise, live performance including performance of covers, radio play and the playing of music in clubs. Such activities generate performance and synchronisation royalties, among others, and the revenue split between owners depends on the particular right in question.\(^{28}\) Payments for such rights are primarily distributed by the collecting societies e.g. PRS (Performance Rights Society) and PPL (formerly Phonographic Performance Limited), but these are not accounted for in the official data and method. The current ONS method also does not account for the growing tendency for live performance to be used as a means to compensate for revenues lost through piracy of recorded music. Live performance is not investment activity in itself but rather rental from the existing capital stock, exactly analogous to the rent of the original in the production of a copy, and performers receive an implicit rental payment in the percentage of ticket revenues they earn. An improved estimate based on the ONS method could therefore be constructed as:

\[
GFCF(\text{MUSIC}) = \lambda(\text{RECORDED SALES}) + \theta(\text{LIVE REVENUES}) + (\text{Additional royalties})
\]  

Such an adjustment to the method would result in a significant revision to estimates of investment, with the live performance market large in terms of revenue and comparable to that for the sale of recordings (Page and Carey 2010). It is worth noting that, conceptually, the income that artists earn from live performance is ‘mixed income’, that is income that includes a return for labour as well as artistic capital, and the implied royalties could be adjusted to account for this.

Third, rather than the UK sales of recorded copies which could have originated (be owned) in any country, conceptually the correct basis for this method is the worldwide sales of copies of UK-owned originals. The current method therefore implicitly assumes trade balance in the sales royalties that flow out of the UK to Rest of the World (RoW) owners and that flow into the UK to UK owners. However, the UK is a prolific producer of music, and a net exporter, suggesting that use of data for UK sales of recorded copies may under-estimate the royalties earned through the sale of copies of UK musical assets.

\(^{28}\) Thanks are due to Will Page and Chris Carey of ‘PRS for Music’ for providing valuable insights into the structure of the music industry.
2.4.4. Books

Official estimates for investment in Books are produced using a method similar to that used for Music. Specifically investment is estimated as 7.5% of UK book sales, where the factor of 0.075 is an estimated royalty rate for authors. Newspapers, magazines and other short-lived goods are therefore correctly excluded since they do not meet the capitalisation criteria. However the result is again an understatement of UK investment activity in producing literary originals for the following reasons.

First, as with Music, the method does not account for the capital compensation earned by other owners of literary originals, namely publishers but can also include illustrators for instance. The royalty rate used only accounts for the incomes that flow to authors. Even then, it appears conservative. Royalty rates are agreed between authors and publishing houses and can vary, usually depending on the past commercial success and therefore market power of the author in question. However, in the UK, typical royalties for hardbacks are between 10 to 12.5%, and 15% for successful authors. For paperbacks, the typical range is 7.5 to 10%, increasing to 12.5% in exceptional cases (Wikipedia 2011). For e-books the royalty rate for authors is higher at around 25% (Flood 2013) and can be as high as 70% (Neill 2010).

Second, the factor used also does not consider the capital compensation earned from other sources besides the sale of copies including fees for secondary rights, such as audio-visuals and public lending rights. The ownership share for each depends on the specific right in question.

Third, as with music, a more appropriate sales measure would be based on the worldwide sales of copies of UK assets, rather than UK sales of copies of assets owned worldwide. The current method implicitly assumes a trade balance in royalties from book sales. If the UK is a net exporter in this field, the current method will under-estimate UK investment in literary originals.

2.4.5. Miscellaneous Art

At present the UK National Accounts include no estimates for investment in any other form of artistic assets such as fine art, photography/images, choreographed routines, etc. Some preliminary estimates for investment in this diverse group of assets are estimated and presented in the following section, referred to as ‘Miscellaneous Art’. There are some measurement issues that require consideration however.

a. Identification of productive fixed assets

The main measurement issue for estimating GFCF in this asset type is that it is important to ensure the correct identification of productive assets and avoid double-counting with assets already included in the National Accounts. This was discussed above, in the context of valuables, where it was argued that the potential for double-counting is limited.
Another aspect to this point is that it is important that actual investment is identified rather than other (short-lived) production activity. Consider photography. Estimates should only include investments in long-lived images that generate revenues over a period greater than one year. It would not be appropriate to include activity that corresponds to final (say wedding or passport photographs) or intermediate consumption. Likewise for choreographed routines, where it would not be appropriate to capture instruction activity.

Despite the difficulties in measurement, investment in this heterogeneous group of assets is a significant omission in UK estimates. Estimates for ‘Miscellaneous Artwork’ are included in the US data developed by Soloveichik (2010a), where investment is estimated at 7.7% of total US investment in artistic originals. In terms of estimation, data on royalty payments (e.g. for the use of photographs, images and potentially art) would be useful, since they would ensure, by definition, that the asset counted is being commercially exploited and estimation could be more easily restricted to only those goods that have a service life of greater than one year.

2.4.6. **Summary**

To summarise: official data for investment in Film are under-estimates since they only refer to a sample of UK-funded productions; for private sector broadcasting the official estimates are affected by a large adjustment for the revenues earned through the sale of advertising; for public broadcasting corporations there seems to be an under-recording of own-account investment and the funding for productions commissioned from the independent sector; for Books and Music, official data on investment is estimated as a percentage of sales where both the sales data and percentage used might be improved, and estimates do not account for royalties earned from the use of secondary rights. No estimates for other forms of originals are currently included in the National Accounts.

**2.5 New data on the UK Artistic Sector, including new estimates for UK GFCF in ‘Artistic Originals’**

Despite Table 2.1 showing that UK GFCF in artistic originals is among the highest in the EEA, discussion of the recommendations made by Eurostat and the OECD, and evaluation of official UK data, has highlighted a number of identifiable gaps in UK coverage. The following section presents ways to build on ONS measurement and improve current estimates in the National Accounts. As a result, new official estimates, largely based on the contents of this chapter, are to be incorporated into the National Accounts in the near future.

In setting out a model of the upstream and downstream sectors and how they interact with each other, it has been shown that there are numerous ways to estimate investment in artistic originals. The two primary methods involve, first, using data on the input costs to upstream asset creation and, second, using data on the
incomes that flow to upstream asset owners. The preferred method depends on the asset being considered and data quality/availability. The following section presents estimates of investment, by asset, and where possible triangulates data from different methods to help determine the robustness of the final estimate.

2.5.1. Film Originals
In line with Eurostat and OECD recommendations, preferred results for film were produced using data on upstream input costs. Estimation was conducted using a dataset for the entire universe of UK films produced since 1991. The dataset was constructed from three sources. First a list of all UK-certified films produced between 1998 and 2010 was acquired from the UK Film Council (UKFC), along with some accompanying data. Second a similar list was acquired from the British Film Institute (BFI 2003a), this time for UK productions between 1991 and 2001, again with some additional data. Third a dataset was purchased from the website “the-numbers.com” containing information on all films they had listed as UK (co-) productions, as well as data they held for all films listed in the UKFC and BFI datasets. By definition, films listed by the-numbers.com but not by the UKFC/BFI, are those that either did not meet the requirements, or did not apply for, UK certification. Note that UK certification is primarily based on cultural content and does not necessarily translate to UK ownership. It was therefore necessary to determine UK ownership shares for each production, and the method for doing so is described below. The final dataset included data for all variables listed in Table 2.4.

29 Thanks are due to Nicholas Maine of the UK Film Council for providing this data.
30 A list of films produced between 1991 and 2001, with additional data, was taken from the BFI publication, “Producing the goods?” (2003).
31 I am grateful to Bruce Nash of the-numbers.com for extracting this data and for valuable insights into the industry structure.
Table 2.4: List of variables, by source

<table>
<thead>
<tr>
<th>Variable</th>
<th>the-numbers.com</th>
<th>UKFC</th>
<th>BFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film Title</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Production Company</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Distributor (Studio)</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Country of Production</td>
<td>√</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Release Date</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Opening Date (UK)</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Int’l (non-US) Box Office</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>US Box Office</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Multi-territory Box Office to date</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>UK Box Office (as of May 03)</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>UK Box Office to date</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>UK Audience</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
<tr>
<td>Multi-territory Audience</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North American DVD Sales Revenue</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North American DVD Sales Units</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Production Method (Live, Animation etc.)</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Production Type (Fiction, Factual etc.)</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Source (Orig screenplay, literary etc.)</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Genre (Comedy, Horror etc.)</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Production Budget</td>
<td>√</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BFI Category (majority UK funding etc.)</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>UKFC Category (Schedule 1, Co-prod etc.)</td>
<td>-</td>
<td>√</td>
<td>-</td>
</tr>
</tbody>
</table>

Note to Table: Final dataset constructed by matching three datasets from a) UKFC, b) BFI and c) the-numbers.com. Dataset includes the above list of variables. BFI categories are defined as follows: “A” refers to films where the cultural and financial impetus is from the UK and the majority of personnel are British; “B” refers to majority UK co-productions, where although there are foreign partners, there is a significant amount of British finance; “C” refers to minority UK co-productions, that is, foreign (but non-US) films in which there is a small UK involvement in finance; “D” refers to US financed or part-financed films produced in the UK, most have a UK cultural content; “E” refers to US films with some British financial involvement. Of the UKFC categories, “Schedule 1” refers to films that are UK-certified according to Schedule 1 of the Films Act (1985). Criteria include at least 70% of spend taking place in the UK and since 2007 UK certification has depended on passing a ‘cultural test’. “Co-productions” are also UK-certified via official bilateral co-production treaties or membership of the European Convention on Cinematic co-production. Note that UK ownership is not a requirement for UK certification.

The final dataset therefore includes data for a total of 2,291 UK productions, produced between 1991 and 2011. However, because the data do not include all films produced in 2010/11, the dataset is only used to produce estimates of GFCF for the years 1991 to 2009. Figure 2.1 below shows the number of UK films in the dataset by year of release.
Figure 2.1: No of UK (co-)produced films, by release year

Note to figure: Number of UK produced films in dataset by year of release. In total there are data for 2291 films produced between 1991 and 2011, including 80 that were produced in either 2010 or 2011. Since the data do not include the complete universe of UK films for 2010/11, estimates for GFCF only extend to 2009.

After cleaning, combining data from the UKFC, BFI and the-numbers.com gives data on production budgets for over half of these films. For most remaining films, where production budgets were missing there were data on international box office revenues which were used to impute missing production budgets, using the “impute” command in Stata. Where international box office revenues were also missing then based on information provided by the-numbers.com it was assumed US box office revenues were equal to North American DVD revenues, and international box office revenues were imputed from the US figures.

It is worth noting that an ideal dataset would also include information on all unfinished or failed projects, as such expenditures are also investments even if they are not successful. However, the nature of the dataset was such that it only included data for completed and released projects. With no information on the frequency of, or expenditure on, failed projects, they were implicitly assumed to be zero.

As the final dataset only included film release dates rather than dates of actual production, allocation of GFCF to the year(s) of investment activity required some assumptions on the average length of film production, as it would be inaccurate to allocate the entire estimate of GFCF in each film to the year of release. Mean production lengths of one year and two years were assumed for live action films and any form of animation respectively. Costs were then spread across the production period as shown in Table 2.5. So

---

32 Since the-numbers data are denominated in dollars and the BFI/UKFC data in sterling, all monetary values in the former are converted using an average annual exchange rate for dollars:sterling, taken from ONS Financial Statistics (AUSS).
33 I was provided with the following industry information by Bruce Nash of the-numbers.com: a) US DVD sales are typically roughly equivalent to US Box Office revenues; b) Typically 50-60% of Box Office revenues return to the studio, as do 50% of DVD revenues.
34 A production length of 2 years was also assumed for films that are part-animated and part-live. The assumptions for production length for each genre were based on information provided by Bruce Nash of the-numbers.com
for live action films: 10% of costs were allocated to the pre-production phase, assumed to last 6 months; 60% to the production phase, assumed to last 2 months; and 30% to the post-production phase, assumed to last 4 months. So for example, if a live action film was released in say April 2006, 30% of costs were allocated to GFCF in 2006, and the remaining 70% to GFCF in 2005.

Table 2.5: Assumptions to allocate GFCF

<table>
<thead>
<tr>
<th>Production phase</th>
<th>Production Type</th>
<th>Live Action</th>
<th>Animation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Month</td>
<td>%</td>
<td>Month</td>
</tr>
<tr>
<td>Pre-production</td>
<td>1-6</td>
<td>10</td>
<td>1-6</td>
</tr>
<tr>
<td>Production</td>
<td>7-8</td>
<td>60</td>
<td>7-24</td>
</tr>
<tr>
<td>Post-production</td>
<td>9-12</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

Note to table: Percentage of production costs allocated to each stage of production. Production schedules and percentages based on industry information provided by Bruce Nash of the-numbers.com

Since the majority of films in the final dataset are co-productions, the main issue faced in estimation was determining the percentage of budgets that represented investment in UK-owned assets. With no direct information on ownership shares, some assumptions were necessary. A number of alternative assumptions were tested but the final estimates proved relatively robust to those alternatives. The following text sets out the assumptions used for the preferred final estimates, which were agreed credible by the UK Film Council.

1) Where the-numbers.com, BFI and UKFC data all indicated that there were no other co-producing countries, it was assumed that the UK holds 100% of the copyright and the entire budget was allocated to UK GFCF.

2) For films listed as BFI Category A or B, that is films for which the majority of funding is from the UK, it was assumed that 55% of IPRs are held in the UK. For those listed as BFI Category C, D or E, that is where minority funding is from the UK, it was assumed that the UK owns a minority of rights and 25% of production costs were allocated to UK GFCF.\(^{35}\)

3) For co-productions with no other information on ownership from the BFI categories, budgets were evenly split according to the number of co-producing countries e.g. if the UK was one of four co-producing countries, 25% of the budget was allocated to UK GFCF.

4) To ensure investment was not overcounted, for films where either the UKFC or BFI listed the UK as a (co-)producer, but the-numbers.com listed a country other than the UK as a sole producer, just 10% of production costs were allocated to UK GFCF.

\(^{35}\) BFI categories are defined as follows: “A” refers to films where the cultural and financial impetus is from the UK and the majority of personnel are British; “B” refers to majority UK co-productions, where although there are foreign partners, there is a significant amount of British finance; “C” refers to minority UK co-productions, that is, foreign (but non-US) films in which there is a small UK involvement in finance; “D” refers to US financed or part-financed films produced in the UK, most have a UK cultural content; “E” refers to US films with some British financial involvement.
5) For non-English language films where the UK was listed as a co-producing country, it was assumed that the UK was a minority partner, and 25% of production costs were allocated to UK GFCF.

Figure 2.2 presents estimates of Film GFCF as included in the National Accounts alongside the new estimates.\(^36\) Comparison suggests that official estimates understate GFCF by a factor of around eight in 2009.

**Figure 2.2: Estimates of UK GFCF in film originals, Nominal £mns**

![Graph showing estimates of UK GFCF](image)

Note to figure: New estimates use custom dataset for universe of UK films, built using data from the-numbers.com, UKFC and BFI. ONS estimates based on a small sample of UK productions.

**Alternative methods of estimating GFCF in Film**

Although not presented here for reasons of space, alternative methods to estimate investment in film were tried, including using data on the earnings of relevant occupations involved in UK film production, as according to the Annual Survey of Hours and Earnings (ASHE). ASHE is a business survey sent out to employers, based on a random sample of National Insurance numbers and contains information on earnings by occupation and industry. To account for other upstream inputs, data on the occupational wagebill were multiplied by a factor to account for the use of capital and materials, based on information for the film production industry from the Annual Business Inquiry (ABI). This gave an estimate of the total value of UK production. Since only part of UK production constitutes UK investment, some information on the time-use of workers, that is the time spent creating UK assets, would have been required to form estimates of UK GFCF. Comparison with the preferred estimates above suggested a time-use assumption of 50% would result in estimates close to those from the preferred source.

\(^36\) Since the dataset used only includes productions from 1991, new estimates were also extended back to 1970 using a series for the budgets of UK/US co-productions kindly supplied by Soloveichik of the BEA.
2.5.2. TV & Radio Originals

The ONS methodology for estimating GFCF in broadcasting originals is an upstream cost-based approach. The following re-estimation builds on the ONS method and improves the data using industry sources. The data used for the new estimates are based on the production spend of UK broadcasters, as published in OFCOM reports on the Public Service Broadcasters (PSBs) (OFCOM 2010) and the Communications Industry (OFCOM 2010). UK Public Service Broadcasters include the BBC, ITV, Channel 4 and Channel 5.

The Channel 4 business model is based entirely on commissions and acquisitions, with no in-house production. ITV broadcast a mix of own-account and commissioned productions, but must meet a requirement that 25% of broadcast hours are filled by productions from the independent sector. Similarly, the BBC is based on a mixed production model, with 25% of broadcast hours filled by independent productions and the additional requirement that 50% of hours are filled by in-house productions. Remaining broadcast hours are filled competitively, by either party. Channel 5 has no such obligations.

The OFCOM data cover the costs of in-house productions and PSB funding for commissions from the independent sector. From equation (6) we know that, conceptually, estimates of upstream input costs should also include estimates of capital compensation for the use of assets in the upstream e.g. cameras, set equipment etc. From discussions with the BBC it was determined that such assets are typically explicitly rented from either a commercial arm or an outside source, and so these rental payments are already included in the OFCOM data.37

The OFCOM data only pertain to UK PSBs. However, virtually all UK investment in the creation of broadcasting originals is undertaken by the PSBs. The major non-PSB broadcaster is Sky. However, despite broadcasting on approximately 400 channels, Sky investments in UK originals are relatively small at around £100m p.a. once sports and other flow programmes are excluded.38 Instead their model is primarily based on licensed imports and repeats, with the majority of expenditure on stock programmes made up of rentals for broadcast rights rather than actual creation. For short-term rentals, it is correct to record such spend as intermediate consumption by the user (in this example Sky), and capital compensation for the owner (say, a US television network). The appropriate treatment becomes more complicated when rights are acquired for a number of years, particularly if they are exclusive in the acquiring country. In that case, it could be argued Sky has made an investment in a “licence for use”, using OECD terminology (OECD 2010). Accounting for this in practice would require detailed data on the timing, type and value of all payments. Such data were simply unavailable.

37 I am grateful to Shaun Day for useful information on production practices in the television industry.
38 Source: Discussions with BBC, and Lecture by BBC Director General, Mark Thompson, Edinburgh International Television Festival. Available at: http://www.guardian.co.uk/media/2010/aug/27/mark-thompson-mactaggart-full-text
Figure 2.3 contains estimates of the total costs incurred by PSBs in the creation of UK stock programmes, whether they originate in-house or are commissioned from the independent sector. They are based on data for production spend by genre and extend back to 1998. In line with international guidelines, GFCF is estimated to include only spend on the production of stock programmes, defined here as ‘Arts and Classical Music’, ‘Religion’, ‘Education’, ‘Factual’, ‘Drama’, ‘Entertainment’ and ‘Children’s’, thereby excluding ‘News, current affairs and weather’ and ‘Sport’. Since ‘Film’ is treated as a separate asset, and as PSB spend on that category will mainly be composed of payments for short-term broadcast rights rather than actual production, spending data for that genre is also excluded.

Additional data were also incorporated to account for investments made in BBC radio stock programmes and Welsh language S4C productions. For radio, estimates were based on OFCOM estimates of BBC radio spend from 2000 to 2009 and data on BBC radio broadcast hours by genre in 2009/10. Multiplying production spend by the share of broadcast hours filled by stock programmes gives an estimate of BBC expenditure on the creation of radio stock originals of around £153m in 2009. Estimates for radio are extended back from 2000 to 1998 using the growth rate of BBC TV expenditure. Note that if the composition of BBC radio broadcast hours by genre has changed significantly over time, there will be some inaccuracy in the back-series (1998 to 2008). There will be further inaccuracy if the production costs for radio vary widely by genre. For S4C there are data on spend for producing Welsh language output, back to 2004. They are extended back to 1998 using the mean growth rate of expenditure in 2004 to 2009.

Figure 2.3 shows that for much of the period after 1998, new estimates are similar to those in the National Accounts. The divergence in the 2000s is primarily due to the conceptual difference in method, with official data incorporating an adjustment for revenues earned by private sector broadcasters through advertising. This adjustment is particularly large in the late 2000s. For comparison, the chart includes a series based on official estimates but excluding the calculation of that factor (µ in the notation given above).

39 I am grateful to Steve Gettings of OFCOM for his assistance and provision of data
40 Unfortunately the OFCOM data only extends back to 1998. The series is extended further using the growth rates of the existing ONS data. Since the methodologies are similar, and with data for broadcasting originals being the best-measured component of official data, this was considered a reasonable approach.
Figure 2.3: GFCF in TV & Radio Originals, Nominal £mns

Notes to figure: Thin black line is the ONS estimate, as recorded in the National Accounts. Dotted black line is an implied ONS estimate after removing the monopolists mark-up, μ. Thick black line is the new estimate, based on data published by OFCOM.

Although the new estimates are an improvement on those currently recorded in the National Accounts, they still include a number of imperfections. First, estimates of investment in Radio stock programmes are based on the share of BBC broadcast hours by genre in 2009/10. If the genre split for previous years was not similar, or if production costs vary considerably by genre, there will be some bias in the final estimates. However, the data for radio is but a small component so the aggregate figure for TV & Radio should not be too adversely affected.

Second, the coverage of multi-channel platforms is inadequate. Whilst the data do include the costs of producing programmes for BBC Digital, they do not include data for Sky or other such providers. However, as noted, investment in the creation of UK stock programmes by Sky is limited.

Third, funding for commissions is usually provided in exchange for the short to medium-term broadcast rights, but some proportion of rights for commissioned programmes remain with the independent production company, for instance long-term broadcast rights, international rights and DVD distribution rights. Therefore there is an incentive for the production company to invest additional resources in creation, alongside that provided by the funder. The OFCOM data only includes the funding provided by PSBs and so do not account for such additional investments. It was not possible to obtain data on any additional investments made by independent production companies.
Fourth, some sports broadcasts are clearly long-lived\textsuperscript{41}, but there would appear to be an element of randomness in those which are, with it being determined as much by the final result or outcome as the nature of the event itself. In practice it is virtually impossible to allow for this using a cost-based approach and so sports are excluded in line with international guidelines. It may be that it is possible to account for long-lived sporting rights using a revenue-based approach, but such data were not available.

\textit{Alternative methods for estimating GFCF in TV & Radio originals}

Although the preferred estimates for investment in TV & Radio are those based on the data from OFCOM, alternative estimates were also produced using ASHE microdata on the earnings of relevant occupations in the television and radio industry, adjusted for additional overheads using data for the industry from the ABI. As an example of how the two series’ compare, estimated GFCF using ASHE was £4.2bn in 2008, compared to the £2.2bn suggested by the OFCOM data. Note however, that the ASHE estimates make no allowance for time-use, that is the amount of time devoted to production of stock and flow programmes respectively, and so would be expected to overestimate GFCF. The comparison therefore suggests that the ASHE data are consistent with around 50% of production expenditures being on the creation of stock programmes and therefore constituting GFCF.

2.5.3. \textit{Literary Originals: Books}

In line with current official UK practice and OECD/Eurostat recommendations, new preferred estimates for investment in literary originals were produced using a primarily revenue-based approach. The main reason royalty based estimates are preferred is that we do not seek to measure all expenditure on creating copyrighted written material, much of which has little value, does not have a long service life and will never be published or commercialised. Rather we wish to measure investment in assets that meet SNA capitalisation criteria and generate a stream of income for owner(s) over a period longer than one year. Data on revenues is therefore helpful as it restricts the sample to only those assets that have been commercialised, by definition. Estimates should also include compensation earned by the other owners of literary originals aside from authors, namely publishers, including that earned from the publication of long-lived periodicals including academic journals.

Before outlining the data and method, it is worth saying a little more about the industry and arrangements for the distribution of royalties, which will help clarify the measurement approach taken. Publishers typically reach individual agreements with authors for the right to commercialise the underlying asset. In some cases the author may retain the copyright, but importantly, they will have signed over the rights to publish, in return for an advance based on a percentage of anticipated revenues. The advance payment made by the

\textsuperscript{41} The re-use of news material from archives also suggests that some small part of that genre can also be long-lived.
A publishing company is some proportion of $P^N N$ in this framework, that is publishers have purchased some component of asset rights in return for a share of revenues. Therefore although the author is the creator, there is actually joint ownership of the final asset in the upstream sector. After the advance has been recovered, author royalties are normally calculated as some percentage of the wholesale price, with the remainder flowing to the publishers. The returns to artistic capital are therefore split between the publisher and author, with the split depending on the negotiating power of each party. There is considerable variation in the type of agreements reached and contracts also usually specify a schedule of revenues for specific media,\textsuperscript{42} sometimes depending on the genre of the book. The business model for textbooks is different, and the rights to those tend to be wholly owned by publishers. Since such works are frequently revised with new editions published, the publisher acquires all rights and edits are typically made by employees of the publishing house.\textsuperscript{43}

Literary royalties are also earned from a variety of sources. Primary rights are the largest source, that is, from the sale of copies of the final asset (book sales). Royalties for secondary rights are primarily distributed through various collecting societies and include payments for educational use (largely textbooks), photocopying, broadcasting (audio-visual) and public lending (libraries). Such royalties are split between owners (authors, co-authors, illustrators, publishers) with the split depending on the right in question.

To ensure all these sources of revenues are accounted for, new estimates of UK Investment in literary originals are produced from a number of different sources.\textsuperscript{44} First, data on total advances cover the direct investments made by publishers, which in equilibrium equate to the anticipated future revenues earned by publishers. Second, these are added to data for the royalties received by UK authors from sales, with those (expected to be) received by publishers already accounted for with the data on advances. Third, to account for revenue from secondary rights, data for royalty distributions by the Authors Licensing and Collecting Society (ALCS) in return for public lending rights, and Publishers Licensing Society in return for educational licensing and copying rights, are also added. Finally, to account for further direct investments, estimates of the cost of own-account writing and editing by publishing houses, for example for textbooks, are also added. Since the rights to such works are typically owned by publishing houses, this element ought not have been counted elsewhere. On this component, the data were for half of the top 11 UK publishing houses and subsidiary publishing firms. Therefore they were scaled up, by doubling the estimate, to represent the full top 11 publishing houses. There are some additional

\textsuperscript{42}A fairly common practice is to determine the royalty rate based on the number of sales achieved i.e. the percentage received by the author increases after the book reaches milestones in sales. Royalties for foreign sales are also typically subject to a different schedule than those from domestic sales.

\textsuperscript{43}I am grateful to Rachel Soloveichik, and Sarah Faulder and representatives of UK publishing houses, for discussions on the business model and ownership of different types of originals.

\textsuperscript{44}Thanks are due to representatives of publishing houses and collecting societies led by Sarah Faulder (PLS) for help in acquiring these data.
120 publishing firms registered with the Publishers Association\(^{45}\) and likely some other small firms in the universe of publishing. This figure is therefore considered a lower bound.

New estimates of UK investment in literary originals are presented below in Figure 2.4 alongside official estimates. It is worth noting that the official figure corresponds very closely with an element of the new estimates, that is, the primary royalties received by authors from sales. The difference between the two series is due to the adjustments to methodology to take account of revenues earned from the use of secondary rights and the inclusion of direct investments made by publishing houses. It is also worth noting that the (primary and secondary) royalties data include payments transferred from international collecting societies to their UK counterparts, for the use of UK assets outside the UK. The data therefore account for the sale of copies of UK assets in other countries, and the method therefore overcomes one of the limitations of the current UK method, which implicitly assumes a trade balance in book royalty payments.

Figure 2.4: UK GFCF in literary originals, Nominal £bns

Note to figure: New estimates based on industry data for revenues earned by owners of rights and direct investments made by publishers. ONS estimates based solely on revenues earned by authors through sales.

Alternative estimates for estimating GFCF in literary originals

Using the same method as described previously, alternative estimates were also produced using data on the earnings of particular occupations in the relevant industries for the creation and publishing of literary works, as recorded in ASHE, and marked up to account for the input of capital and materials using industry data from the ABI. The results using each method are relatively similar. With no information on industry or occupational time-use, and therefore the proportion of workers output that is investment and consumption goods respectively, it might be expected that the ASHE method would produce an over-estimate of GFCF in

\(^{45}\)http://www.publishers.org.uk/index.php?option=com_content&view=category&layout=blog&id=73&Itemid=1202
literary originals. On the other hand, if authors are inadequately sampled in ASHE, as would be expected since they are largely freelance or self-employed, the result may be an under-estimate. Comparison with the preferred estimates suggests that the impact of these two factors roughly cancel each other out.

2.5.4. Musical (or Recorded) Originals

In line with the current official method and international guidelines from Eurostat (2003) and the OECD (2010), new estimates of investment in music originals are based on the revenues earned by the owners of rights, which is assumed to equate to annual investment. However, the official data and methodology as currently used by ONS are added to in numerous ways.

First the current ONS method includes estimates of the revenues returned to artists via sales, but not those returned to publishers and record labels who also own some proportion of asset rights after investing in artists. Based on discussions with the industry, it was determined that the total revenues that accrue to all rights holders from recording sales\(^{46}\) are better estimated by removing VAT, margins for manufacturing and distribution, and marketing costs.\(^{47}\) What remains is the return to music capital, from the sale of copies, that flows to all the owners of rights. This methodology is similar to that used by the BEA in forming estimates of investment in music originals (Soloveichik 2010b).

Second, added to the income from sales are the incomes returned to creators by music collecting societies, including royalties earned from the rights to lyrics; composition; direct live performance (for performance of covers); re-production (e.g. on CDs, DVDs etc.); public performance and synchronisation.

Third, the sources of artist revenues have changed considerably in recent years, with a much greater proportion now earned through the live performance of their own works. These revenues are effectively rental payments earned by artists for the performance of their own songs. These payments are also accounted for in the new method by adjusting estimates of total live revenues and removing other components, so what remains are the revenues that flow to artists. The following elements of total live revenues are subtracted: secondary ticket sales; at-event-spend; VAT; booking fees; promoter margins and venue costs. Direct live royalties are also subtracted so as not to double-count with the revenues earned through live performance of covers. What remains are the earnings of performers. Conceptually these earnings are “mixed income”, representing a return to both labour and capital. Therefore the capital component is estimated as 33% of the mixed income based on the long-standing ratio between Compensation of Employees and Gross Operating Surplus in the National Accounts.

\(^{46}\) Data on recording sales are taken from British Phonographic Industry (BPI) statistics

\(^{47}\) VAT and retail margins had already been removed from the BPI numbers. In the US work (Soloveichik, 2010) the manufacturing and distribution margins are estimated at 15%. Since the distribution margin has already been removed, a margin of 10% is assumed for manufacturing. Then of the remainder, 33% is estimated to cover marketing, with this factor again based on Soloveichik (2010).
Data on the above components of revenue earned by music originals were collated following discussions with industry representatives who also assisted with the provision of data. The following chart presents a breakdown of all revenues earned by UK music originals in 2008. First it includes the revenues earned by all owners of music originals through the sale of copies, therefore consisting of £174m each earned by songwriters and publishers, record labels and artists. Note that the current ONS method estimates only a part of these revenues: those royalties earned by artists through the sale of recordings. The new estimate for this component of royalties in 2009 is £174m, very close to the £168m investment figure recorded in the National Accounts.

Second, the new estimates also include data on the additional royalties earned from the use of secondary rights. It therefore includes royalties distributed by PPL (formerly Phonographic Performance Limited) which cover the payments made to record companies and performers for the playing of music or music videos in public (for instance in pubs and clubs) and for that broadcast on TV or radio. It also includes royalties distributed by ‘PRS for Music’. Under the umbrella of PRS for Music are the Performing Right Society (PRS) and the Mechanical-Copyright Protection Society (MCPS). PRS collect on behalf of songwriters, composers and publishers, and distributed payments include those for the public performance of either live or recorded music. MCPS also represents songwriters, composers and publishers and collects payments for the re-production of music, for instance for CDs, downloads, toys etc.

Third, the method also incorporates revenues earned by music originals through live performance, estimated in the way described above, which amounted to £176m in 2008.

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48 I am extremely grateful to Will Page and Chris Carey of PRSforMusic for making this data available and for providing valuable insights into the structure of the music industry.
As the data on secondary royalties and total live revenues were only available for 2008, the data were backcast using data on sales of recordings (BPI 2010).

In terms of comparison between methods, it is worth making two points. First, the ONS method applies a factor of 0.095 to an estimate of recording sales. These new estimates suggest that a more appropriate factor, that would account for all the royalties earned by all owners of music originals, is more in the order of 0.57. Second, the current method includes no estimates of revenues earned from a) the use of secondary rights or b) live performance of own work. On live performance, a similar factor that could be applied to total live revenues would be in the order of 0.11.

One of the weaknesses of the official method, highlighted in a previous section, partly remains in these new estimates. The data for recording sales and live revenues are revenues earned in the UK by world artists, rather than world revenues earned by UK artists. Although more appropriate conceptually, data on the worldwide earnings of UK artists were not available. This part of the data and method therefore implicitly assumes a trade balance in UK music. Since the UK is a net exporter of music, these estimates can be considered a lower bound. However the royalties distributed by the collecting societies are those distributed to UK members including those transferred from sister societies abroad. Similarly the revenues earned by non-UK artists in the UK are transferred to similar societies in other countries and so are excluded from those estimates. These elements of the data and method therefore do account for the international revenues earned by UK rights holders.
Alternative estimates for estimating GFCF in music originals

Again, alternative estimates for investment in music originals, using the upstream input cost-based approach, were produced using ASHE, which provides data on the incomes of relevant occupations. To account for remaining input costs a ratio of non-employment costs to employment costs in relevant industries was used, based on data from the ABI. The result using this method was considerably lower than that from the preferred method, possibly because musicians and related occupations are not well sampled in ASHE.

2.5.5. Miscellaneous Artwork

From the discussion of the Eurostat Taskforce reports ((2003) and (2004)) and their criteria, as well as the development work by Soloveichik (2010a) of the BEA, we know that investment in any original: that is covered by copyright; can be commercialised; has a service life of greater than one year; and is not already recorded elsewhere in the National Accounts; can be counted as GFCF in artistic originals. Outside of the four assets already discussed, no other forms of investment in artistic originals are included in official estimates of GFCF in the UK National Accounts. This leaves a wide range of potential candidates for inclusion, including investments in photography, images, artwork, choreography and cartography, although in the case of the latter, it may be these are already partly included in estimates for literary originals. The difficulty when considering such asset types, for which less data are typically available, is that it is necessary to ensure that what is being counted is the production of assets rather than intermediate goods.

One method for estimating investment in this diverse group of assets is to estimate the input costs to their creation, using ASHE data on the earnings of relevant creative occupations. To account for other inputs to production, detailed industry data from the ABI can be used to generate a reasonable proxy for a factor, $\gamma$ in (7). However, even with this information from ASHE and the ABI, this remains a difficult category to estimate. The result might be an underestimate if the coverage of the survey is incomplete e.g. lack of coverage of the self-employed. It might be an overestimate if those reporting these professions are actually earning wages from some other occupation.

Table 2.6 below presents the list of occupations identified from ASHE that were considered to be involved in the creation of artistic originals not already counted elsewhere. Cartographers were excluded so as to avoid potential double counting.
### Table 2.6: Miscellaneous Artwork, occupations involved in asset creation

<table>
<thead>
<tr>
<th>Asset</th>
<th>SOC2000</th>
<th>Additional note:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Miscellaneous</strong></td>
<td>3411: Artists</td>
<td>Excluding those in: Film (92.1); TV &amp; Radio (92.2); Design (74.2 &amp; 74.872); Printing (22)</td>
</tr>
<tr>
<td></td>
<td>3414: Dancers and choreographers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3434: Photographers and audio-visual equipment operators</td>
<td></td>
</tr>
</tbody>
</table>

Note to table: All occupations used to calculate investment in all other intangible assets are excluded. Workers recorded in public sector dominated industries (Public Administration & Defence (L), Education (M) and Health (N)) are also excluded, so final estimates are reflective of the market sector.

ABI data on employment and non-employment costs are available for the following industries: ‘Photographic Activities’ (74.81), ‘Other Artistic and Literary Creation’ (92.139) and ‘Dance Halls and Dance Instructor Services’ (92.341). Although these industries do not provide an exact match for the activities we are looking to estimate, they should provide a reasonable proxy for overheads incurred in the creation of these assets. Using data for an aggregate of these industries over the period 1999 to 2007 gives an average estimate for $\gamma$ of 2.87.

As already discussed in the context of other assets, estimates of activity or production may not be representative of investment as some activity will represent production of short-lived consumption goods. Kretschmer, Bently et al. (2011) report on a survey of 5,500 visual artists earnings registered to the Design and Artists Copyright Society (DACS). Most of the sample consisted of artists, illustrators and photographers, with some designers, 87% of whom spent at least 50% of their time on visual creation, and 35% of whom had a second job. For some of the detailed questions, the response rates were very small, but one figure stands out: in 2009, economy wide median wages were £21,000, but earnings from artistic endeavour were £12,000 (page 43). Even for those reporting themselves as professional artists, only 50% of their total income was from their professional activity (page 51). Based on this information it was assumed that 50% of the earnings reported in ASHE are derived from the creation of long-lived artistic assets. Applying this factor to the data on wage-bills provides the results displayed in Figure 2.6.
Figure 2.6: GFCF in Miscellaneous Artwork, Nominal £mns

Source: ONS (ASHE, ABI)
Note to figure: Series estimated using data on earnings for relevant occupations, adjusted for additional overheads using data from the ABI. A time-use assumption of 50% was applied to try to account for investment activity rather than short-lived production and to exclude earnings that are potentially from other sources.

Prior to estimation the preferred approach for estimating investment in this asset category was to use data on royalty payments for their use, such as from DACS, thus avoiding a number of conceptual and practical difficulties. The use of data on royalties would mean that:
- by definition ‘valuables’ would be excluded, since they are non-productive assets that are held as stores of value and not used in the generation of final output. Royalties would only be paid for assets that are being actively used in production;
- by definition, all estimates of investment would be in assets that are protected by copyright;
- it would be possible to only include goods with a service life of longer than one year. Any good that generated royalties for less than one year could be excluded, thus removing the problem in distinguishing between the production of assets and consumption goods.

Theoretically it should be possible to generate valid estimates of GFCF in photography and artwork using data from the Design Artists Copyright Society (DACS) and the major photography libraries e.g. Corbis. Whilst it was intended to make use of such data, due to legal and data protection issues, the data were not available.

2.5.6. Summary of results

The following chart presents a snapshot of new estimates of investment in artistic originals and those recorded in the National Accounts for 2008, for the five asset categories and the final aggregate. Total investment in 2008 is estimated at £4.6bn, exceeding official estimates of £3.2bn. Investment in TV &
Radio is estimated at £2.2bn, lower than the official estimate of £2.8bn. However, as noted, official estimates for TV & Radio include an adjustment designed to account for additional revenues earned through the sale of advertising. Removing that element reduces the official figure for TV & Radio to £1.4bn in 2008, and reduces total investment in originals to just £1.8bn. New estimates for Film, Books and Music, particularly the latter, are all higher than the official numbers, due to new data and methods accounting for a broader range of production in the case of Film, and a broader range of revenues in the case of Books and Music. The new data also include estimates for investment in Miscellaneous Art, a category not currently included in official estimates.

Figure 2.7: Investment in Artistic Originals, 2008, Current Prices (£m)

Source: ONS estimates are from the National Accounts. For new estimates the sources are: i) Film, the-numbers.com, UK Film, Council, British Film Institute; ii) TV & Radio, OFCOM; iii) Books, Publishers Association; iv) Music, PRSforMusic; v) Misc Art, ONS, ASHE

Note to figure: All data are nominal and for 2008. Dark blue bars show new estimates and are compared to investment as measured by ONS and recorded in the National Accounts, represented with light blue bars. The latter are effected by an assumed mark-up for monopoly power in private sector broadcasting, highlighted with the stacked red contribution for ‘ONS TV & Radio’ and ‘ONS Total’.

2.6. Conclusions

The work described in this chapter attempts to contribute to the measurement of the UK creative sector and the creation of long-lived artistic original assets protected by copyright. Official data and methods for measuring investment in artistic originals were evaluated in light of the appropriate conceptual framework for measurement and international guidelines, and UK investment re-estimated using new data and improved methods. The main outputs are improved estimates of UK investment in artistic originals, with the data and methods incorporated into the National Accounts in a recent revision. Using the preferred method for each
asset type it is shown that in 2008, official UK data in the National Accounts under-estimated investment in originals by approximately £1.4bn.
Chapter 3: The price and productivity of UK investment in own-account software*

Peter Goodridge

ABSTRACT

Estimated at £22.6bn in 2009, UK market sector investment in software is almost as large as that in plant and machinery (£27.8bn excluding ICT) and almost twice as large as that in computer hardware and telecommunications equipment combined (£12.3bn). Of that £22.6bn, almost 60% (£13.5bn) is in own-account, or in-house, software creation. In recent years there has been considerable progress in the estimation of prices and volumes for hardware and purchased software, which has meant that technical progress in their production is better accounted for. However, the current measurement convention for own-account software is to assume zero or very low productivity growth in its creation. This chapter sets out a framework to: a) describe the current methodologies used in estimating own-account software price indices, and b) exploit the ubiquity of own-account software investment in the UK market sector to form a new price index that explicitly considers estimated technical progress in its creation. The result is an index that falls on average at a rate of -1.85% p.a. over the period 1970 to 2009, compared to an average rise of +6.5% in the official price index. Applying this new deflator has a significant impact on estimates of real investment and growth in the capital stock, and incorporating those new measures into a growth-accounting analysis more than doubles the contribution of software to UK growth in the last decade.

*The author is grateful for financial support from ESRC (Grant ES/I035781/1) and the NESTA Innovation Index project. Thanks are also due to Graeme Chamberlin of the OBR and John Appleton of ONS for providing data and documentation, and to Professor Jonathan Haskel for advice, supervision and helpful discussions. This work contains statistical data from ONS which is crown copyright and reproduced with the permission of the controller HMSO and Queen's Printer for Scotland. The use of ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. All errors are my own.
3.1. Introduction

Software, along with artistic originals, mineral exploration and soon scientific R&D, is one of the few categories of intangible assets currently capitalised in the System of National Accounts (SNA). Measured investment in software is comprised of three components: own-account, pre-packaged; and custom; where the latter two refer to purchased software.\(^{49}\) This chapter focuses on the first of these components, own-account software (OAS), that is, software written in-house by investing firms. Examples of such software could include risk analysis software written by banks, inventory control systems in manufacturing, databases for customer relationship management in retail (consider the software behind supermarket loyalty schemes for instance) or many other applications.\(^{50}\) In the UK and elsewhere, OAS investment is estimated by observing the labour input of occupations that write in-house software, with some adjustment for the proportion of their time spent writing it, and a further adjustment to account for other inputs in the production process.

In recent years, the majority of UK market sector software investment has been on that created in-house. In fact, UK investment in OAS has been estimated as greater than that in purchased software since 2002. Furthermore OAS investment made up as much as 11.2% of total UK market sector investment as defined by the SNA in 2009.\(^{51}\) Some means of accurately estimating the price of OAS investment is therefore a first order issue for national accountants and productivity analysts.

It has been remarked that the benefits of the new economy in terms of productivity are not so evident in the measured data. However, one potential reason for this is that real investment, capital services, and to a lesser extent final output and productivity, have all been growing faster than observed in the official statistics. In recent years there has been considerable improvement to the measurement of ICT prices. The use of hedonic and matched model techniques (see Triplett (1989) in the context of computer hardware; and Byrne and Corrado (2009) in the context of communications equipment) mean that measurement now better reflects increases in the quality, and therefore volume, of ICT investment. There has also been improvement in the measurement of the price and volume of pre-packaged software investments. The pre-packaged software price index used in both the UK and US National Accounts is the hedonically adjusted series developed by

\(^{49}\) Own-account production is likely to share similar characteristics with purchased custom software, with both being tailored to the use of the investing firm.

\(^{50}\) Own-account software investment can also incorporate renovations or modifications of existing pre-packaged software, but should exclude “repairs and maintenance” of existing software. In practice, the distinction between renovation and maintenance is likely to be somewhat blurred.

\(^{51}\) That is, when considering tangibles (buildings, plant & machinery including ICT, vehicles) and only software, artistic originals and mineral exploration as intangibles; and defining the market sector as in EU KLEMS as SIC03 sections A-K & O, excluding real estate. Note that this definition of the market sector differs slightly from that used by ONS, which excludes public delivery of some services in O (e.g. libraries, refuse collection etc.), and includes private delivery of public services such as education and health.
the Bureau of Economic Analysis (BEA) which exhibits a fast rate of decline of approximately -8.5% p.a. over the period 1970 to 2009.52

However, whilst the price of pre-packaged software can be observed from market transactions, and then adjusted to account for quality change, that of OAS outputs cannot. Instead it must be estimated. If it were possible to observe the real quantity of OAS output, then the price could be derived implicitly. But accurately observing the quantity would require the ability to identify each “unit” of software and observe changes in its quality. Instead, in both the UK and US, OAS asset price indices are estimated using data on the prices of inputs used in OAS production. In the US, the final price index is a share-weighted combination of the price of labour and materials used in OAS production. In the UK, only the price of labour is considered, with a small adjustment made to account for assumed changes in productivity, based on labour productivity growth in the service sector. Unsurprisingly, the result in both countries is a steadily rising index, primarily driven by growth in the reported wages of software writers.

It is worth noting that the estimated price of OAS also affects the measurement of purchased software. In both the UK and US, the price of purchased software is estimated as an average of the price indices for pre-packaged and own-account software, with the latter used as a proxy for custom software which is assumed to have price characteristics similar to OAS. In the US the price for purchased software is a weighted average, with the weights based on the proportion of purchased software that is custom and pre-packaged respectively. In the UK no information is available on these proportions, so the price indices for pre-packaged and custom are equally weighted.

However, if productivity growth in the creation of own-account and custom software has been in any way comparable to that implied by the price profile of pre-packaged software, current measurement practice may be severely overstating growth in software prices, and therefore severely understating growth in real software output, real software investment, software capital services and the contribution of software capital deepening to growth.

There are a number of reasons why productivity growth in OAS production may be considerably higher than assumed in the official UK method. First, the ONS productivity adjustment is based on labour productivity growth in the service sector. It might be expected that productivity growth in an innovative knowledge-based activity such as software creation would be higher than that in the wider service sector, where measured productivity growth is typically low. Second, since strong productivity gains in the production of pre-packaged software are observed from the rate of decline in its price index, then it would seem likely that

52 The UK Office for National Statistics (ONS) applies the BEA pre-packaged software price index with an adjustment for the sterling:dollar exchange rate. After the adjustment the rate of decline is on average -7.36% p.a. over the period 1970 to 2009.
there have also been productivity gains in the production of own-account (and custom) software. Why should the writers of pre-packaged software be getting considerably more productive but not the writers of own-account software? It would seem reasonable for productivity across software professionals, who likely move between roles of writing software for in-house use or for general sale, to be similar. Third, it seems intuitive that growth in the quality of hardware and the volume of its processing power, and the decline in its cost, would have had a beneficial impact on productivity in OAS creation. Fourth, one element of OAS investment is the renovation or customisation of pre-packaged software. Therefore as the quality of pre-packaged output improves, these improvements have the potential to benefit productivity in the own-account sector. Fifth, the increased production and availability of open source software would appear to offer the potential for significant productivity gains in the creation of software, via the pooling of expertise and expansion in the pool of knowledge freely available to writers and investors.

On open source software, Shaikh and Cornford (2011) discuss the potential benefits to organisations of open source software over proprietary, including: flexibility, both in terms of the software itself and the agility of the organisation; the ability to “tweak and customise”; lower costs of maintenance; and the ability to collaborate. These are all features, quoted by users of open source software in surveys and interviews undertaken by Shaikh and Cornford, which appear to have potential benefits, in terms of ability to innovate and productivity, for the development of software in-house and its use. The ability to: access and modify code with lower costs of upgrading; customise software to business needs; experiment and innovate; are all potential sources of productivity gain in the creation of OAS. The reduced degree of “lock-in” and lower exit costs, compared to proprietary software, are other cited features of open source that can enhance organisational agility and assist innovation.

Conversely, it could be argued that if OAS output is more difficult to produce due to its tailored, customised nature, then productivity growth in OAS creation may have been slower than in standard pre-packaged software production. However, it is also possible to argue that, even if OAS projects are more difficult and slower to generate output, the produced output is of a higher real volume since it offers higher potential for productivity gains from use. That is, if we could observe a “standard unit” of software (say Q=1, where Q denotes the real quantity), then if the OAS output is customised, tailored and has a greater marginal product (say Q=1.5), then this additional volume of real software output ought to be reflected in the OAS price index.

Since the majority of UK software investment is in the form of own-account, and because the own-account price index also feeds into the purchased price index, the implicit assumption in the official UK methodology is that the majority of software production experiences very little growth in productivity. This would appear unrealistic to many users of software, which undergoes continuous improvements to functionality and speed. Potential sources for productivity gains in production include those mentioned above plus improvements in the functionality of operating systems; improvements in software “languages”; and improved
communications technology and the internet increasing opportunities for the sharing of information and collaboration. It has also been said that due to algorithmic improvements, software feature verification is subject to a Moore-like curve, with a problem that used to take seven days now being done in seven seconds (Jorgenson and Wessner 2002). Furthermore, improvements in software have also transformed activities such as scientific research in biology and pharmaceuticals, and allowed the production and analysis of databases that add value to consumer sales and allow firms to better manage relationships with customers (think of supermarket loyalty schemes for example). Many of these applications are developed on own-account, to maintain proprietary rights and appropriate additional revenues in commercial exploitation of the asset.

The aim of this chapter is to construct a new price index for UK OAS that explicitly considers productivity growth in UK OAS creation. The results of this exercise suggest that the price of own-account software has actually been falling at a rate of -1.85% p.a. over the period 1970 to 2009. During the era that the internet has been widely used (post-1995), it has fallen at a significantly faster rate of -5.95% p.a.. This compares to growth of +6.5% p.a. and +2% p.a. in the official UK deflator over the same respective periods. As a result the total contribution of software capital deepening to UK labour productivity growth in 2005-09 is 0.31% p.a., more than double the 0.13% p.a. estimated using the official ONS deflators. Note that these contributions refer to all types of software, as since the deflator for purchased software also incorporates the own-account price index in order to account for custom software, the contribution of purchased software is also affected.

This chapter proceeds as follows. Section two discusses the official UK and US approaches to measurement in the national accounts. Section three presents the theoretical framework used in the estimation, highlighting potential issues with the official method. Section four discusses the data, measurement, and associated issues. Sections five and six present results and discuss the practical implications of the newly estimated price index. Section seven concludes.

3.2. Current UK and US official practice

In estimating a price index for own-account software, both the UK and US statistical agencies base their estimate on the prices of inputs in OAS production. In both countries the OAS price index also feeds into the deflator for purchased software. Purchased software includes both pre-packaged and custom software, so the OAS index is also assumed to apply to custom.

In the US, the custom price index is estimated as a weighted average of the pre-packaged index and the own-account index, where the weights are 0.25 and 0.75 respectively (Moylan 2001). The US custom and pre-

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53 In a Report of the Workshop on “Measuring and Sustaining the New Economy” (Jorgenson and Wessner, 2002), Dr Aho notes the degree of collaboration between Application Service Providers in providing “suites of services”.
packaged indices are then weighted together to form the purchased index, with the weights being the respective shares of investment. In the UK, no information is available on the proportions of purchased software investments that are in pre-packaged and custom respectively, so in practice the purchased price index is an average of the pre-packaged and own-account indices, with a weight of 0.5 applied to each. In both countries the pre-packaged price index is the hedonically adjusted series developed by the BEA, adjusted for the dollar:sterling exchange rate in the case of the UK. The own-account software price index therefore effects the measurement of both real purchased software and real own-account software.

In the US, investment in OAS is estimated as follows, with investment a sum of the inputs payments to labour and materials in OAS production:

\[ P^N N^{OAS,US} = P^L L^N + P^M M^N \]  \hspace{1cm} (1)

Where N denotes OAS output, L^N OAS labour input, M^N OAS intermediate inputs and P their respective prices. The US OAS price index is therefore constructed as a share weighted average of the prices for labour and material inputs:

\[ \Delta \ln P^{N,US} = s_L^N \Delta \ln P^{L,N} + s_M^N \Delta \ln P^{M,N} \]  \hspace{1cm} (2)

Where the weights (s_L^N and s_M^N) are informed from data on the payments for labour and materials in OAS production and by definition sum to one. Due to an absence of information on productivity in the creation of own-account software, there is no adjustment for productivity, or rather it is assumed that productivity growth in OAS production is zero (Moylan 2001).

In the UK, OAS investment is estimated as follows:\textsuperscript{54}:

\[ P^N N^{UK,OAS} = \lambda P^L L^N \]
\[ = P^L L^N + P^M M^N + \delta^{K,N} P^K K^N \]  \hspace{1cm} (3)

Where payments to software writers are first adjusted for the time they spend producing assets, giving an estimate of \( P^L L^N \), and then adjusted by a factor (\( \lambda \)) to account for payments to other upstream inputs, namely materials (\( P^M M^N \)) and the depreciation of capital (\( \delta^{K,N} P^K K^N \)).\textsuperscript{55}

\textsuperscript{54} This refers to ONS practice at the time of writing. Since then the ONS have revised the methodology and estimates of OAS investment are increased by a further 15% to account for operating surplus in OAS production.

\textsuperscript{55} ONS estimate the input of capital using a nominal estimate of depreciation. Therefore it can be expressed as the depreciation rate multiplied by the nominal value of the stock.
In the UK, the OAS deflator is constructed as:

\[
\Delta \ln P^{N,UK} = \Delta \ln P^{L,N} - \Delta \ln \left( \frac{Y}{H} \right)^{SERVICES}
\] (4)

Where the second term on the right-hand side is labour productivity growth in the service sector. Therefore in the UK, estimated changes in the price of own-account software are based on the changes in the reported wages of software writers, with an adjustment to account for assumed changes in labour productivity.

3.3. Theoretical Framework

This section presents the appropriate theoretical framework to model the production of own-account software, and which will be applied to estimating the price of UK OAS in the following sections. It is argued that the results it generates provide a more accurate picture of UK own-account software prices than the current official method, and that they are internally consistent with wider measures of output, productivity and the national accounts. The framework also highlights potential issues with the official measurement approach described in the previous section.

3.3.1. The upstream-downstream model

Consider an economy with three factors of production (labour, tangible capital and knowledge capital) and two broad sectors: an innovation sector and a final output sector. The innovation sector, hereafter referred to as the upstream, produces knowledge assets. In this chapter the knowledge asset considered is own-account software, but the model could be applied to any other form of knowledge capital used in final production.\(^5\)

The final output sector, hereafter referred to as the downstream, uses knowledge assets in the production of final output, which can be either tangible capital or consumption goods. In this application, upstream activity is located in the same firm/industry (as classified by the Standard Industrial Classification (SIC)) as the downstream, but is modelled as in a different sector: for instance a retailer that also produces in-house software for say, the management of inventories and relationships with customers/suppliers.

The upstream produces new knowledge output (here, own-account software), \(N\), using labour (\(L^N\)), tangible capital (\(K^N\)), intermediate goods (\(M^N\)) and “basic”, or freely available, knowledge (\(R^N\)). Since the upstream consists of monopoly producers of unique assets then, as in Romer (1991), it earns an additional mark-up (\(\mu\)) over its costs of production. The production function and accounting identities for the upstream can be written as:

\(^5\)Corrado, Goodridge and Haskel (2011) apply an extension to the model to estimating annual price changes in UK market sector R&D. The previous chapter applied the model to estimation of UK investment in artistic originals.
\( N_t = F^N \left( I_t^N, K_t^N, M_t^N, R_t^N, t \right) \)
\( P_t^N N_t = \mu \left( P_t^L I_t^N + P_t^K K_t^N + P_t^M M_t^N \right) \)  \( (5) \)

Where \( P^N \) is the price of finished or commercialised OAS, and \( P^L, P^K \) and \( P^M \) are the respective prices of labour, tangible capital and materials, per unit of input, in the upstream. Since \( R^N \) is assumed to be freely available it earns no factor payments. Accumulation of the stock of tangible capital used in the upstream sector can be represented using a perpetual inventory model (PIM):

\[ K_t^N = I_t^N + \left( 1 - \delta^{K,N} \right) K_{t-1}^N \]  \( (6) \)

Where \( K^N \) is the real stock of tangible capital used in upstream production, \( I^N \) is real investment in upstream tangible capital and \( \delta^{K,N} \) is a geometric rate of deterioration. \( \delta^{K,N} \) is of course effectively a weighted average of rates for individual asset, which will depend on the composition of the upstream tangible stock. Ignoring taxes and capital gains, the rental price of capital (\( P^K \)) and the asset price (\( P^I \)) are related as:

\[ P_t^K = P_t^I \left( \rho + \delta^{K,N} \right) \]  \( (7) \)

Where \( \rho \) is the net rate of return to capital (effectively a profit rate) and \( \delta^{K,N} \) a geometric rate of depreciation\(^{57} \). Assuming \( \rho \) and \( \delta^{K,N} \) are approximately constant, the rental price is approximately a constant proportion of the asset price, and in that case changes in the rental price will closely correspond to changes in the asset price. The implication is that if the primary item of tangible capital employed in the upstream is ICT equipment, the price falls of which are well-documented in the productivity literature, the rental price of tangible capital used in the upstream will also have been falling at a rapid rate.

Corresponding equations for the downstream complete the model. The downstream, or knowledge-using, sector, uses own-account software in the production of final goods. Downstream inputs can be denoted as \( L^Y \) (labour), \( K^Y \) (tangible capital), \( R^Y \) (knowledge capital) and \( M^Y \) (intermediates), with prices \( P^L, P^K, P^R \) and \( P^M \) respectively. \( Y \) are real units of final output and \( P^Y \) their price. \( R^Y \) is the stock of own-account software accumulated from upstream output, \( N \). Note the distinction here between \( R^Y \), the commercialised knowledge (own-account software) used in downstream production, and \( R^N \), the basic (freely available) knowledge used in upstream production. The downstream production function and accounting identity can be written as:

\(^{57}\text{As set out in the theoretical framework in Chapter 1, in the case of geometric rates, the rates of depreciation and deterioration are equivalent.}\)
\[ Y_i = F^Y (L_i^Y, K_i^Y, R_i^Y, M_i^Y, t) \]
\[ P^Y Y_i = P^Y L_i^Y + P^Y K_i^Y + P^R R_i^Y + P^M M_i^Y \]

(8)

Upstream output accumulates into a stock, with that stock used in the production of downstream output. That accumulation can also be represented using a perpetual inventory model (PIM):

\[ R_i^Y = N_i + (1 - \delta^{R,Y}) N_{i-1} \]

(9)

In this chapter the aim is to estimate changes in the implicit price of OAS. The upstream income identity can be used to better understand how the price of own-account software is related to the prices of upstream inputs and sectoral technical progress. Taking natural logs of the income flows and differentiating with respect to time yields the following price dual:

\[ \Delta \ln P^N_i = \bar{\delta}_i^{L,N} \Delta \ln P^{L,N}_i + \bar{\delta}_i^{K,N} \Delta \ln P^{K,N}_i + \bar{\delta}_i^{M,N} \Delta \ln P^{M,N}_i - \Delta \ln TFP_i^N \]

(10)

Where \( \bar{\delta}_i^{L,N} \), \( \bar{\delta}_i^{K,N} \), \( \bar{\delta}_i^{M,N} \) are Tornqvist shares of upstream gross output.

\[ \bar{\delta}_i^{X,N} = \frac{\left( \frac{P^X X_{i-1}^N}{P^N N_i} + \frac{P^X X_i^N}{P^N N_{i-1}} \right)}{2}, X = L, K, M \]

(11)

Comparing (10) with (4) reveals the potential issues with current UK measurement practice. First, although accounted for in measured OAS investment, the official price index in (4) does not consider the price of upstream intermediate inputs. Second, again although measured investment accounts for the use of capital in the upstream, the official price index does not consider the contribution of capital prices to upstream output prices. If it is thought that the predominant item of upstream capital is hardware, and given that the price of hardware has fallen rapidly, this omission is potentially significant. Third, it can also be seen that the official price index incorporates the incorrect productivity term. Instead of an estimate of \( \Delta \ln \text{TFP}^N_i \), it incorporates a term for service sector labour productivity growth. For a number of reasons, growth in measured output and therefore labour productivity tends to be low in the service sector. This term therefore

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\(^{58}\) As will be discussed later, actually the UK method for measuring OAS investment only partly accounts for the use of capital, as it only accounts for depreciation. Conceptually it should also account for the net rate of return on capital, or the profit rate.

\(^{59}\) Including difficulties in measuring output itself and also difficulties in identifying where there has been an increase in the quality or volume of service output.
potentially understates the true rate of technical change in the knowledge-intensive activity that is software creation.

As has already been noted, it is assumed that the knowledge employed in the upstream is basic knowledge, assumed freely available and determined outside the model, and that it is therefore different in nature to that produced in the upstream and used in the downstream. Therefore there is no term in (10) for the use of own-account software in the upstream. Although in reality the stock of own-account software may be used in the creation of new own-account software, introducing a term for it in (10) would introduce a circularity, where information on the rental price of OAS would be required to estimate the asset price. Another way of viewing the distinction between basic and commercialised knowledge is that the knowledge used in the upstream is some underlying platform, whilst that employed in the downstream are versions of knowledge: MS Word1997, MS Word2003 etc., as also discussed in Corrado, Goodridge and Haskel (2011).

Growth in basic knowledge (in the context of software) is therefore part of growth in upstream technical progress, $\Delta \ln TFP^N$. A non-exhaustive list of drivers of upstream TFP includes: knowledge generated in universities; the quality of training for software programmers; spillovers from knowledge embedded in software written by other programmers; spillovers from knowledge embedded in software writers that transition between firms or industries; dissemination of open-source software etc..

From (10) it can be seen that $\Delta \ln TFP^N$ is one of the determinants of changes in the OAS asset price. But since the upstream resides in-house, within the firms and industries that use its output, and as its output is not sold on the market, $\Delta \ln TFP^N$ cannot be observed in the measured data. However, from work by the BEA and others (for example, Brynjolfsson and Kemerer (1996) and Gandal (1994)) it is known that productivity growth in the production of pre-packaged software has been very rapid indeed. Further support for this is provided on the website softwaremetrics.com which shows that the number of software titles has been increasing at a rate equalling the falling rate of the cost of hardware.\(^60\) Given this, surely it is reasonable to consider that productivity in OAS creation may also have been growing rapidly.

3.3.2. Deriving an estimate of upstream TFP

Implementation of (10) therefore requires an estimate of $\Delta \ln TFP^N$. The following sub-section considers the identities in the measured data and shows how that data can be used to derive an estimate for upstream

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\( \Delta \ln TFP \). In what follows, ' denotes the measured terms, and * the true. Where terms are marked neither ' or *, then the measured conforms to the true.

a) Measurement of aggregate output

First, consider aggregate gross output, with real and nominal aggregate gross output labelled \( Q \) and \( P_0Q \) respectively. Since expenditures on own-account software are already capitalised in national accounting measurement, measured nominal gross output (\( P_0Q' \)) is a sum of measured output in the upstream and downstream:

\[
P_0Q' = P'_kK + P'_L + P'_MM + P'_K'y + P'_L'y + P'_M'M' + P'^{OAS}R'^{OAS,y}
\]

\[= P'^{OAS}N'^{OAS} + P'_Y
\] (12)

The two terms in (12) are as follows. The first term is measured OAS output, where the ' on \( P'^{OAS}N'^{OAS} \) distinguishes it from the “true” term in (5). That is, as measured, OAS output does not incorporate the producer mark-up (\( \mu \)). Instead measured upstream output is estimated as:

\[
P'^{OAS}N'^{OAS} = P'_kK^{OAS} + P'_L^{OAS} + P'_M^{OAS}
\] (13)

The second term covers the remainder of market sector output, produced in the downstream, where the input payments include those for the use of the OAS stock, accumulated from upstream output:

\[
P'_Y = P'_kK'^{y} + P'_L'^{y} + P'_M'^{y} + P'^{OAS}R'^{OAS,y}
\] (14)

The objective is to use observed terms in the measured data to derive an estimate of \( \Delta \ln TFP \) in the OAS sector. This is done as follows. First, from the definition of \( \Delta \ln TFP \) which is derived residually, measured real output growth in each sector is:

\[
\Delta \ln N'^{OAS} = \frac{P'_kK^{OAS}}{P'^{OAS}N'^{OAS'}}\Delta \ln K^{OAS} + \frac{P'_L^{OAS}}{P'^{OAS}N'^{OAS'}}\Delta \ln L^{OAS} + \frac{P'_M^{OAS}}{P'^{OAS}N'^{OAS'}}\Delta \ln M^{OAS} + \Delta \ln TFP'^{OAS}
\] (15)

\[
\Delta \ln Y = \frac{P'_kK'^{y}}{P'_Y}\Delta \ln K'^{y} + \frac{P'_L'^{y}}{P'_Y}\Delta \ln L'^{y} + \frac{P'_M'^{y}}{P'_Y}\Delta \ln M'^{y} + \frac{P'^{OAS}R'^{OAS,y}}{P'_Y}\Delta \ln R'^{OAS,y} + \Delta \ln TFP'^{y}
\] (16)
Note that, where appropriate, terms in the upstream are denoted by ‘ to distinguish them from the true model. Elements of the downstream are also marked as ‘ because the contribution of OAS in the measured data is affected by the use of the current official price index, thus also affecting implied downstream ΔlnTFP. Since capital compensation is derived residually, implied estimates of $P_kK^y$ are also affected.

By definition, measured growth in real aggregate gross output (ΔlnQ’) is equivalent to a weighted sum of real gross output growth in the upstream and downstream sectors, where the weights are the shares of nominal sector output in gross output:

$$\Delta \ln Q’ = \frac{P_N^{OAS}N^{OAS}}{P_0Q’} \Delta \ln N^{OAS} + \frac{P_Y}{P_0Q’} \Delta \ln Y$$

(17)

Substituting (15) and (16) into (17) gives:

$$\Delta \ln Q’ = \left( \frac{P_N^{OAS}N^{OAS}}{P_0Q’} \left( \frac{P_NK^{OAS}}{P_N^{OAS}N^{OAS}} \Delta \ln K^{OAS} + \frac{P_L^{OAS}}{P_N^{OAS}N^{OAS}} \Delta \ln L^{OAS} + \frac{P_M^{OAS}}{P_N^{OAS}N^{OAS}} \Delta \ln M^{OAS} + \Delta \ln TFP^{OAS} \right) \right) + \frac{P_Y}{P_0Q’} \left( \frac{P_NK^{OAS}K^{OAS}}{P_Y} \Delta \ln K^{OAS} + \frac{P_LL^{OAS}}{P_Y} \Delta \ln L^{OAS} + \frac{P_MM^{OAS}}{P_Y} \Delta \ln M^{OAS} + \frac{P_R^{OAS}R^{OAS,Y'}}{P_Y} \Delta \ln R^{OAS,Y'} + \Delta \ln TFP^{OAS} \right)$$

(18)

Multiplying through the factor and sector shares, inside and outside the parentheses respectively, then (18) reduces to:

$$\Delta \ln Q’ = \frac{P_NK^{OAS}}{P_0Q’} \Delta \ln K^{OAS} + \frac{P_LL^{OAS}}{P_0Q’} \Delta \ln L^{OAS} + \frac{P_MM^{OAS}N^{OAS}}{P_0Q’} \Delta \ln M^{OAS} + \frac{P_R^{OAS}R^{OAS,Y'}}{P_0Q’} \Delta \ln TFP^{OAS} + $$

(19)

$$\frac{P_NK^{OAS}}{P_0Q’} \Delta \ln K^{OAS} + \frac{P_LL^{OAS}}{P_0Q’} \Delta \ln L^{OAS} + \frac{P_MM^{OAS}}{P_0Q’} \Delta \ln M^{OAS} + \frac{P_R^{OAS}R^{OAS,Y'}}{P_0Q’} \Delta \ln R^{OAS,Y'} + \frac{P_Y}{P_0Q’} \Delta \ln TFP^{OAS}$$

Now moving terms for the factor inputs to the left-hand side:
\[
\Delta \ln \hat{Q} - \frac{P_k K^{\prime}}{P_0 Q'} \Delta \ln K^Y - \frac{P_L L^Y}{P_0 Q'} \Delta \ln L^Y - \frac{P_M M^Y}{P_0 Q'} \Delta \ln M^Y - \frac{P^{OAS} R^{OAS,\prime}}{P_0 Q'} \Delta \ln R^{OAS,\prime} \\
- \frac{P^OAS K^{OAS}}{P_0 Q'} \Delta \ln K^{OAS} - \frac{P^OAS L^{OAS}}{P_0 Q'} \Delta \ln L^{OAS} - \frac{P^OAS M^{OAS}}{P_0 Q'} \Delta \ln M^{OAS} \\
= \frac{P^Y}{P_0 Q'} \Delta \ln TFP^{\prime \prime} + \frac{P^{OAS N^{OAS}}}{P_0 Q'} \Delta \ln TFP^{OAS} \tag{20}
\]

From the measured data, \( \Delta \ln \text{TFP} \) at the aggregate level can be estimated as follows, which corresponds to the left-hand side in (20):

\[
\Delta \ln \text{TFP}^{\prime \prime} = \Delta \ln \hat{Q} - \frac{P_k K^{\prime}}{P_0 Q'} \Delta \ln K^Y - \frac{P_L L^Y}{P_0 Q'} \Delta \ln L^Y - \frac{P_M M^Y}{P_0 Q'} \Delta \ln M^Y - \frac{P^{OAS} R^{OAS,\prime}}{P_0 Q'} \Delta \ln R^{OAS,\prime} \\
- \frac{P^OAS K^{OAS}}{P_0 Q'} \Delta \ln K^{OAS} - \frac{P^OAS L^{OAS}}{P_0 Q'} \Delta \ln L^{OAS} - \frac{P^OAS M^{OAS}}{P_0 Q'} \Delta \ln M^{OAS} \tag{21}
\]

Therefore measured \( \Delta \ln \text{TFP} \) can also be expressed as a weighted sum of \( \Delta \ln \text{TFP} \) in the downstream and upstream sectors, where the weights are the shares of sectoral gross output in total gross output:

\[
\Delta \ln \text{TFP}^{\prime \prime} = \frac{P^Y}{P_0 Q'} \Delta \ln TFP^{\prime \prime} + \frac{P^{OAS N^{OAS}}}{P_0 Q'} \Delta \ln TFP^{OAS} \tag{22}
\]

The terms \( \Delta \ln \text{TFP}^{OAS} \) and \( \frac{P^{OAS N^{OAS}}}{P_0 Q'} \) can be observed from the measured data. The first is simply labour productivity growth in the service sector, which the ONS implicitly use as a proxy for \( \Delta \ln \text{TFP}^{OAS} \). The second is measured OAS investment as a share of measured aggregate gross output. Therefore the second term on the right-hand side of (22) can in principle be estimated.

But ideally we are seeking a true measure of upstream \( \Delta \ln \text{TFP} \), \( \Delta \ln \text{TFP}^{OAS} \). The two reasons why the measured differs from the true are as follows. First, true upstream output incorporates the mark-up (\( \mu \)), which is not present in the measured data, or rather the measured data assumes that \( \mu=1 \). \(^6^1\) Second, measured aggregate TFP (\( \Delta \ln \text{TFP}^{\prime \prime} \) as in (21)) and implied measured downstream TFP (\( \Delta \ln \text{TFP}^{\prime \prime} \)) are estimated

\(^6^1\) This refers to the data used and the situation at time of writing. Since then the ONS have introduced a mark-up of 1.15 to estimates of investment in own-account software. It is not fully clear whether this mark-up ought to conceptually be considered an estimate of \( \mu \), or an attempt to improve the estimate of \( P^OAS K^{OAS} \), that is, capital input to OAS production.
accounting for the contribution of own-account software. But construction of the OAS stock requires using the existing investment deflator, and it has so far been argued that the official price index does not correctly or adequately account for productivity growth in the OAS sector. From the user cost relation in (7), the measured income share for OAS is also affected by the use of the existing deflator:

\[ P_r^{OAS,Y} = P'^Y (\rho + \delta^R - \pi')R' \]  

(23)

Where \( P'^Y \) is the existing OAS deflator and \( \pi' \) is a term to account for any capital gains/losses incurred in the holding of OAS, estimated using the changes in \( P'^Y \).

Therefore some way is needed of relating the measured data to the true model. This is done in the following sub-section by considering the first term on the right-hand side of (22), which is \( \Delta \ln TFP'^Y \) as implied by the measured data, and its associated weight.

b) Downstream \( \Delta \ln TFP \) (\( \Delta \ln TFP'^Y \))

Measured aggregate TFP (\( \Delta \ln TFP'^Y \)) and downstream TFP as implied by the measured data (\( \Delta \ln TFP'^Y \)), account for the contribution of the OAS stock in the production of downstream output. That is in the measured data:

\[ \Delta \ln TFP'^Y = \Delta \ln Y - \frac{P\Delta K^Y}{P Y} \Delta \ln K^Y - \frac{P\Delta L^Y}{P Y} \Delta \ln L^Y - \frac{P\Delta M^Y}{P Y} \Delta \ln M^Y - \frac{P^{OAS} R^{OAS,Y}}{P Y} \Delta \ln R^{OAS,Y} \]  

(24)

But in the true model:

\[ \Delta \ln TFP'^* = \Delta \ln Y - \frac{P\Delta K^Y *}{P Y} \Delta \ln K^Y - \frac{P\Delta L^Y}{P Y} \Delta \ln L^Y - \frac{P\Delta M^Y}{P Y} \Delta \ln M^Y - \frac{P^{OAS} R^{OAS,Y} *}{P Y} \Delta \ln R^{OAS,Y} * \]  

(25)

The main source of difference between the measured and the true is that in the measured data the OAS stock (\( R^{OAS,Y} \)) has been constructed using the official OAS price index, \( P'^Y \), so \( \Delta \ln TFP'^Y \) differs from its true counterpart. Also, as shown in (23), since OAS capital compensation (\( P^{OAS} R^{OAS,Y} \)) has also been constructed using the mismeasured \( R^{OAS,Y} \) and the mismeasured \( P'^Y \), that also differs from its true counterpart. Subtracting (24) from (25):
\[ \Delta \ln TFP^Y - \Delta \ln TFP^Y = \left( \frac{P_K K^Y}{P_Y} - \frac{P_K K^Y}{P_Y} \right) \Delta \ln K^Y - \left( \frac{P_O^{OAS} R^{OAS,Y}}{P_Y} - \frac{P_O^{OAS} R^{OAS,Y}}{P_Y} \right) \Delta \ln R^{OAS,Y} \]

(26)

The first term on the right-hand side of (26) is the mismeasurement in the contribution of non-OAS capital, due to a difference between the measured income share and the true share. However, the non-OAS capital stock is the same in the measured and true models so that is unaffected. Therefore assuming the mismeasurement in the contribution of non-OAS capital is small, then true downstream TFP, \( \Delta \ln TFP^Y \), is approximately equal to measured downstream TFP, \( \Delta \ln TFP^Y \), less any additional contribution from OAS capital services not accounted for in the measured contribution:

\[ \Delta \ln TFP^Y \approx \Delta \ln TFP^Y - \left( \frac{P_O^{OAS} R^{OAS,Y}}{P_Y} \Delta \ln R^{OAS,Y} - \frac{P_O^{OAS} R^{OAS,Y}}{P_Y} \Delta \ln R^{OAS,Y} \right) \]

(27)

Re-arranging (27) gives an additional term that can be incorporated into (22), giving:

\[ \Delta \ln TFP^Y = \frac{P_Y}{P_Q} \left( \Delta \ln TFP^Y + \frac{P_O^{OAS} R^{OAS,Y}}{P_Y} \Delta \ln R^{OAS,Y} - \frac{P_O^{OAS} R^{OAS,Y}}{P_Y} \Delta \ln R^{OAS,Y} \right) + \frac{P_O^{OAS} N^{OAS'}}{P_Q} \Delta \ln TFP^{OAS'} \]

(28)

And therefore simplifying to:

\[ \Delta \ln TFP^Y = \frac{P_Y}{P_Q} \Delta \ln TFP^Y + \left( \frac{P_O^{OAS} R^{OAS,Y}}{P_Q} \Delta \ln R^{OAS,Y} - \frac{P_O^{OAS} R^{OAS,Y}}{P_Q} \Delta \ln R^{OAS,Y} \right) + \frac{P_O^{OAS} N^{OAS'}}{P_Q} \Delta \ln TFP^{OAS'} \]

(29)

Equation (29) includes terms for the OAS income share, \( P_O^{OAS} R^{OAS,Y} \), which is related to OAS investment, \( P_O^{OAS} N^{OAS} \). Following Corrado, Goodridge and Haskel (2011), who in turn follow Griliches (1980), the following expression was derived in Chapter 2:
where $\rho$ is the net rate of return, $\delta^{\text{R,OAS}}$ is the depreciation rate for OAS and $g^{N,OAS}$ is the growth rate in real OAS investment (and the accumulated stock). As $g^{N,OAS}$ approaches $\rho$, $\tau$ approaches one and OAS capital income therefore approaches OAS investment (Jorgenson 1966). Since the difference between true and measured OAS investment is the factor $\mu^{\text{OAS}}$, then it follows that $\mu^{\text{OAS}}$ is also the difference between true OAS capital compensation and measured, that is:

$$P^\text{OAS}_N N^{\text{OAS}} = \mu^{\text{OAS}} P^\text{OAS}_N N^{\text{OAS}}$$

(31)

Now we need to consider the difference between $\Delta \ln P^{\text{OAS},Y}$ and $\Delta \ln P^{\text{OAS},Y'}$. The change in the real stock can be written as the change in the nominal stock less the change in the asset price:

$$\Delta \ln P^{\text{OAS},Y} = \Delta \ln P^{\text{OAS},Y}_N - \Delta \ln P^{\text{OAS}}_N$$

(32)

If $\mu^{\text{OAS}}$ is a constant, the change in the nominal (or “wealth”) stock is the same in the measured and true data. Therefore:

$$\Delta \ln P^{\text{OAS},Y} - \Delta \ln P^{\text{OAS},Y'} = \left( \Delta \ln P^{\text{OAS},Y}_N - \Delta \ln P^{\text{OAS}}_N \right) - \left( \Delta \ln P^{\text{OAS},Y}_N - \Delta \ln P^{\text{OAS}}_N \right)$$

(33)

Combining (31) and (33), the difference between the measured OAS contribution and the true contribution, the second term on the right-hand side of (29), is approximately equal to the following:

$$\left( \frac{P^{R,\text{OAS},Y} N^{\text{OAS}}}{P^{Q}} - \Delta \ln R^{\text{OAS},Y} - \Delta \ln R^{\text{OAS},Y'} \right) = \frac{P^{R,\text{OAS},Y'} N^{\text{OAS}}}{P^{Q}} \left( \mu^{\text{OAS}} \Delta \ln P^{\text{OAS}}_N - \Delta \ln P^{\text{OAS}}_N \right)$$

(34)
That is it is equal to the difference between the price change in the measured and true model, with some additional terms for the mark-up and the measured factor income share. The measured OAS price index and the true OAS price index can be written as in (35) and (36) respectively:

\[
\Delta \ln P_{N}^{OAS} = P_{N}^{L,N} - \Delta \ln TFP_{OAS}^{'}
\]

\[
\Delta \ln P_{N}^{OAS *} = \bar{s}_{N}^{L,N} \Delta \ln P_{N}^{L,N} + \bar{s}_{N}^{K,N} \Delta \ln P_{N}^{K,N} + \bar{s}_{N}^{M,N} \Delta \ln P_{N}^{M,N} - \Delta \ln TFP_{OAS}^{*}
\]

Where \(\bar{s}_{N}^{L,N}, \bar{s}_{N}^{K,N}, \bar{s}_{N}^{M,N}\) are Tornqvist shares of upstream gross output, as defined in (11).

From the discussion so far we know that the difference between the measured OAS price index and the true price index can be approximated by the difference between \(\Delta \ln TFP_{OAS}^{'}\) and \(\Delta \ln TFP_{OAS}^{*}\).\(^{62}\) Therefore assuming that:

\[
\Delta \ln P_{N}^{L,N} \approx \bar{s}_{N}^{L,N} \Delta \ln P_{N}^{L,N} + \bar{s}_{N}^{K,N} \Delta \ln P_{N}^{K,N} + \bar{s}_{N}^{M,N} \Delta \ln P_{N}^{M,N}
\]

Then we can write:

\[
\Delta \ln P_{N}^{OAS} - \Delta \ln P_{N}^{OAS *} = -\Delta \ln TFP_{OAS}^{'} + (-\Delta \ln TFP_{OAS}^{*})
\]

\[
= \Delta \ln TFP_{OAS}^{*} - \Delta \ln TFP_{OAS}^{'}
\]

Using (34) and (38), (29) can be re-written as:

\[
\Delta \ln TFP_{Q'}^{R} = \frac{P_{Q}^{R}}{P_{Q}^{Q'}} \Delta \ln TFP_{Q'}^{R} + \frac{P_{Q}^{R}}{P_{Q}^{Q'}} \left( \mu_{OAS}^{'} \ln TFP_{OAS}^{*} - \Delta \ln TFP_{OAS}^{'} \right) + \frac{P_{N}^{OAS}}{P_{Q}^{Q'}} \Delta \ln TFP_{OAS}^{'}
\]

(39)

Now using the term \(\tau\) from equation (30), we can write:

\[
\Delta \ln TFP_{Q'}^{R} = \frac{P_{Q}^{R}}{P_{Q}^{Q'}} \Delta \ln TFP_{Q'}^{R} + \tau \frac{P_{N}^{OAS}}{P_{Q}^{Q'}} N_{OAS}^{*} \left( \mu_{OAS}^{'} \ln TFP_{OAS}^{*} - \Delta \ln TFP_{OAS}^{'} \right) + \frac{P_{N}^{OAS}}{P_{Q}^{Q'}} \Delta \ln TFP_{OAS}^{'}
\]

(40)

\(^{62}\) Recall that \(\Delta \ln TFP_{OAS}^{*}\) in the ONS methodology is the rate of labour productivity growth in the service sector.
Which in turn can be re-written as:

$$\Delta \ln TFP^{O^*} = \frac{P_Y}{P_O^Q} \Delta \ln TFP^{Y^*} + \mu^{OAS} \frac{P_N^{OAS} N^{OAS'}}{P^{OAS'} Q'} \Delta \ln TFP^{OAS^*} + (1 - \tau) \frac{P_N^{OAS} N^{OAS'}}{P^{OAS'} Q'} \Delta \ln TFP^{OAS^*}$$

(41)

In maximal consumption golden-rule steady-state, $\tau$ is equal to one. Deriving an estimate of $\tau$ would require information on the growth of real investment, which would in turn require the appropriate price index which we do not yet have. However we do possess information on the growth of nominal investment. Over the whole dataset (1970 to 2009) and at the market sector level, growth in nominal OAS investment is 14.8% p.a.. Over the earlier years (1970 to 1980) it is 25.2% p.a., falling to 19.3% p.a. in 1980 to 1990, 7.6% p.a. in 1990 to 2000 and to 6.7% p.a. in 2000 to 2009. Assuming a net rate of return ($\rho$) of 0.1 and applying an estimate of $g^N = 14.8\%$ results in an estimate of $\tau = 1.02$. Applying the alternative investment growth rates of 25.2% p.a. and 6.7% p.a. yields estimates of $\tau = 0.91$ and $\tau = 1.16$ respectively. An assumption that $\tau = 1$ therefore appears reasonable. Assuming that $\tau = 1$, equation (41) reduces to:

$$\Delta \ln TFP^{O^*} = \frac{P_Y}{P_O^Q} \Delta \ln TFP^{Y^*} + \mu^{OAS} \frac{P_N^{OAS} N^{OAS'}}{P^{OAS'} Q'} \Delta \ln TFP^{OAS^*}$$

(42)

Meaning that a decomposition of $\Delta \ln TFP^{O^*}$ using the investment share, $\frac{P_N^{OAS} N^{OAS'}}{P^{OAS'} Q'}$, will yield a measure of $\Delta \ln TFP^{OAS^*}$ multiplied by the mark-up, $\mu^{OAS}$.

Let us take stock here. The key equation is equation (42) which says that measured $\Delta \ln TFP$ is a share-weighted average of true downstream and true upstream (OAS) $\Delta \ln TFP$. The weights are the measured sector shares in output. We can observe $\Delta \ln TFP^{O^*}$, and the shares $\frac{P_Y}{P_O^Q}$ and $\frac{P_N^{OAS} N^{OAS'}}{P^{OAS'} Q'}$. We cannot observe $\Delta \ln TFP^{Y^*}$, $\Delta \ln TFP^{OAS^*}$ or $\mu^{OAS}$. Therefore we must estimate them in some other way.

c) Estimation of $\Delta \ln TFP^{OAS^*}$ via a regression

Since we cannot observe some of the necessary variables in (42), such as true downstream TFP, $\Delta \ln TFP^{Y^*}$, and the mark-up ($\mu^{OAS}$), $\Delta \ln TFP^{OAS^*}$ must be determined econometrically. The following sets out the regression to be estimated.
Call the measured output weight for the upstream, $s^N$, so that:

$$s^N = \frac{P^OAS_N}{P_0Q'}$$  \hfill (43)

Then (42) is equivalent to the following:

$$\Delta \ln TFP' = (1-s^N)\Delta \ln TFP^* + s^N \mu^OAS \Delta \ln TFP^{OAS} *$$

$$= \Delta \ln TFP^* - s^N \Delta \ln TFP^* + s^N \mu^OAS \Delta \ln TFP^{OAS} *$$

$$= \Delta \ln TFP^* + s^N (\mu^OAS \Delta \ln TFP^{OAS} * - \Delta \ln TFP^* *)$$  \hfill (44)

Suppose we estimate the following regression:

$$\Delta \ln TFP' = \hat{\alpha} + \hat{\beta} sN + \epsilon$$  \hfill (45)

Then comparing with (44) we see that $\hat{\alpha}$ provides an estimate of true downstream TFP, $\Delta \ln TFP^* *$, and $\hat{\beta}$ an estimate of: $(\mu^OAS \Delta \ln TFP^{OAS} * - \Delta \ln TFP^* *)$. Therefore adding $\hat{\alpha}$ to $\hat{\beta}$ yields an estimate of true upstream TFP multiplied by the mark-up: $\mu^OAS \Delta \ln TFP^{OAS} *$. However, knowing the true value of OAS sector TFP would require some knowledge of $\mu^OAS$.

On the factor $\mu^OAS$, unfortunately little information exists on its potential magnitude in the context of own-account software. It has however been studied in the context of own-account R&D. In a study of six pharmaceutical firms, Hulten and Hao (2008) form estimates of R&D based on costs of investment plus a mark-up for profit based on the share of R&D in operating surplus. Their implied estimate for $\mu^R&D$ is around 1.5, so that costs of R&D are marked up by approximately 50% to account for the additional returns made by investors in R&D. They also note that the estimated mark-up would be much larger if one were to account for the time-value of money, that is, the opportunity cost of money tied up during the development process. In the results that follow, alternative assumptions on $\mu^OAS$ will be used in deriving estimates of $\Delta \ln TFP^{OAS} *$.

3.4. Data and Measurement

The theoretical framework and evaluation of its practical application by national statistical institutes, presented above, suggest that changes in the price of UK OAS, as measured in the official data, may be over-
estimated for two reasons. First, the UK estimation procedure does not incorporate the contributions of upstream capital and intermediate prices. In the case of capital, if the predominant item of upstream capital is ICT hardware, that factor would be expected to make a negative contribution to OAS prices. Second, the use of service sector labour productivity growth as a proxy for upstream technical progress may also underestimate the contribution of that component.

The following chart is intended to highlight the growing importance of this potential mismeasurement. Figure 3.1 presents nominal market sector investment in ICT assets from 1984 to 2009. As can be seen, OAS investment (solid thick line in Figure 3.1) has grown strongly over the period, outstripping investment in purchased software since 2002, and investment in hardware since 2008. As a share of market sector GVA, OAS investment has risen from 0.39% in 1984 to 1.46% in 2009. As a share of market sector investment as defined in the National Accounts,\textsuperscript{63} it has risen from a share of 2.3% in 1984 to 11.2% in 2009.\textsuperscript{64}

**Figure 3.1: Nominal market sector investment in ICT assets, (£bns)**

Note to figure: Nominal market sector investment in ICT assets in £ billions. Series labelled as: “softoa” refers to own-account software; “softp” to purchased software; “com” to computer hardware; and “telecom” to telecommunications equipment.

Source: ONS Volume Index of Capital Services (VICS) dataset

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\textsuperscript{63} That is including tangibles and only software, mineral exploration and artistic originals as intangibles.

\textsuperscript{64} The source of these data is the dataset underlying the NESTA Innovation Index, as reported in Goodridge, Haskel and Wallis (2012).
The aim therefore is to implement equation (10) and form an improved estimate of $\Delta \ln P^N$. This therefore requires data on the input prices to OAS creation, that is estimates of changes in the price of upstream labour input ($\Delta \ln P_{t}^{L,N}$), the price of capital upstream capital input ($\Delta \ln P_{t}^{K,N}$) and the price of upstream materials ($\Delta \ln P_{t}^{M,N}$). It also requires estimates of their nominal shares in upstream output ($\tilde{s}^{L,N}_{t}$, $\tilde{s}^{K,N}_{t}$ and $\tilde{s}^{M,N}_{t}$) and an estimate of upstream TFP growth. Therefore it is necessary to form an estimate of all these terms in (10), with the key unknown parameter being $\Delta \ln TFP^{N}$, which will be estimated as described in the previous section.

The dataset used includes data for UK OAS investment ($P^N N$) at a detailed industry-level (122 industries). These data were constructed by ONS using data on the reported wages of software occupations, by industry, and an estimate of the proportion of their time that they spend writing OAS. Those payments are then adjusted to account for the use of intermediates and capital, using ABI data for the software industry, as outlined in Chamberlin et al (2007) and summarised in equation (3). The ABI factor ($\lambda$ in (3)) is estimated as follows. Using data for the software industry (SIC03 72.2) the ONS take the ratio of non-employment costs to employment costs, where non-employment costs are estimated as: total purchases minus purchases of: goods for resale; road transport services, computer services and advertising; plus total taxes and levies plus total depreciation minus depreciation of vehicles. It is then assumed that the ratio of non-employment costs to employment costs in the software industry apply to OAS production in all other industries.

The result is an estimate of $\lambda=1.84$, meaning that approximately 54% of $P^N N$ is accounted for by labour payments and 46% by payments for intermediates and capital. Recall from (3) and the description immediately above, that the payments for capital are based on estimates of depreciation. Using the same ABI data as used by the ONS, the method can be replicated and the factor ($\lambda$) broken down further to break out the separate components for intermediates and capital. It turns out that the estimate of capital input based on depreciation in the software industry is very small, and the implied upstream shares are as follows: $s^{L,N}=0.54$; $s^{M,N}=0.45$; and $s^{K,N}=0.01$. The nature of the estimation using the constant factor, $\lambda$, means that the upstream factor shares are also constants across both industries and years. At just 1%, the capital input share appears small, possibly implausibly so, especially if hardware is considered a key input to upstream production. Therefore two other methods to form alternative estimates of the upstream capital share are considered, which might better account for the input of capital in OAS production.

The first adopts the methodology recommended in the OECD Handbook on Deriving Capital Measures of Intellectual Property Products (OECD 2010). That is, the factor to account for upstream capital compensation is re-estimated using the ratio of gross operating surplus to labour compensation in the software industry itself. This is only valid if capital intensity in OAS production is similar to that in the production of software for general sale, which seems a reasonable assumption. These data do support the
implication in the ONS data that software creation is labour intensive with less of a role for capital, although using this method does increase the upstream capital share somewhat. According to the EUKLEMS data for the computer services industry (SIC03 72), capital compensation is just 7.2% of industry value-added (compared to the typically observed capital income share of around 1/3) and 9.7% of industry labour compensation, over the period 1970 to 2007. Applying this data and method to estimating upstream capital compensation yields the following estimates for the upstream input shares: $s_{1}^{L,N}=0.52$; $s_{2}^{M,N}=0.43$; $s_{3}^{K,N}=0.05$.

Note that the method applies the average ratio of operating surplus to labour compensation as it is not appropriate to assume that capital compensation in the upstream varies annually with capital compensation in the software industry itself. Therefore the resulting upstream input shares are again constants across both years and industries.

The second approach taken to re-estimating the upstream capital share reconsiders the upstream dual in (10) and the user cost relation in (7). From these two equations it is clear that the correct estimate of upstream capital compensation incorporates the net rate of return to capital as well as depreciation. That is:

$$
P^{K,N} = P^{I,N}(\rho + \delta^{K,N})K^{N}
$$

By only accounting for depreciation, the ONS method for estimating $P^{K,N}K^{N}$ only incorporates the second of the two terms on the second line in (46). Therefore taking the ONS estimate of $P^{K,N}K^{N} (= \delta^{K,N}P^{I,N}K^{N})$ and dividing by an estimate for $\delta^{K,N}$, it is possible to back out an estimate of the nominal upstream stock, $P^{I,N}K^{N}$, apply an estimate of $\rho$, and reconstruct $P^{K,N}K^{N}$ so that it accounts for the full user cost of capital.

An estimate of $\delta^{K,N}$ can be constructed using data from the ONS Volume Index of Capital Services (VICS) dataset, as a nominal investment share weighted average of the depreciation rates for the capital present in the computer services industry (SIC03 72).

The geometric depreciation rates used are those used in EUKLEMS and are as follows: buildings, 0.044; computers, 0.315; other plant & machinery, 0.144; telecommunications equipment, 0.115.

The average is calculated from 1984 since that is the year the ONS data for investment in computers begins. To extend the estimates over the full length of the dataset, the average of the investment shares in 1984 and 1985 are assumed to also apply to 1970-83.

Recall that ONS subtract purchases of computer services and the depreciation of vehicles from estimates of non-employment costs in the construction of $\lambda$. 

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65 The geometric depreciation rates used are those used in EUKLEMS and are as follows: buildings, 0.044; computers, 0.315; other plant & machinery, 0.144; telecommunications equipment, 0.115.

66 The average is calculated from 1984 since that is the year the ONS data for investment in computers begins. To extend the estimates over the full length of the dataset, the average of the investment shares in 1984 and 1985 are assumed to also apply to 1970-83.

67 Recall that ONS subtract purchases of computer services and the depreciation of vehicles from estimates of non-employment costs in the construction of $\lambda$. 

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the ONS annual figure for upstream capital input (estimated as depreciation) in each industry, by the estimated annual rate of \(\delta^{K,N}\) gives an annual estimate of the nominal upstream stock, \(P^{I,N}K^N\), for each industry. Assuming a constant net rate of return, \(\rho=0.1\), and applying the formula in (46), generates an alternative annual estimate of \(P^{K,N}K^N\) that accounts for the full user cost of capital rather than just depreciation. Since \(\delta^{K,N}\) varies slightly by year, then the upstream shares estimated using this method also vary slightly by year. At the aggregate level, and on average for the period 1970 to 2009, the estimated shares are as follows: \(s^{L,N}=0.54; s^{M,N}=0.445; s^{K,N}=0.015\). To test the sensitivity of the estimated \(\Delta \ln P^{N,\text{OAS}}\) to the way in which capital is accounted for, equation (10) will be implemented using each of the three alternative estimates of the upstream shares.

In implementing the price dual in (10), then as well as the upstream income shares, it is also necessary to acquire or construct estimates for changes in price of each of the inputs. In the case of labour, the series used is that for the changes in the wages of software writers as used in the construction of the official ONS deflator (\(\Delta \ln P^{L,N}\) in (4)). For intermediates the series used is the price index for intermediate inputs in the computer services industry (SIC03 72) from EUKLEMS. Since the EUKLEMS data are only to 2007, the series is extended to 2009 using changes in the price index for intermediates in the broader industry of business services (SIC03 7174), as reported in the World Input Output Database (WIOD).\(^{68}\) For capital, the appropriate price measure is the change in the rental price of capital rather than the change in the asset price. The relation between the rental price and asset price is summarised by the user cost formula in (7). In practice, as \(\rho\) is assumed to be constant at 0.1, and since the estimate of \(\delta^{K,N}\) is approximately constant, then estimated changes in the rental price of capital closely follow changes in the asset price. A series for the rental price of upstream capital is estimated using a constructed asset price index and applying the user cost formula. The asset price index is constructed as a nominal investment (Tornqvist) share weighted average of the individual asset deflators for buildings, ICT, and plant & machinery in the ONS VICS dataset.

With the dataset now including data for the upstream income shares and the price changes for each upstream input, the remaining parameter that needs to be estimated is \(\Delta \ln TFP^N\). The method to be used was described above, that is by decomposing measured TFP into that for the downstream and the difference between upstream and downstream TFP, via a regression that uses measured TFP as the dependent variable and the share of measured OAS output in measured gross output as an independent variable.

Before the regression can be estimated it is necessary to estimate measured TFP (on a gross output basis) at an industry-level compatible with the data on software investment and upstream inputs. The upstream data

\(^{68}\) The industry breakdown in WIOD is not as fine as in EUKLEMS so a price index for materials in the software industry is not available from this source.
are therefore combined with industry data from WIOD and EUKLEMS (WIOD for 1995 to 2009 and backcast using EUKLEMS for earlier years), on: real and nominal gross output; real and nominal intermediate inputs; labour income and capital compensation; where the nominal data are used to estimate income shares in industry gross output. Since the more recent data from WIOD are at a more aggregated level than EUKLEMS, combining the output and input data with that for own-account software results in a panel of 30 industries over the period 1970 to 2009. Since residential dwellings do not form part of the productive capital stock, data for the real estate industry is excluded. The final industry breakdown is presented below in Table 3.1.

Table 3.1: Industry breakdown of final dataset

<table>
<thead>
<tr>
<th>No.</th>
<th>Industry Description</th>
<th>SIC03</th>
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<tr>
<td>1</td>
<td>Agriculture, Hunting and Forestry; Fishing</td>
<td>AtB</td>
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<tr>
<td>2</td>
<td>Mining and Quarrying</td>
<td>C</td>
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<tr>
<td>3</td>
<td>Manufacture of Food Products, Beverages and Tobacco</td>
<td>15t16</td>
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<tr>
<td>4</td>
<td>Manufacture of Textiles and Textile Products</td>
<td>17t18</td>
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<tr>
<td>5</td>
<td>Manufacture of Leather and Leather Products</td>
<td>19</td>
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<tr>
<td>6</td>
<td>Manufacture of Wood and Wood Products</td>
<td>20</td>
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<tr>
<td>7</td>
<td>Manufacture of Pulp, Paper and Paper Products; Publishing and Printing</td>
<td>21t22</td>
</tr>
<tr>
<td>8</td>
<td>Manufacture of Coke, Refined Petroleum Products and Nuclear Fuel</td>
<td>23</td>
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<td>9</td>
<td>Manufacture of Chemicals, Chemical Products and Man-made Fibres</td>
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<td>10</td>
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<td>63</td>
</tr>
<tr>
<td>27</td>
<td>Post and Telecommunications</td>
<td>64</td>
</tr>
<tr>
<td>28</td>
<td>Financial Intermediation</td>
<td>J</td>
</tr>
<tr>
<td>29</td>
<td>Business Activities (excluding Real Estate)</td>
<td>71t74</td>
</tr>
<tr>
<td>30</td>
<td>Other Community, Social and Personal Service Activities</td>
<td>O</td>
</tr>
</tbody>
</table>

Note to table: Final estimation conducted using the above industry breakdown. Industries and labels based on SIC03

Since the capital stocks data in WIOD and EUKLEMS only extend to 2007, capital data from the ONS VICS dataset are used instead. Growth in capital services for each industry is then estimated by taking the change in logs of the stock at detailed asset/industry level, and the changes weighted up for each industry using the Tornqvist shares for each asset/industry in operating surplus, as in (47):
\[ \Delta \ln K_i = \frac{P^K K_j}{\sum P^K K_i} \Delta \ln K_j + \frac{P^K K_q}{\sum P^K K_i} \Delta \ln K_q \]  

(47)

Where \( \Delta \ln K_j \) is the change in the capital services for industry \( i \), \( \frac{P^K K_j}{\sum P^K K_i} \) and \( \frac{P^K K_q}{\sum P^K K_i} \) are the asset income shares for assets \( j \) and \( q \) in industry capital compensation, and \( \Delta \ln K_j \) and \( \Delta \ln K_q \) are the changes in the stock of assets \( j \) and \( q \).

Industry TFP on a gross output basis can therefore be estimated as 69:

\[ \Delta \ln TFP_{i,t}^Q = \Delta \ln Q_{i,t} - \bar{s}_{j,t}^L \Delta \ln L_{i,t} - \bar{s}_{j,t}^M \Delta \ln M_{i,t} - \bar{s}_{j,t}^K \Delta \ln K_{i,t} \]  

(48)

Where \( \bar{s}_{j,t}^X \) are Tornqvist shares of factor income in nominal gross output, constructed as:

\[ \bar{s}_{j,t}^X = \left( \frac{P^X_i X_{i,t} + P^X_{i,t-1} X_{i,t-1}}{P^Q_i Q_{i,t} + P^Q_{i,t-1} Q_{i,t-1}} \right) \]  

\[ X = L, K, M \]  

(49)

Using these industry-level estimates of \( \Delta \ln TFP^Q \), the following regression can be estimated on a panel of 30 industries over the period 1970 to 2009:

\[ \Delta \ln TFP_{i,t}^Q = \alpha_{i,t} + \beta_{i,t} s_{i,t} + \epsilon_{i,t} \]  

(50)

The independent variable to be used is the share of OAS output in gross output for each industry (\( s_{i,t}^X \)).

Figure 3.2 presents an average of this share over the period 1970 to 2009, for each of the 30 industries and the market sector aggregate (labelled MS). As can be seen, by far the most OAS-intensive industries are ‘financial intermediation’ (J) and ‘business services’ (71t74), followed by ‘auxiliary transport activities’ (64) and ‘retail’ (52). All those industries that produce no own-account software are in manufacturing and include: ‘food, beverages and tobacco’ (1516); ‘textiles’ (1718); ‘leather’ (19); ‘wood’ (20); ‘rubber and plastic’ (25) and ‘non-metallic minerals’ (26).

69 Here capital, \( K \), is defined as in the SNA, therefore including tangibles (buildings, plant, ICT, vehicles) and (purchased and own-account) software, mineral exploration and artistic originals as intangibles.
Figure 3.2: Share of own-account software investment in industry gross output (average, 1970-2009)

Note to figure: Mean share of OAS investment in industry gross output. Within OAS investment the estimate of capital input has been adjusted using the ratio of operating surplus to labour compensation in the software industry, as recommended in OECD (2010) and described above. In practice the impact of this adjustment to measures of investment are minimal.

Source: ONS data

Figure 3.3 also presents the average share of OAS investment in gross output, but over time for the market sector aggregate. The data show software intensity rising over time throughout the dataset, with larger changes noticeable in 1979, 1986, 1990, 1997 and 2009.
Figure 3.3: Share of own-account software investment in market sector gross output by year, 1970-2009

Note to figure: Mean share of market sector OAS investment in aggregate market sector gross output over time. Within OAS investment the estimate of capital input has been adjusted using the ratio of operating surplus to labour compensation in the software industry, as recommended in OECD (2010) and described above. In practice the impact of this adjustment to measures of investment are minimal.

Source: ONS for OAS investment, EUKLEMS for gross output

The above two charts summarise the independent variable to be used in the estimation, $s^N_{it}$. The dependent variable to be used is measured industry TFP constructed on a gross output basis ($\Delta \ln TFP^Q_{it}$ in (48)). In estimating the regression in equation (50) a number of options are available. One is to simply run an OLS regression of annual/industry $s^N$ on measured annual/industry TFP. To account for the cyclical variation in TFP, year dummies could also be included, as in (51).

$$\Delta \ln TFP^Q_{it} = \alpha_{it} + \beta s^N_{it} + \alpha_{t} + \epsilon_{it}$$  \hspace{1cm} (51)

The interpretation of the constant\(^70\) is that it is an average estimate of TFP in the downstream, OAS-using sectors. It would be reasonable to consider that there are other determinants of industry TFP besides the

\(^{70}\) With terms in $\alpha_{it}$ dropped as appropriate in cases where dummies are included.
share of OAS investment. Therefore another option is to allow downstream TFP to vary by industry in a fixed effects model, as in (52).

\[ \Delta \ln TFP_{i,t} = \alpha_{i,t} + \beta S_{i,t}^{N} + \alpha_{i} + \epsilon_{i,t} \]  

An alternative way of removing the cyclicality from TFP is to run the regression on the mean values over different periods, with the periods chosen referring to distinct productivity episodes, as in (53).

\[ \Delta \ln TFP_{i} = \alpha_{i} + \beta \bar{S}_{i}^{N} + \epsilon_{i} \]  

Figure 3.4 presents a Domar-weighted aggregate\(^71\) measure of ΔlnTFP for the definition of the market sector applied in this chapter (i.e. as the aggregate of ΔlnTFP in the industries presented in Table 3.1). Based on this chart the following nine productivity episodes can be observed, where P denotes peak, and T trough: P-T, 1973-74; T-P, 1975-78; P-T, 1979-80; T-P, 1981-87; P-T, 1988-89; T-P, 1990-92; P-T, 1993-98; T-P, 1999-04; P-T, 2005-09. The black lines indicate the peaks and troughs observed in TFP growth.

---

\(^71\) Where the Domar weights are constructed as shares of nominal industry gross output in nominal market sector value-added.
Figure 3.4: Aggregate market sector $\Delta\ln TFP$, 1970-2009

Note to figure: Aggregate market sector TFP, 1970 to 2009. Constructed as a Domar-weighted aggregate of industry TFP estimated on a gross output basis, where the domar weights are industry gross output as a share of market sector value-added, where the weights sum to greater than one. Vertical lines are peaks and troughs observed in TFP growth.

The following chart presents the scatter relationship and line of best fit for average values of industry TFP and $s^N$ in the nine productivity episodes identified in Figure 3.4. The data suggest a slight positive correlation between industry OAS intensity and measured industry TFP.
Figure 3.5: Relationship between mean industry TFP and $s^N$ in observed productivity episodes

Note to figure: Scatter relationship between mean industry TFP and mean industry $s^N$ for each of the nine productivity episodes identified in Figure 3.4.

A number of alternative specifications for the regression have been discussed. The following table presents a selection of results for those alternatives. From (44), $\Delta \ln TFP^{OAS}$ can be derived as the sum of the coefficient on $s^N_i$ and the intercept. As outlined above, the coefficient on $s^N_i$ will also implicitly include the factor $\mu^{OAS}$. The estimate of upstream TFP implied by each regression using alternative assumptions on $\mu^{OAS}$ is presented as a memo item.
Table 3.2: Estimation of $\Delta \ln TFP^N$. Regression results, estimation of (50), (51), (52) and (53), dependent variable: $\Delta \ln TFP_i^Q$

<table>
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<tr>
<th>VARIABLES</th>
<th>Robust OLS (71-09)</th>
<th>Robust OLS (71-07)</th>
<th>Robust OLS (86-07)</th>
<th>Robust OLS (86-09)</th>
<th>Robust OLS (71-07)</th>
<th>Robust OLS (71-09)</th>
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<th>Fixed Effects (71-09)</th>
<th>Robust OLS (71-09)</th>
<th>Fixed Effects (71-09)</th>
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<tbody>
<tr>
<td>$sN_{i,t}$</td>
<td>0.121 (0.560)</td>
<td>0.397* (0.0759)</td>
<td>0.0787 (0.734)</td>
<td>0.228 (0.343)</td>
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<td>0.502 (0.172)</td>
<td>0.164 (0.688)</td>
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<td>mean $sN$, pooled</td>
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<td></td>
<td></td>
<td>0.358** (0.0151)</td>
<td>1.255*** (2.06e-06)</td>
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<td>Year dummies</td>
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<tr>
<td>Industry Dummies</td>
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<tr>
<td>Constant</td>
<td>0.00442*** (3.10e-07)</td>
<td>0.00448*** (4.54e-07)</td>
<td>0.00491 (0.192)</td>
<td>0.00453 (0.265)</td>
<td>0.00800 (0.108)</td>
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<td>Observations</td>
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<td>1,110</td>
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<td>660</td>
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<td>R-squared</td>
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<td>0.141</td>
<td>0.295</td>
<td>0.002</td>
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<td>0.023</td>
<td></td>
</tr>
<tr>
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<td>30</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>30</td>
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</tbody>
</table>

Memo: Implied $\Delta \ln TFP^N$ ($\mu=1$) 12.5% 40.1% 8.4% 23.3% 11.2% 50.5% 16.8% 36.3% 125.6%

Implied $\Delta \ln TFP^N$ ($\mu=1.25$) 10.03% 32.12% 6.69% 18.60% 8.96% 40.40% 13.45% 29.03% 100.50%

Implied $\Delta \ln TFP^N$ ($\mu=1.5$) 8.36% 26.77% 5.57% 15.50% 7.47% 33.67% 11.21% 24.19% 83.75%

Implied $\Delta \ln TFP^N$ ($\mu=2$) 6.27% 20.07% 4.18% 11.63% 5.60% 25.25% 8.41% 18.14% 62.81%

p-values in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note to table: Selected results for alternative specifications of model in equation (45), as set out in equations (50), (51), (52) and (53). Columns 1 to 5 and 8 report results for robust OLS regressions. Columns 6, 7 and 9 report results for a fixed effects specification. Columns 1 to 7 are estimated using individual observations for each year/industry. Columns 8 and 9 use pooled cross sections of the averages of $s^N$ and measured TFP over the observed productivity episodes identified in Figure 3.4. Columns 1, 6, and 7 are estimated over the full period, 1971 to 2009. Columns 2 and 5 drop the latest two years and so are run over a sub-sample, 1971 to 2007. Columns 3 and 4 exclude earlier years of data when OAS investment was relatively low, and are run over the periods 1986-2007 and 1986-2009 respectively. All columns use data for all 30 industries except column 4 which excludes the six non-performing industries and column 7 which excludes Financial Intermediation. P-values reported in parentheses below coefficient.
Column 1 presents results from a robust OLS regression of $s_{i,t}^N$ on $\Delta \ln TFP_{i,t}^O$ over the period 1971 to 2009. Although the coefficient on $s_{i,t}^N$ is not statistically significant, the results imply an estimate of upstream TFP of approximately 12.5% ($0.121 + 0.00442$) if it is assumed that $\mu=1$. If it is assumed that $\mu=1.25$, upstream TFP reduces to 10%, and to 8.4% and 6.3% for assumptions of $\mu=1.5$ and $\mu=2$ respectively. The constant, interpreted as an estimate of $\Delta \ln TFP_Y$, that is $\Delta \ln TFP$ in the downstream, is 0.4%.

There is however some sensitivity to the endpoints used in the regression. Column 2 presents results for the same regression but this time over the years 1971 to 2007, thus excluding data for the recent recession. The magnitude of the coefficient on $s_{i,t}^N$ is over three times greater, and is statistically significant at the 10% level, implying upstream TFP of 40.1% in the case of $\mu=1$, reducing to 20.1% if $\mu=2$. Although not reported here for reasons of space, incorporating year dummies into these two regressions renders the coefficient negative and statistically insignificant.

For obvious reasons investment in OAS was lower in the earlier years of the dataset. Also, in line with the standard “it takes a while” hypothesis often cited in the context of ICT, in the earlier years investors may not have been as effective in either producing OAS or in utilising that software to generate gains in productivity. Figure 3.3 shows that the share of OAS investment in market sector gross output increased significantly in 1986. Running the regression with year dummies and over the period 1986 to 2007, as in column 3, yields a statistically insignificant coefficient on $s_{i,t}^N$ that implies an estimate of upstream TFP of approximately 8.4% if $\mu=1$, reducing to 6.7% if $\mu=1.25$, 5.6% if $\mu=1.5$ and 4.2% if $\mu=2$.

The results are also sensitive to the industries included. Running the same regression as in column 3 but this time over the period 1986 to 2009 and with the non-performing industries excluded, as in column 4, increases the estimate of upstream TFP to 23.3% in the case of $\mu=1$, although the coefficient on $s_{i,t}^N$ remains statistically insignificant. Although not reported here, running these regressions using weighted least squares (where the weight used was the natural log of total industry hours worked) did not improve the precision of estimates.

The sensitivity to which industries are included suggests the use of industry dummies or a fixed effects model may be more appropriate. Column 5 reports the results of a robust OLS regression over 1971 to 2007 that includes both year and industry dummies. The coefficient on $s_{i,t}^N$ is statistically insignificant, and the coefficients imply an estimate of upstream TFP of 11.2% in the case where $\mu=1$, reducing to 5.6% if $\mu=2$. 

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Column 6 reports the results of a fixed effects estimation across industries over 1971 to 2009. The results of the F-test do not reject the use of a fixed effects model and the coefficient on $s_{it}$ is among the more precisely estimated of the results presented here, although it remains statistically insignificant. The implied estimate of upstream TFP is however very high, seemingly implausibly so, at 50.5% if $\mu=1$ and 25.3% if $\mu=2$.

This specification is again somewhat sensitive to which industries are included. As shown in Figure 3.2, the most OAS intensive sector is financial intermediation (SIC03 J), an industry which also has high measured $\Delta \ln TFP$. Therefore Column 7 reports the results for the same specification used in Column 6 but this time excluding data for financial intermediation. The coefficient on $s_{it}$ is reduced considerably, implying upstream TFP of 16.8% in the case of $\mu=1$, but is less precisely estimated. Unfortunately incorporating year dummies into the fixed effects specification removes all the variation from the data and renders the coefficient negative.

An alternative method of estimation is to use averages of $\Delta \ln TFP_{it}^O$ and $s_{it}^N$ for each of the distinct productivity episodes identified from Figure 3.4. Column 8 presents results for such a pooled regression, with a robust OLS specification, over the nine identified periods. The coefficient is statistically significant at the 5% level, but with a very large magnitude, implying upstream TFP of 36.3% in the case of $\mu=1$, reducing to 18.1% for $\mu=2$. Incorporating these pooled data into a fixed effects specification also results in extremely high coefficients on $\bar{s}_i^N$, that are highly statistically significant, and imply implausibly high estimates of upstream TFP. Column 9 presents an example of such a result.

The results from the fixed effects specifications, using either the pooled data or the individual years, tend to be the more precisely estimated and less sensitive to changes in years/industries included. However, the magnitudes of the coefficient (on $s_{it}^N$ or $\bar{s}_i^N$) in those specifications are the least plausible. Assuming higher values for $\mu$ does reduce the implied estimates of $\Delta \ln TFP^N$, but unfortunately there is no prior knowledge on the potential magnitude of $\mu$ to apply in the estimation.

One possibility is that the coefficient on $s^N$ is capturing other effects on productivity aside from productivity growth in the upstream sector. For example, the implementation of new organisational processes which improve productivity, and possibly use own-account software as an input, with such implementation possibly correlated with the industry share of OAS investment and growth in those investments.

A related possibility is that the coefficient is partially capturing productivity gains from use rather productivity gains in production. As noted the measured data does not incorporate the mark-up, $\mu$. If $\mu$ were
known and could be incorporated, its inclusion would result in a different estimate of the contribution of OAS since the factor income share would change, as in equation (31). To try and account for this the reported specifications were also run including terms for either the estimated growth in the stock of OAS, $\Delta \ln R^{OAS}$, or the estimated contribution of OAS, $s^{R,OAS}\Delta \ln R^{OAS}$, where $R^{OAS}$ is the real stock of OAS constructed using the official deflator, as independent variables. However, including these terms as independent variables did not improve the consistency of the results, or reduce the magnitude of the coefficients in the more implausible cases. In the case of the fixed effects models on the pooled data, as in Column 9 of Table 3.2, including a term for $\Delta \ln R^{OAS}$ did reduce the coefficient on $s^N$ but the results still implied implausibly high estimates of upstream TFP in the range of 80-100% p.a. depending on the exact specification.

There are also other potential drivers of industry TFP that have not been accounted for so far. One such potential variable is factor utilisation. Therefore, following Basu, Fernald et al. (2004), an estimate of changes in utilisation at the industry-level was also constructed as $\Delta \ln(H/N)$, where H is total person-hours worked and N the number in employment, as reported in EUKLEMS and WIOD. Including this variable had little impact on the magnitude of the coefficient on $s^N$ or its statistical significance. As shown in Corrado, Goodridge and Haskel (2011) another driver is industry intensity of R&D investment, $s^{N,R&D}$. Specifications incorporating this variable are not presented here as the R&D data from BERD is not compatible with this industry breakdown. However the R&D investment share can be incorporated if the output and software data are re-aggregated to a 23 industry breakdown. Re-aggregating and incorporating $s^{N,R&D}$ into the regression did not improve the precision of the estimation.

The results are therefore somewhat inconsistent, and the more plausible estimates of upstream TFP are based on a statistically insignificant coefficient for $s^N$. The results are however economically significant. Whilst they do not provide a precise estimate of $\Delta \ln TFP^V$, they certainly provide evidence for upstream TFP being considerably higher than the estimate of service sector labour productivity growth as used in the official ONS methodology (on average 1.81% p.a. over the period 1994 to 2010). The more plausible estimates of $\Delta \ln TFP^V$ (Columns 1, 3, 4, 5 and 7 in Table 3.2), although not precisely estimated, suggest upstream TFP in the order of 4% to 23% p.a.. Those estimates are also supportive of results elsewhere in the literature. For example, in analysing data for purchased software (spreadsheets) over the period 1987-1992, Brynjolfsson and Kemerer (1996) find that although nominal prices rose slightly, quality-adjusted prices fell at a rate between -9% and -24% p.a., and -16% p.a. in the baseline model, suggesting TFP in software production of around 9 to 24% p.a.. Similarly Gandal (1994) finds the quality-adjusted price of spreadsheets to have declined by approximately 15% to 22% p.a., with similar implications for technical progress in their

\[72\] Assuming that $s^{R,OAS} = s^{N,OAS}$. That is that the capital income share is equal to the investment share. In the golden rule steady state, defined as the maximisation of intertemporal consumption as a constant proportion of output, these two terms are equivalent (Jorgenson, 1966).
creation. Furthermore, the BEA hedonic price index for pre-packaged software shows an average decline in price of -8.46% p.a. over the period 1971 to 2009. With reported prices in pre-packaged software rising only a small amount annually, that index also suggests productivity in the creation of pre-packaged software in the order of +9% p.a.

Due to the imprecise estimation, and the implausible magnitude of some of the reported coefficients, for reasons of conservatism and because it is more appropriate for the chosen specification to include year dummies, the chosen estimate of $\Delta \ln TFP^N$ is that reported in Column 3 of Table 3.2, with $\Delta \ln TFP^N$ estimated at 8.4% p.a. (based on $\mu=1$). By definition, the estimate derived from the reported coefficients is an average measure of $\Delta \ln TFP^N$ across time and industries. In implementing (10), a time-varying estimate of $\Delta \ln TFP^N$ would be preferable. Therefore by estimating a parameter, $\lambda$, as:

$$\lambda = (\hat{\beta} + \hat{\alpha}) - \overline{TFP^{Q,Agg}}$$

Where $\hat{\beta}$ is the reported coefficient on $s^N$, $\hat{\alpha}$ is the reported intercept and $\overline{TFP^{Q,Agg}}$ is a weighted average of TFP, where the weights used are Tornqvist shares of industry gross output in aggregate gross output. Since (10) is a gross output equation, this is the appropriate weighting scheme. $\lambda$ can then be applied to annual average estimates of $TFP^{Q,Agg}$, again aggregated using shares in gross output, to yield annual estimates of $\Delta \ln TFP^N$. Since $TFP^{Q,Agg}$ is so volatile, the estimate of $\Delta \ln TFP^N$ is smoothed as a 5-year moving average, equally weighted.

$$\Delta \ln TFP^N_t = \lambda + \Delta \ln TFP^{Q,Agg}$$

3.5. Results

With estimates for all the price terms and their respective income shares in (10), plus an estimate of $\Delta \ln TFP^N$, all the data is in place to estimate the final OAS price index. Figure 3.6 presents the change in natural logs for all three versions of the newly estimated price index, labelled one to three. The first (labelled “one”) uses estimates of the upstream capital share as implied by the ONS data. The second (labelled “two”) uses adjusted estimates of the upstream capital share, based on the ratio of gross operating surplus to labour compensation in the software industry as reported in EUKLEMS, as described in a previous section. The third (labelled “three”) re-estimates upstream capital compensation using estimates of the upstream depreciation rate ($\delta^{K,N}$) and an assumed net rate of return ($\rho$), as also described in a previous section.
As can be seen, there is very little difference between the results using either method one or three, as although the estimated rental price of capital in the upstream has been falling (because computers are the predominant item of upstream capital), its share is very small using either method. The results for method two in general fall faster, due to the larger estimate of the upstream capital share using this method.

**Figure 3.6: Annual changes in estimated price index for OAS**

Note to figure: Changes in natural logs of all three versions of the estimated deflator. Series labelled “one” based on estimates of the upstream capital share in the official data. Series labelled “two” re-estimates the capital share based on the ratio of gross operating surplus to labour compensation in the software industry as reported in EUKLEMS. Series labelled “three” re-estimates the capital share using an estimate of the upstream depreciation rate and an assumed net rate of return.

The average rates of change over 1970 to 2009 are as follows: -1.1% p.a. using method one; -1.85% p.a. using method two; and -1.17% p.a. using method three. The chart also shows that the rate of decline is faster during the 1990s, a time which coincides with the widespread diffusion of the internet. Looking at the post-1995 period, the average changes are: using method one, -5.39% p.a.; using method two, -5.95% p.a.; using method three, -5.45% p.a.

Therefore although using method two does result in a faster decline in the estimated price of OAS, comparison of the results shows that the method for accounting for the contribution of upstream capital has much smaller implications than estimation of, or assumptions on, $\Delta \ln TFP^Y_t$. The following chart breaks
down the annual price changes into the contributions from the price of labour, capital and materials, and that from $\Delta \ln TFP^N_t$. As can be seen the annual contribution from the price of capital tends to be small. That of materials is larger but the index is share-weighted, and because the price changes for materials are relatively similar to those for labour, incorporating the price of materials has a relatively small impact compared to the ONS methodology.

Figure 3.7: Decomposition of the annual changes in price of OAS

![Graph showing annual decomposition of the changes in the price of OAS. Solid black line is the annual price change. Stacked contributions include the contributions of capital (purple), materials (green), labour (red) and TFP (blue).](image)

Note to figure: Annual decomposition of the changes in the price of OAS. Solid black line is the annual price change. Stacked contributions include the contributions of capital (purple), materials (green), labour (red) and TFP (blue).

In the official UK methodology, the implicit estimate of $\Delta \ln TFP^N_t$ is measured labour productivity growth in the service sector. The following chart compares the growth rates of the official OAS deflator with the preferred index developed in this paper, using method two. As can be seen, the different assumptions surrounding $\Delta \ln TFP^N_t$ make a considerable difference to the final results. In comparison to the growth rates presented earlier, the official OAS price index grows on average at a rate of +6.5% p.a. over the period 1970 to 2009, and +1.96% p.a. in the post-1995 period.
Figure 3.8: Annual changes in price of OAS: this paper (preferred index) and the official UK price index

![Graph showing annual changes in price of OAS](image)

Note to figure: Solid line shows the annual changes in logs of the OAS price index developed in this paper. Dashed line shows the annual changes in logs of the official UK OAS price index.

In fact, as shown in Figure 3.9, since the 1990s at least, the estimated price index for OAS looks more similar to the BEA pre-packaged price index. Over the entire series, 1970-2009, the BEA pre-packaged index falls on average at a rate of -8.46% p.a., compared to -1.85% p.a. for the OAS price index. In the 1990-2009 period, the growth rate in the BEA index is -5.61% p.a. compared to -5.76% p.a. for the OAS price index.
Figure 3.9: Annual price changes for OAS and pre-packaged software (BEA)

Note to figure: Solid line shows the annual changes in the OAS price index developed in this paper. Dashed line shows the annual changes in the BEA price index for pre-packaged software.

How does this new price index affect estimates of real investment? Figure 3.10 compares estimates of real investment in OAS using the price index developed in this paper and the official UK index. As can be seen the effect is substantial. On average over the period 1970 to 2009, the rate of growth in real OAS investment using the new deflator is 16.8% p.a. compared to 8.3% p.a. using the official own-account deflator, more than double.
Figure 3.10: Real investment in own-account software, new vs. official deflator, £bns constant prices (base=2005)

Note to figure: Real investment in own-account software. Thin dashed line is deflated using the official deflator from the National Accounts. Thick solid line is deflated using the price index developed in this paper. The base year for each series is 2005.

A second question is how does using the new asset price index for OAS affect the contribution of software to growth in a sources of growth decomposition? There will be a number of effects. First deflating own-account software with a new price index will change the measure of real output growth, although as the share of OAS investment in value-added is small, the impact on measured growth will also be small. Second, as highlighted above, it will also change measured real investment and estimates of the changes in the capital stock, directly effecting the estimated contribution. Third, the new investment price index will also effect estimation of the rental price, as in equation (23), also effecting the estimated contribution via the income share.

Table 3.3 looks at the impact of using the new deflator on the contribution of software in a growth accounting decomposition. As noted previously, the own-account price index also affects the estimated

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73 The growth-accounting decomposition presented below is conducted using the dataset reported in Goodridge, Haskel and Wallis (2012) and Chapter 4 of this thesis, but only treating as capital assets those identified in the System of National Accounts, therefore only including software, mineral exploration and artistic originals as intangible assets.
contribution for purchased software, since the UK purchased deflator is constructed as an equally weighted average of the BEA pre-packaged deflator (adjusted for the dollar: sterling exchange rate) and the own-account deflator, where the latter is considered to reflect changes in the price of custom software. The first panel presents the results when using the official ONS deflators. It is worth noting from these baseline results that the role of own-account software has grown over the period considered. In the earliest period, 1990-95, the contribution of own-account software was just a quarter of that of purchased software. In the 2000s however, the contribution of purchased software declined and that of own-account software increased, so that by the 2005-09 period the contribution of own-account software was higher. This reversal in the relative importance of purchased and own-account software in terms of their contribution to growth, emphasises the importance of more accurately estimating the price of OAS in the official data.

The second panel presents the growth-accounting contributions this time using the new OAS price index developed in this chapter. The first point to note is that using the new deflator increases growth in labour productivity by 0.01% p.a. on average after 1995. Looking at the purchased contribution, comparing panel 2 with panel 1 shows that using the new deflator has a strong impact on the purchased contribution, particularly in the 2000s, increasing it more than four-fold in 2000-05 and more than doubling it in 2005-09. Looking at the own-account contribution, that is more than doubled in each period using the new deflator so that in the latest period, 2005-09, the contribution of own-account software is 0.19% pa. As a result, the total contribution of software is considerably higher in all periods, and more than double that previously estimated in the 2000s.

Table 3.3: Growth Accounting results using alternative deflators, 1990-2009

<table>
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<td></td>
<td>DlnV/H</td>
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<tr>
<td>1) Baseline Results: Using official ONS deflators</td>
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<tr>
<td>1990-95</td>
<td>3.22%</td>
<td>0.23%</td>
<td>1.17%</td>
<td>0.16%</td>
<td>0.04%</td>
<td>0.20%</td>
<td>0.04%</td>
<td>1.58%</td>
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<tr>
<td>1995-00</td>
<td>3.16%</td>
<td>0.29%</td>
<td>1.15%</td>
<td>0.19%</td>
<td>0.06%</td>
<td>0.26%</td>
<td>0.01%</td>
<td>1.46%</td>
<td>0.63</td>
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<tr>
<td>2000-05</td>
<td>2.32%</td>
<td>0.18%</td>
<td>0.96%</td>
<td>0.02%</td>
<td>0.07%</td>
<td>0.09%</td>
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<td>1.09%</td>
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<tr>
<td>2005-09</td>
<td>0.33%</td>
<td>0.46%</td>
<td>0.83%</td>
<td>0.05%</td>
<td>0.08%</td>
<td>0.13%</td>
<td>0.00%</td>
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<td>2) Using deflator developed in this chapter</td>
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<tr>
<td>1990-95</td>
<td>3.22%</td>
<td>0.23%</td>
<td>1.17%</td>
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<td>0.10%</td>
<td>0.27%</td>
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<td>1.51%</td>
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<tr>
<td>1995-00</td>
<td>3.17%</td>
<td>0.29%</td>
<td>1.15%</td>
<td>0.24%</td>
<td>0.14%</td>
<td>0.38%</td>
<td>0.01%</td>
<td>1.34%</td>
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<tr>
<td>2000-05</td>
<td>2.33%</td>
<td>0.18%</td>
<td>0.96%</td>
<td>0.09%</td>
<td>0.18%</td>
<td>0.26%</td>
<td>0.00%</td>
<td>0.92%</td>
<td>0.66</td>
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<td>2005-09</td>
<td>0.34%</td>
<td>0.46%</td>
<td>0.83%</td>
<td>0.13%</td>
<td>0.19%</td>
<td>0.31%</td>
<td>0.00%</td>
<td>-1.26%</td>
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The rate of depreciation used for software is a geometric rate of 33%. The capital income shares are estimated such that the net rate of return is equalised across assets and operating surplus is exhausted.
Note to table: Column 1 is labour productivity growth. Column 2 is the contribution of labour composition, that is the labour income share times growth in labour services per hour. Column 3 is the contribution of tangible capital (plant & machinery including hardware; buildings; and vehicles) that is the income share of tangible capital times growth in tangible capital services. Column 4 is the contribution of purchased software. Column 5 is the contribution of own-account software. Column 6 is the total software contribution, which is also the sum of columns 4 and 5. Column 7 is the contribution of other intangibles capitalised in the national accounts (mineral exploration and artistic originals). Column 8 is growth in TFP. Column 9 is the labour income share in value-added.

3.6. Practical implications

The above results provide evidence that: a) estimation of, or assumptions on, $\Delta \ln TFP^N_t$ are key to estimating $\Delta \ln P^{N,OAS}_t$; and b) that the assumption that this parameter is approximate to service sector labour productivity growth results in a considerable overstatement of OAS price changes. The results presented in this chapter suggest upstream TFP is in the order of 4% to 23% p.a., with an estimate of 8.4% used in the construction of a new OAS price index.

It is therefore worth asking, what practical measures could the national statistical office take to improve on current measurement practice? One option could be to replace the service sector labour productivity term with an estimate of TFP growth in the “Information and Communications” industry (SIC07 J), which includes computer programming and other information services. In the official ONS Multi-Factor Productivity (MFP) release, MFP in this industry is estimated to have grown at an average rate of 3.92% p.a., in 1997 to 2010, peaking at 16.8% in 2000 (Appleton and Franklin 2012). In comparison, over the same period, service sector labour productivity growth, as currently used in the official method, grew on average at a rate of 1.57% p.a.. The use of the official MFP estimates for this knowledge-intensive industry would therefore offer both a practical and conservative solution to the problem of producing an informed estimate of $\Delta \ln TFP^N_t$.

3.7. Conclusions

Investment in own-account software is a significant item in measured gross fixed capital formation in the National Accounts. At £13.5bn for the market sector in 2009, it is larger than investment in computer hardware and telecommunications equipment combined (£12.3bn in 2009), an item that has received a large amount of attention in terms of measurement. Accurately estimating the price of own-account software is therefore a first order issue for national accountants and productivity analysts.

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74 Conceptually this estimate for MFP is not compatible with the upstream framework used in this chapter as it is constructed on a value-added basis, whereas the estimates for the upstream in this chapter are based on a gross output framework. Nevertheless, it still appears a more appropriate option than the use of a term for labour productivity growth in the service sector as in current practice.
The key parameter in the estimation of a price index for OAS is upstream TFP growth. The inclusion of terms for the price of upstream materials and capital have much less impact. The current measurement convention assumes very low productivity growth in OAS creation. However, the results presented in this chapter suggest that productivity gains in the creation of software have not been confined to the pre-packaged variety, with evidence of strong productivity growth in the creation of own-account software. As a result the official deflator for own-account software considerably overstates its price changes, causing an understatement of real OAS investment, the capital stock and the contribution of OAS capital deepening to growth. The price index estimated in this chapter falls on average at a rate of -1.85% p.a. over the period 1970 to 2009, compared to growth of +6.5% p.a. in the official UK deflator. As a result the total contribution of software capital deepening to UK labour productivity growth in 2005-09 is 0.31% p.a., more than double the 0.13% p.a. estimated using the official deflators. Finally it is worth noting that the finding of falling prices for own-account software could partly explain the strong growth in OAS investment that has taken place in recent years.
Chapter 4: UK Innovation Index: Productivity and Growth in UK Industries*

Peter Goodridge, Jonathan Haskel and Gavin Wallis

ABSTRACT

This chapter presents work on the UK Innovation Index and tries to calculate some facts for the “knowledge economy”. Building on the work of Corrado, Hulten and Sichel (2005; 2009), using new data sets and a new micro survey, we (1) document UK intangible investment and (2) see how it contributes to economic growth. Regarding investment in knowledge/intangibles, we find (a) this is now 34% greater than tangible investment, in 2009, £124.2bn and £92.7bn respectively; (b) that R&D is about 11% of total intangible investment, software 18%, design 12%, and training and organizational capital 21% each; (d) the most intangible-intensive industry is manufacturing (intangible investment is 17% of value added) and (e) treating intangible expenditure as investment raises market sector value added growth in the 1990s due to the ICT investment boom, but has less impact on aggregate measures of growth in the 2000s. Regarding the contribution to growth, for 2000-09, (a) intangible capital deepening accounts for 26% of labour productivity growth, against computer hardware and telecommunications equipment combined (16%) and TFP (-0.4%); (b) adding intangibles to growth accounting lowers TFP growth by about 18 percentage points (c) capitalising R&D adds 0.04% to input growth and reduces ΔlnTFP by 0.02% and (d) manufacturing accounts for 47% of intangible capital deepening plus TFP.

*This chapter is a co-authored work by myself, Jonathan Haskel and Gavin Wallis. I am grateful for financial support from ESRC (Grant ES/I035781/1) and the NESTA Innovation Index project. This work contains statistical data from ONS which is crown copyright and reproduced with the permission of the controller HMSO and Queen's Printer for Scotland. The use of ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. All errors are of course my own.
4.1. Executive Summary

This chapter presents the NESTA Innovation Index for the period 1990 to 2009. The aim is to better understand the contribution of innovation to productivity growth in the UK market sector including the contribution of individual industries to the market sector aggregate. In doing so we apply an approach that is consistent with National Accounts methods of measuring output, income and investment. Innovation is estimated by calculating the contributions of a wider range of assets to growth in GDP in a more complete, but national accounts consistent, framework, that avoids double-counting.

The work makes three contributions. First, we set out our approach and results on innovation accounting, namely our best estimate of how much firms are spending on knowledge. Second, we set out our approach and present results using a growth-accounting based innovation index, namely our best estimate of how much all forms of knowledge contribute to growth. Third, we provide new estimates of growth in the UK economy over the period 1990-2009, restated by adding in to the official National Accounts investments in knowledge assets normally counted as intermediate input purchases by firms. Treating these inputs as investment has the effect of raising GDP levels and changing growth rates over the period. We do this for (a) the whole market sector and (b) for eight disaggregated industries.

Knowledge takes different forms, so quantifying it is not straightforward. In this framework we measure (a) investment in intangible assets to approximate the knowledge stock created by firms (b) consider improvements in the knowledge held by workers in the labour force thanks largely to their qualifications and experience and (c) since knowledge can leak across firms (in a way that tangible capital cannot), we also consider freely-available knowledge.

We define our innovation index as the growth in output – that is, value-added created by new products and services, processes and ways of working – over and above the contributions of physical capital and labour hours. Therefore, the widest definition of our index includes the shares of growth which can be attributed to knowledge investment in the market sector, to improvement in labour composition due to education and experience, and to Total Factor Productivity (TFP) which accounts for spillovers and other unmeasured knowledge inputs to firms (as well as measurement error). Other variants of the index include the joint contributions to growth of TFP and knowledge capital.

This builds on previous work on intangible asset spending and growth. It continues the research programme set out in Corrado, Hulten and Sichel (2005; 2006) and Van Ark and Hulten (2007) and incorporates some of the previous work for the UK, including Marrano, Haskel et al. (2009) and the additional industry detail used in previous work, as in Dal Borgo, Goodridge, Haskel and Pesole (2011).
Following that approach, the intangible assets that we measure include software, design, product development in financial services and artistic creation, and investment in brands, firm-specific human capital and organisations. Relative to previous work the following is new:

1. **Improved estimates of intangible spending**

Our improved estimates come from the following sources. First, we have undertaken two runs of the Investment in Intangible Assets survey, asking firms for data on intangible spending and life lengths of intangible assets. This enables us to cross-check our spending and deprecation results against micro data. We find our deprecation assumptions to be largely in line with micro evidence, as is our spending data for software, R&D, marketing and training. More research is necessary to better measure design and spending on organisational capital.

Second, we have improved our methodology for estimating private investments in knowledge. First, we have incorporated new estimates for UK investment in artistic originals (as outlined in Chapter 2 of this thesis). Second we have refined our estimates of purchased assets by eliminating potential double-counting that arises for outsourced or sub-contracted activity.

2. **Industry-level data to better understand the industry contributions to market sector innovation**

Again we provide data at the industry level, consistently aggregated to the market sector, so that we can work out the contributions of each industry to overall growth and innovation. In this work we apply a more complete definition of the UK market sector, including the range of consumer, personal and recreational services contained in section ‘O’ of SIC2003.

3. **Up-to-date official estimates to build market sector GDP, hours, tangible investment and labour skill composition.**

We use Blue Book\textsuperscript{75} data for ONS, published in November 2011 with data up to 2010, and detailed input-output data up to 2009. Due to changes in the Standard Industrial Classification implemented in Blue Book 2011, our data include a mix of Blue Book 2010 and 2011 data, all mapped to SIC2003. We also use the latest ONS data for capital services (VICS) and quality-adjusted labour input (QALI).

Our definition of the UK market sector excludes the public sector, private delivery of public services such as education and health, and dwellings (actual and imputed rents). Dwellings are removed for both conceptual and practical reasons. First, housing services produced by households (imputed rents) do not represent true

\textsuperscript{75} The Blue Book is the annual ONS publication of the UK National Accounts.
economic output. Second, dwellings are not a part of productive capital stock and so its associated services are removed from the output data to be consistent with the capital input data. Third, they inhibit international comparability since the proportions of people that choose to own/rent housing varies across countries for social and cultural reasons. This is standard practice in growth accounting exercises.

4. **Tax adjustment of rental prices for growth accounting.**

Previous work has not tax adjusted the rental prices used for growth accounting. We have constructed a full set of tax-adjustment factors for both tangible and intangible assets. This has meant better estimation of rental prices, capital income shares and the contributions of capital deepening in our dataset. Specifically on intangibles, this adjustment is particularly important for R&D as the R&D tax credit introduced in 2002 had a large impact on the cost of capital which our data now reflects. Appropriate tax adjustment factors for mineral exploration and purchased software are also incorporated.

5. **Data from EUKLEMS, up to 2007, to build industry-level estimates of value added, gross output, intermediate inputs, hours, tangible investment and labour skill composition.**

ONS do not publish data on real intermediate input use and so we use EUKLEMS data for this to undertake gross output growth accounting at the industry level. We then aggregate this up to the market sector level. EUKLEMS data ends in 2007.

With this in mind, our major findings are as follows:

1. **Investment in knowledge.**

UK investment in intangible or knowledge assets has been greater than that for tangible assets since the early 2000's. In 2009 it stood at £124bn, as opposed to £93bn tangible investment. Of that intangible spend, training by firms and organisational capital account for £26bn each, design £16bn, software £23bn and scientific R&D £14bn.

The industry that is most intensive in intangible spend is manufacturing, which invests 17% of value added in intangibles (agriculture is the least intensive at 6%). Financial services was the clear intensity leader in the late 1990s and early 2000s, spending 26% of value added on intangibles (mostly software) in 2001, but has since fallen back to 15%.
The effect of treating intangible expenditure as capital spending is to raise market sector gross value added (MSGVA) growth in the late 1990s, with little change in the 2000s. MSGVA growth is raised in the late 1990s due to strong growth in investment in software, training and organisational change which accompanied the rise of the internet and boom in ICT hardware investment.

2. Innovation in the market sector

Beginning with some background, if we ignore intangibles, labour productivity growth was steady in the 1990s, at 3.07% p.a. in 1990-95 and 3.06% p.a. in 1995-2000. This is contrary to the slowdown reported in most studies. This difference is not due to intangibles, but the result of the incorporation of FISIM, along with new methodology and data for investment in own-account software and numerous other methodological reviews, particularly for the service sector, most of which were incorporated in Blue Book 2008. Labour productivity growth slowed down in the 2000s to 1.44%pa.

When we include intangibles, labour productivity growth speeds up in the 1990s, from 3.36% p.a. in 1990-95, to 3.57% p.a. in 1995-00. From 2000-09, it grew at 1.43% p.a., consisting of 2.45% p.a. between 2000-05 and 0.17% p.a. in 2005-09. Of the 2000-09 growth in value added per hour of 1.43% p.a., we have the following contributions:

- Intangible capital deepening: 0.38% p.a.
- Total factor productivity, that is, learning from knowledge spillovers (plus other mismeasured factors): -0.01% p.a.
- Improved general worker human capital due to formal qualifications, age and experience changes: 0.27% p.a.

If we define innovation as the contribution of knowledge capital and TFP, then innovation raised growth in output per person-hour in the UK by 0.38%+(-0.01%) = 0.37% in 2000-09, which is 33% (0.37/1.43) of labour productivity growth in 2000-09. On this same measure, innovation was responsible for about 64% p.a. of labour productivity growth in the late 1990s, reflecting the boom in investment in software along with the mass take up of the internet, and for 61% of labour productivity growth in the early 1990s.

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76 In the National Accounts, intangible spending is categorised as intermediate consumption. Since gross value-added is defined as gross output less intermediate consumption, treating such spending as investment results in an increase to the level of MSGVA. The impact on growth depends on the respective growth rates of real intangible investment and other real final output, and their shares in adjusted output.

77 Financial Institutions generate revenue in two ways, via direct charges or interest differentials in their lending and borrowing activities. FISIM represents the second, and stands for ‘Financial Intermediation Services Indirectly Measured’.
If we define innovation more widely, that is the contribution of knowledge capital, TFP and labour composition\textsuperscript{78}, we find that innovation raised growth in output per person-hour in the 2000s $0.38\% + (-0.01\%) + 0.27\% = 0.64\%$ p.a. in the 2000s, which is $45\% (0.64/1.43)$ of labour productivity growth.

3. \textit{Innovation in industries and their contribution to the overall market sector}

At the industry level, financial services, manufacturing and business services have the highest industry-level gross output based TFP. Manufacturing, business services and distribution/communications have the highest contributions of intangible investment to their gross output based labour productivity, reflecting strong investment in intangibles in these sectors. Thus the most innovative sectors at the industry level (defined as shares of gross output based labour productivity growth accounted for by intangible spend, improvements in labour composition plus TFP growth) are financial services, business services and manufacturing.

The contributions however of each sector to overall innovation depend upon both this and their weights in overall activity. For intangible investment this depends on the sector’s intangible contribution weight in the total. For TFP, it depends upon the sector’s Domar weight (since an increase in TFP in sector A raises overall TFP, but also TFP in other sectors to the extent that that sector A’s output is an intermediate into other sectors). When all this is added consistently, we find that manufacturing is particularly important. Defining innovation as productivity growth accounted for by growth in intangible capital deepening, labour composition and TFP, manufacturing accounts for $46\%$ of the innovation in the UK market sector (its employment share is only $17\%$). We also find important contributions from distribution/communications, accounting for $29\%$ of innovation, business services which contributes $25\%$ and finance $15\%$ (their employment shares are $36\%$, $20\%$ and $5\%$ respectively).

\textsuperscript{78} Labour services are an adjusted measure of labour input where growth in hours of different worker types are weighted by their share of the total wage-bill. Total labour services therefore reflect input from hours plus additional input due to labour composition. The methodology used is in line with the internationally accepted OECD methodology. Labour services input has grown steadily through the period, reflecting growth in the quality of labour input, while total hours worked have been relatively flat from 1998 until the recent recession when they obviously fell sharply.
4.2. Introduction

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

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

However, there are two points illustrated nicely by Tufano’s (1989) description of a typical financial product innovation. He states it requires

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

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

79 The qualification measured is important. In the UK at least, the Business Enterprise R&D survey (BERD) defines R&D to respondents as ‘undertaken to resolve scientific and technological uncertainty’. Indeed, up until very recently, no firms in financial intermediation for example were even sent a form. See below for more discussion.
This is done by implementing the framework set out in the widely-cited papers by Corrado, Hulten and Sichel (2005; 2009), hereafter CHS. Whilst CHS builds upon the methods of capitalising tangible assets, and intangible assets such as software which are now capitalised in national accounts, it was the first paper to broaden the approach to a fuller range of intangible or knowledge assets. Thus it fits with the range of innovation investments mentioned above.

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

Second, we use these data to perform a sources-of-growth analysis for the UK using the CHS framework. Whilst one might have reservations about the assumptions required for growth accounting, see below, we believe this is also of interest. The main reason is that it enables us to investigate a number of questions that could either not be addressed without these data, or all relegated to the residual. First, as CHS stress, the capitalisation of knowledge changes the measures of both inputs and outputs. Insofar as it changes outputs, it alters the labour productivity picture for an economy. Thus we can ask: what was the productivity performance in the late 1990s when the UK economy was investing very heavily (as we document below) in intangible assets during the early stages of the internet boom? Second, we can then ask: how was that performance accounted for by contributions of labour, tangible capital, intangible capital and the residual? Here we can describe how sources of growth will differ when R&D is capitalised and how other knowledge contributes and alters TFP. Third, we also ask and try to answer this question at industry level. So we can ask, for example, how much productivity in non-R&D intensive sectors, such as retail and financial services, was accounted for by other intangibles or was it mostly TFPG?

In implementing the CHS framework, we proceed as follows, going, we believe, a bit beyond their work for the US. First, we gather data on the intangible assets that CHS suggest, but by industry (Fukao, Miyagawa et

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81 We also shed light on recent considerable interest in “creative” industries, including the software, design, film/television, literary, music, and other artistic industries. Most papers that study such activity select a number of creative industries, and then document their employment or value added from published sources. This understates the output of creative assets, since much intangible creation is done on own-account in industries not in the usual creative list e.g. software spending in financial services or design in retail. Nor does this approach show how much creative industries contribute to economic growth, as we are able to do (conditional on the assumptions we make).
al. (2009) and van Rooijen-Horsten, van den Bergen et al. (2008) do this for Japan and Holland, but they do not do growth accounting to derive the contributions of the industries to the total).

Second, we update some of the methods of CHS. For example, much intangible spend, like R&D, is own-account. CHS had no own-account estimates for design or for financial services. We apply the National Accounts software method to estimate such own-account spending, using interviews with design and financial companies to identify occupations and time use and thereby derive intangible spend from wage data. 82 We have also improved estimates of investment in artistic originals (Goodridge and Haskel 2011), as detailed in Chapter 2, and are currently working with the Office for National Statistics (ONS) and Intellectual Property Office (IPO) to incorporate those into the National Accounts. In addition, there is almost no information on the depreciation of intangible assets. 83 Thus we conducted a survey of over 800 companies on the life lengths of their intangible spend, by asset, to gather data on depreciation. For this work we have re-run that survey with additional sample boosts for the devolved UK countries; Scotland, Wales and Northern Ireland, on this occasion giving us 1,180 total responses from firms on intangible spend and the expected life length of those investments. Similarly little work has been done on the price of intangible assets. Corrado, Goodridge and Haskel (2011) estimate an implied price for R&D assets, with significant implications for measurement of real R&D investment and its contribution to growth. We also apply that price index in this work where indicated.

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

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

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

83 With the honourable exceptions of Soloveichik (2010) who estimates depreciation rates for artistic originals and Peleg (2005) who surveyed a small number of Israeli R&D performers.
extend their framework with additional intangibles, explicitly setting out the industry/market sector aggregation.

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

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

We have two sets of findings (a) on knowledge spending and (b) implications for growth. On knowledge spending, first, investment in long-lived knowledge, which creates intangible assets, now exceeds tangible investment, at around, in 2009, £124bn and £93bn respectively. R&D is about 11% of such spend. Training, organisational investments and software are the largest categories of intangible investment, and are particularly important in services. The effect, of treating intangible expenditure as investment, on market sector gross value added (MSGVA) is to raise MSGVA growth in the 1990s, but very slightly reduce it in the 2000s. Second, around 70% of this spending is own account. Thus measures of the “creative economy” (Mahajan 2006; DCMS 2011) that assemble data for a list of “creative industries” are missing significant creative activity outside those industries.

On the implications for growth, for 2000-09, the most recent period with data available, intangible capital deepening accounts for 26% of labour productivity growth, a larger contribution than computer hardware (15%), telecommunications equipment (2%), and human capital (19%). Other tangibles (buildings, vehicles, non-ICT plant) accounted for 39% of productivity growth. Due to the general slowdown in TFP in the 2000s, followed by the collapse in 2008 and 2009, TFP makes a slight negative contribution at minus 0.4% of LPG. These findings are quite robust to variations in depreciation and assumptions on intangible measures. Capitalized R&D accounts for about 2.5% of LPG and lowers the contribution of TFP by 2 percentage points.
Regarding industries, the main finding here is the importance of manufacturing, which contributes 47% of the total contribution to MSGVA growth of intangible investment and TFPG (but with a 17% share of total hours worked). We also find important roles for distribution/communications, (34% of the total contribution), business services (22%) and finance (18%).

The rest of this chapter proceeds as follows. Section 3 sets out a formal model, and section 4 our data collection. Section 5 presents our results and section 6 concludes.

4.3. A formal model and definitions

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

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

\[
\Delta \ln TFP_j \equiv \Delta \ln Y_j - \bar{v}_{K,j} \Delta \ln K_j - \bar{v}_{L,j} \Delta \ln L_j - \bar{v}_{X,j} \Delta \ln X_j
\]  

(1)

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

\[
\Delta \ln TFP \equiv \Delta \ln V - \bar{v}_K \Delta \ln K - \bar{v}_L \Delta \ln L
\]  

(2)

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

\[
\Delta \ln Y_j \equiv \bar{v}_{V,j} \Delta \ln V_j + \bar{v}_{X,j} \Delta \ln X_j
\]  

(3)
which says that (changes in real) industry gross output are weighted averages of changes in real value added and intermediates. Second, write changes in aggregate real value added as a weighted sum of changes in industry real value added as follows.

\[
\Delta \ln V = \sum_j \bar{w}_j \Delta \ln V_j, \quad w_j = \frac{P_{s,j} V_j}{\sum_j (P_{s,j} V_j)}, \quad \bar{w}_j = 0.5(w_{j,j} + w_{j,j-1})
\]  

(4)

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

\[
\Delta \ln V_j = \frac{V_{K,j}}{V_{V,j}} \Delta \ln K_j + \frac{V_{L,j}}{V_{V,j}} \Delta \ln L_j + \frac{1}{V_{V,j}} \Delta \ln \text{TFP}_j
\]

(5)

where the weights on K and L are a combination of the shares of K and L in industry gross output and the shares of industry value-added in industry gross output. We are now in position to write down our desired relationship, that is the relation between economy-wide real value added growth and its industry contributions

\[
\Delta \ln V = \left(\sum_j \bar{w}_j \frac{V_{K,j}}{V_{V,j}} \Delta \ln K_j \right) + \left(\sum_j \bar{w}_j \frac{V_{L,j}}{V_{V,j}} \Delta \ln L_j \right) + \sum_j \bar{w}_j \Delta \ln \text{TFP}_j
\]

(6)

Which says that the contributions of \(K_j\) and \(L_j\) to whole-economy value added growth depend upon the share of \(V_j\) in total \(V (w_j)\) and the shares of \(K\) and \(L\) in industry gross output and industry value added in industry gross output. The contribution of \(\Delta \ln \text{TFP}_j\) depends on the share of \(V_j\) in total \(V (w_j)\) and the share of industry value added in gross output. As Jorgenson, Ho et al. (2007) point out, the weight on TFP is approximately \((P_{s,j} Y_j / P_s V)\) which is of course the usual interpretation of the Domar (1961) weight. It sums to more than one, since an improvement in industry TFP contributes directly to the average of all TFPs and indirectly if it produces output that is then an intermediate in other industries.\(^\text{84}\)

Finally, in reality we do not of course have one capital and labour unit, but many. These are then aggregated across different types: for labour, see below, we use, education, age (experience), and gender; for capital, different types of both tangible assets and intangible assets. Denoting the capital and labour types \(k\) and \(l\) we

\(^{84}\) As Jorgenson, Ho et al point out, comparing (6) with (2) gives the relation between this industry aggregated input/output relation and that implied by the TFP expression in (2), which involves some additional terms in reallocation of \(K\) and \(L\) between industries. These terms turn out to be very small in our data.
have the following industry and aggregate variables for each type where industry is defined as industry $j$ and the aggregate variables are unsubscripted:

$$\Delta \ln K = \sum_k \tilde{\omega}_k \Delta \ln K_k, \quad \text{capital type } k$$

$$\Delta \ln L = \sum_l \tilde{\omega}_l \Delta \ln L_l, \quad \text{labour type } l$$

$$w_k = \frac{P_{K,k} K_k}{\sum_k (P_{K,k} K_k)}, w_l = \frac{P_{L,l} L_l}{\sum_l P_{L,l} L_l}, \quad K_j = \sum_j K_{j,k} \forall k, L_j = \sum_j L_{j,l} \forall l,$$

$$\tilde{w}_i = 0.5(w_i + w_{i-1}) \quad (7)$$

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

Before proceeding to the data, some further theory remarks on the measurement of capital. As pointed out by e.g. Jorgenson and Griliches (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 (2001b). We estimate the now standard measure as follows. First, we build a real capital stock via the perpetual inventory method whereby for any capital asset $k$, the stock of that asset evolves according to

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

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

4.4.1. Time period

For the industry analysis, ONS does not publish real intermediate input data and so we used the EUKLEMS, November 2009 release which gives data up to 2007. For intangibles, our industry level data is available 1992-2009 since this is when Input-Output (IO) tables are consistently available from. Data for the whole market sector is available going back to 1980 up to 2010 (the most recent year National Accounts are available). Thus we work with two data sets: (1) market sector, 1980-2009, consistent with National Accounts 2011, and (2) industry level 1992-2007 (the data turn out to be very close over the overlapping years).

4.4.2. Industries

The EUKLEMS data includes measures of output, and various categories of employment and capital at the industry level for 71 industries, classified according to the European NACE revision 1 classification. We then aggregate these data to the eight industries described in Table 4.1. The choice of the eight industries is dictated by the availability of the intangible data: training and management consulting data are only available at these aggregated levels for example.

Table 4.1: Definition of eight industries

<table>
<thead>
<tr>
<th>#</th>
<th>Sectors</th>
<th>SIC(2003) code</th>
<th>NACE1 sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agriculture, Fishing and Mining (AgrMin)</td>
<td>1-14</td>
<td>A Agriculture, hunting and forestry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>B Fishing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C Mining and quarrying</td>
</tr>
<tr>
<td>2</td>
<td>Manufacturing (Mfr)</td>
<td>15 - 37</td>
<td>D Total manufacturing</td>
</tr>
<tr>
<td>3</td>
<td>Electricity, Gas and Water Supply (Util)</td>
<td>40 - 41</td>
<td>E Electricity, gas and water supply</td>
</tr>
<tr>
<td>4</td>
<td>Construction (Constr)</td>
<td>45</td>
<td>F Construction</td>
</tr>
<tr>
<td>5</td>
<td>Wholesale and Retail Trade, Hotels and Restaurants, Transport and Communications (RtHtTran)</td>
<td>50 - 64</td>
<td>G Wholesale and retail trade</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H Hotels and restaurants</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>I Transport and storage and communication</td>
</tr>
<tr>
<td>6</td>
<td>Financial Services (FinSvc)</td>
<td>65 - 69</td>
<td>J Financial services</td>
</tr>
<tr>
<td>7</td>
<td>Business Services (BusSvc)</td>
<td>71- 74</td>
<td>K Business activities (excluding imputed and actual letting of dwellings)</td>
</tr>
<tr>
<td>8</td>
<td>Personal Services (PersSvc)</td>
<td>90-97</td>
<td>OP Other community, social and personal service activities; Private households with employed persons</td>
</tr>
</tbody>
</table>

We measure output for the market sector, defined here as industries A to K and OP as in EUKLEMS, excluding actual and imputed housing rents. Note this differs from the ONS official market sector definition, which includes part of section O, as well as the private delivery of education, health and social care. We also used disaggregated real value added data for this industry definition.
For the years where industry level data is available, the data are bottom-up, that is derived at the industry level and aggregated subsequently. Aggregation of nominal variables is by simple addition. Aggregates of real variables are a share-weighted superlative index for changes, benchmarked in levels to 2005 nominal data. For other years, the intangible data are for the market sector and the other output and input data from ONS, latest National Accounts, aggregated from industry values.

4.4.3. Outputs and tangible and labour inputs.

EUKLEMS also provides growth accounting data, but since we have expanded the amount of capital and changed value added we do our own growth accounting. In addition, the EUKLEMS labour composition data is slightly different to the ONS data due to differences in the method and compositional breakdown as well as the series on actual hours worked. From the output and intermediate accounts of the EU KLEMS dataset we have used the series of industry Gross Output and Gross Value Added at current basic prices, Intermediate Inputs at current purchasers’ prices and their corresponding price and volume indices. Intermediate inputs comprise energy, materials and services.

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

The EUKLEMS capital data distinguishes nine asset types, of which we use transport equipment, computing and communications equipment, other machinery and equipment and total non-residential investment. We use ONS estimates for software and mineral exploration, and our own estimates for artistic originals; the latter are expected to be incorporated into ONS estimates in the near future. We excluded residential structures (they are not capital for firm productivity analysis).

Depreciation rates for ICT tangible capital are as in the EUKLEMS. Depreciation is assumed to be geometric at rates for vehicles, buildings, plant and computer equipment of 0.25, 0.025, 0.13 and 0.40 respectively. As for intangible assets, they are assumed to be the same for all industries. In contrast to previous work, we have now incorporated appropriate tax adjustment factors for all assets, tangible and intangible.
4.4.4. **Labour services**

The labour services data are for 1992-2007 and are our own estimates based on ONS person-hours by industry. We use these along with LFS microdata to estimate composition-adjusted person hours, where the adjustment uses wage bill shares for composition groups for age, education and gender. Person hours are annual person-hours, with persons including the employed, self-employed and those with multiple jobs. Data are grossed up using population weights.

4.4.5. **Comparison with ONS data**

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

4.4.6. **Labour and capital shares**

The Compensation of Employees (COE) data are consistent with the labour services data. Mixed income is allocated to labour and capital according to the ratio of labour payments to MSGVA excluding mixed income. Gross operating surplus (GOS) is always computed as MSGVA less COE so that GOS +COE =MSGVA by construction.

4.4.7. **Details of measurement of intangible Assets**

CHS (2006) distinguish three classes of intangible assets:

i) **computerised information**: software and databases

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

iii) **economic competencies**: firm investment in reputation, human and organisational capital.
Our intangible data update industry-level data reported in Gil, Haskel et al. (2008). Own account investment is allocated to the industry wherein the investment is carried out. Purchased is allocated to industries via the input output tables, with the exception of organisational capital which is allocated using MCA industry information.\textsuperscript{85} Particular industry categories (e.g. product development in finance, exploration of minerals, copyright) are allocated to that industry.\textsuperscript{86}

\textit{Computerised information}

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

\textit{Innovative property}

For business \textit{Scientific R&D} we use expenditure data by industry derived from the Business Enterprise R&D survey (BERD). To avoid double counting of R&D and software investment, we subtract R&D spending in “computer and related activities” (SIC 72) from R&D spending since this is already included in the software investment data.\textsuperscript{87} Since BERD also includes physical capital investments we convert those investments into a capital compensation term, using the resulting physical capital stocks for the R&D sector and the user cost relation.\textsuperscript{88}

\textsuperscript{85} IO data refers to the product “market research and management consultancy” up to BB2010 and “services of head offices; management consulting services” in BB2011. Due to the implied differences with the MCA data in the i) the industry composition of purchases; ii) the level of those purchases; iii) growth in such purchases and even iv) the direction of growth in recent years, we have chosen to base our industry breakdown on that published by the MCA.

\textsuperscript{86} Copyright, or more accurately, investment in artistic originals, is problematic for the correct allocation likely is somewhere between publishers (manufacturing) and artists, since each have some ownership share of the final original. The latter are mostly in the omitted sector “O”, which covers a miscellany of businesses from performing arts to museums. For simplicity we have allocated all investment in artistic and literary originals to O. Overall however, the numbers are small and any error in allocation is likely trivial.

\textsuperscript{87} The BERD data gives data on own-account spending. Spending is allocated to the industry within which the product upon which firms are spending belongs. That is we assume that R&D on say, pharmaceutical products takes place in the pharmaceutical industry. General R&D spending is allocated to business services. Thus the BERD data differs from that in the supply use tables, which estimates between-unit transactions of R&D.

\textsuperscript{88} \[ P^K = P^I (\rho + \delta) \], where \( P^K \) is the rental price of physical capital; \( P^I \) is the asset price, \( \rho \) is the net rate of return and \( \delta \) is the depreciation rate.
Like computerised information, mineral exploration, and production of artistic originals (copyright for short) are already capitalised in National Accounts. Data for mineral exploration here are simply data for Gross Fixed Capital Formation (GFCF) from the ONS, valued at cost ONS (1998) and explicitly not included in R&D. Data for copyright are our own estimates produced with the co-operation of ONS and the Intellectual Property Office, as detailed in Chapter 2. The production of artistic originals covers, “original films, sound recordings, manuscripts, tapes etc., on which musical and drama performances, TV and radio programmes, and literary and artistic output are recorded.”

The measurement methodology for New product development costs in the financial industry follows that of own account software above (and therefore replaces the CHS assumption of 20 per cent of intermediate consumption by the financial services industry). This new method reduces this category substantially. Further details are in Haskel and Pesole (2010) but a brief outline is as follows. First, we interviewed a number of financial firms to try to identify the job titles of workers who were responsible for product development. Second, we compared these titles with the available occupational and wage data from the Annual Survey on Hours and Earnings (ASHE). The occupational classification most aligned with the job titles was ‘economists, statisticians and researchers’. Third, we asked our interviewees how much time was spent by these occupations on developing new products that would last more than a year. Some firms based their estimates on time sheets that staff filled out. Fourth, we asked firms about the associated overhead costs with such workers. Armed with these estimates, we went to the occupational data in the ASHE and derived a time series of earnings for those particular occupations in financial intermediation. Own-account investment in product development is therefore the wage bill, times a mark-up for other costs (capital, overheads etc.), times the fraction of time those occupations spend on building long-term projects. All this comes to around 0.52% of gross output in 2005 (note that reported R&D in BERD is 0.01% of gross output).

For new architectural and engineering design we again updated the CHS method (that used output of the design industry). To measure better such spending, we used the software method for own-account, and purchased data, by industry, are taken from the supply-use tables, see details in Galindo-Rueda, Haskel et al. (2008). Our estimates for purchased design as contained in this paper are lower than those published in previous years. The reason is that we have chosen to exclude purchases of design by the industry itself (‘Other Business Services’, SIC74), since some of these purchases will certainly include outsourcing and subcontracting arrangements which would be double-counting. The choice of occupations and the time allocation are, as in financial services, taken from interviews with a number of design firms. Interestingly, almost all of the design firms we interviewed have time sheets for their employees which break out their time into administration, design and client interaction/pitching for new business (almost all firms target, for example, that junior designers spend little time on administration and senior more time on pitching). Finally,
R&D in social sciences and humanities is estimated as twice the turnover of SIC73.2 “Social sciences and humanities”, where the doubling is assumed to capture own-account spending. This is a small number.

Economic competencies

Advertising expenditure is estimated from the IO Tables by summing intermediate consumption on Advertising and market research services (product group 73) for each industry. Our estimates for advertising and market research as contained in this report are lower than those published in previous years. The reason is that we have chosen to exclude purchases of marketing services by the industry itself (‘Other Business Services’, SIC74), since some of these purchases will include outsourcing and subcontracting arrangements which would be double-counting.

Firm-specific human capital, that is training provided by firms, was estimated as follows. Whilst there are a number of surveys (such as the Labour Force Survey) which ask binary questions (such as whether the worker received training around the Census date), to the best of our knowledge there is only one survey on company training spending, namely the National Employer Skills Survey (NESS) which we have available for 2004 and 2006-09. We also have summary data for 1988 (from an unpublished paper kindly supplied by John Barber). The key feature of the survey, like the US Survey of Employer-provided Training (SEPT) used in CHS, is that it asks for direct employer spending on training (e.g. in house training centres, courses bought in etc.) and indirect costs via the opportunity cost of the employee’s time whilst training and therefore not in current production. This opportunity costs turns out to be about equal to the former.

One question is whether all such surveyed training creates a lasting asset or is some of it short-lived. We lack detailed knowledge on this, but the NESS does ask what proportion of training spend is on Health and Safety or Induction Training. In the past we have subtracted spending on Health and Safety training, which was around 10% of total spend. Our new data has a component for both Health and Safety and Induction training, and we note that in the production industries this is between 30 and 40 per cent of the total. Since it seems reasonable that Health and Safety training may have more impact on firm productivity in the production industries compared to say Business Services, and that Induction training in production may be more likely to include training on job-specific skills, we decided to include this component for production but exclude it in the service sector. Whilst this subtraction lowers the level of training spending, it turns out

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

90 Firms are asked how many paid hours workers spend away from production whilst training and the hourly wage of such workers.
to have little impact on the contribution of training to growth. A second question is the extent to which such training financed by the firm might be incident on the worker, in the sense of reducing worker pay relative to what it might have been without training, unobserved by the data gatherer. O’Mahony and Peng (2010) use the fraction of time that training is reported to be outside working hours, arguing that such a fraction is borne by the worker. Our data is for all training in working hours.

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

4.4.8. Prices and depreciation

Rates of depreciation and the prices of intangible assets are less well established. The R&D literature appears to have settled on a depreciation rate of around 15-20%, and OECD recommend 33% for software. Soloveichik (2010a) has a range of 5% to 30% for artistic originals, depending on the particular asset in question. To shed light on this and the depreciation of other assets, in our intangible assets survey we asked for life lengths for various intangibles (Awano, Franklin et al. 2010b). The responses we obtained were close to the assumed depreciation rates in CHS, depending on the assumptions one makes about declining balance depreciation. Thus we use 33% for software, 60% for advertising and market research, 40% for training and organisational investments, and 20% for R&D. Once again, we shall explore the robustness of our results to depreciation, but note in passing that our assets are assumed to depreciate very fast and so are not very sensitive to depreciation rates, unless one assumes much slower rates, in which case intangibles are even more important than suggested here.

The asset price deflators for software are the official deflators (own-account and purchased), but otherwise the GDP deflator is used for intangible assets. This is an area where almost nothing is known, aside from some very exploratory work by the BEA (e.g. Copeland, Medeiros et al. (2007)) and Corrado, Goodridge and Haskel (2011). These papers attempt to derive price deflators for knowledge from the price behaviour of knowledge intensive industries and the productivity of knowledge producing industries. Chapter 3 presented work that estimated the price of own-account software by explicitly considering productivity change in that sector. Two observations suggest that using the GDP deflator overstates the price deflator for knowledge, and so understates the impact of knowledge on the economy. First, many knowledge-intensive prices have been falling relative to GDP prices. Second, the advent of the internet and computers would seem to present

91 When excluding Health and Safety and induction training from the service sector, our estimates of the contribution of training capital deepening to growth are: (1990-95) 0.09%; (1995-00) 0.13%; (2000-09) 0.06%. Once we include the omitted expenditure, they change to: (1990-95) 0.12%; (1995-00) 0.16%; (2000-09) 0.08%.
a potential large rise in the capability of innovators to innovate, which would again suggest a lowering of the price of knowledge, in contrast to the rise in prices implied by the GDP deflator. Thus our use of the GDP deflator almost certainly understates the importance of intangible assets.

4.4.9. Relation of intangible approach to other approaches

Haskel, Goodridge et al. (2011) discusses how this work relates to the definition of innovation and the Frascati and Oslo manuals. It is clearly consistent with the work on IT and economic growth, see, for example, Jorgenson, Ho et al. (2007), the capitalisation of software and the forthcoming capitalisation of R&D in national accounts, both of which are part of the process of recognizing spending on intangibles as building a (knowledge) capital stock. Van Ark and Hulten (2007) point out that with an expanded view of capital following the CHS argument innovation “...would appear in several forms in the sources of growth framework: through the explicit breakout of IT capital formation, through the addition of intangible capital to both the input and output sides of the source of growth equation, through the inclusion of human capital formation in the form of changes in labor “quality,” and through the “multifactor productivity” (MFP) residual.” For shorthand, we refer to the “innovation” contribution as the sum of the intangible contribution and TFP (and sometimes labour composition), but take no stand on this: we provide other components for the reader.

4.4.10. Accuracy of intangible measures

The following points are worth making. First, data on minerals, copyright, software and R&D are taken from official sources. As mentioned above, official data is an undercount of copyright spending and so we use our own data for that, but we are currently working with ONS to incorporate them in to the official data. Second, data on workplace training are taken from successive waves of an official government survey, weighted using ONS sampling weights. Once again one might worry that such data are subject to biases and the like but this does look like the best source currently available.

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

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

Second, we undertook our own survey of firms for a second year. The results of the first survey are fully documented in Awano, Franklin et al. (2010a). Results from the second year will be available in the near future. In terms of the spending numbers here, that micro study found spending on R&D, software, marketing and training to be in line with the macro-based numbers in this report. However, the implied spending on design and organisational capital were very much lower in the survey. This again suggests that these investment data require further work.

4.5. Results

4.5.1. Intangible spending: market sector over time

Figure 4.1 presents market sector nominal total tangible and intangible investment data. In the 2000s intangible investment has exceeded tangible. Note that in previous years our data have shown intangible investment to be greater than tangible from an earlier point. That feature of the data was due to the coverage of market sector activity, which excluded a large part of the service sector. We have rectified that for this work, with a new definition of the UK market sector that is consistent with that used in EUKLEMS, but note that the new sector (‘O’) is highly capital intensive particularly in buildings (sports stadia etc.) thus adding much more tangible investment into our dataset. It is also not possible to exclude some of the non-market elements of this industry which are also quite capital intensive.

Note that, intangible investment has fallen less than tangible investment in the recent recession. In 2008-09 tangible investment fell sharply whilst although intangible investment does fall it is nowhere near as steeply. Part of the effect in the case of tangibles may be due to the sharp increase that took place in 2007, part of which may have been an ‘Olympic effect’ from associated infrastructure investment. However, depreciation rates for intangible assets are significantly faster than those for tangibles. Thus a relatively small slowdown in intangible investment turns out to generate the same fall in capital stock as a steep fall in tangible spend, so the changes in resulting capital services are similar.
Table 4.2 shows investment by intangible asset for 1990, 1995, 2000 2005, 2008 and 2009 with tangible investment included for comparison. The intangible category with the highest investment figures is training, growing to over a quarter of tangible investment by 2009 and over double that of ICT tangible (hardware and telecommunications) investment. For information we also report MSGVA including and excluding intangibles.
Table 4.2: Tangible and Intangible Investment, £bns

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<tr>
<th></th>
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</thead>
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<td>5.7</td>
<td>9.2</td>
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<td>10.6</td>
<td>9.1</td>
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<td>10.2</td>
<td>12.2</td>
<td>13.5</td>
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<td><strong>Total Software</strong></td>
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<td>22.6</td>
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<td>14.4</td>
<td>14.0</td>
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<td>13.5</td>
<td>15.5</td>
<td>15.5</td>
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<td>0.3</td>
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<td>0.8</td>
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<td>Mineral Exploration</td>
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<td>0.4</td>
<td>0.6</td>
<td>0.6</td>
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<td>Financial Innovation</td>
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<td>0.9</td>
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<td>1.5</td>
</tr>
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<td>Film Originals</td>
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<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>TV (fiction) Originals</td>
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<td>0.9</td>
<td>1.2</td>
<td>1.5</td>
<td>1.6</td>
<td>1.4</td>
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<tr>
<td>TV (non-fiction) Originals</td>
<td>0.2</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Total TV Originals</td>
<td>0.7</td>
<td>1.4</td>
<td>1.7</td>
<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Literary Originals</td>
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<td>1.0</td>
<td>1.1</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
</tr>
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<td>Music Originals</td>
<td>0.9</td>
<td>1.4</td>
<td>1.7</td>
<td>1.7</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Miscellaneous Art</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total Artistic Originals</strong></td>
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<td>5.0</td>
<td>5.2</td>
<td>5.0</td>
<td>5.1</td>
</tr>
<tr>
<td><strong>Total Innovative Property</strong></td>
<td>19.1</td>
<td>21.2</td>
<td>27.2</td>
<td>32.5</td>
<td>37.4</td>
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</tr>
<tr>
<td>Advertising</td>
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<td>9.4</td>
<td>10.0</td>
<td>10.8</td>
<td>10.8</td>
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<tr>
<td>Market Research</td>
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<td>1.2</td>
<td>1.5</td>
<td>2.4</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Total Branding</strong></td>
<td>5.2</td>
<td>7.2</td>
<td>10.8</td>
<td>12.4</td>
<td>12.9</td>
<td>12.8</td>
</tr>
<tr>
<td>Own-Account Organisational Capital</td>
<td>4.6</td>
<td>9.8</td>
<td>14.5</td>
<td>19.5</td>
<td>23.5</td>
<td>21.8</td>
</tr>
<tr>
<td>Purchased Organisational Capital</td>
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<td>1.7</td>
<td>3.3</td>
<td>6.0</td>
<td>4.4</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>Total Organisational Capital</strong></td>
<td>5.4</td>
<td>11.4</td>
<td>17.8</td>
<td>25.5</td>
<td>27.9</td>
<td>25.7</td>
</tr>
<tr>
<td>Training</td>
<td>12.3</td>
<td>14.9</td>
<td>21.4</td>
<td>26.6</td>
<td>27.4</td>
<td>25.8</td>
</tr>
<tr>
<td><strong>Total Economic Competencies</strong></td>
<td>22.9</td>
<td>33.5</td>
<td>50.0</td>
<td>64.6</td>
<td>68.2</td>
<td>64.3</td>
</tr>
<tr>
<td><strong>TOTAL INTANGIBLES</strong></td>
<td>48.2</td>
<td>64.7</td>
<td>93.7</td>
<td>115.7</td>
<td>128.4</td>
<td>124.2</td>
</tr>
<tr>
<td>Buildings</td>
<td>30.1</td>
<td>21.8</td>
<td>34.5</td>
<td>35.9</td>
<td>50.1</td>
<td>40.7</td>
</tr>
<tr>
<td>Plant &amp; Machinery (excl ICT)</td>
<td>25.5</td>
<td>25.8</td>
<td>33.9</td>
<td>34.5</td>
<td>35.6</td>
<td>27.8</td>
</tr>
<tr>
<td>Vehicles</td>
<td>9.4</td>
<td>9.8</td>
<td>12.3</td>
<td>14.3</td>
<td>14.5</td>
<td>11.9</td>
</tr>
<tr>
<td>IT Hardware</td>
<td>6.2</td>
<td>9.0</td>
<td>15.9</td>
<td>12.4</td>
<td>11.1</td>
<td>8.6</td>
</tr>
<tr>
<td>CT</td>
<td>2.9</td>
<td>3.6</td>
<td>7.4</td>
<td>5.1</td>
<td>4.5</td>
<td>3.7</td>
</tr>
<tr>
<td><strong>ICT (excluding software)</strong></td>
<td>9.1</td>
<td>12.7</td>
<td>23.3</td>
<td>17.5</td>
<td>15.7</td>
<td>12.3</td>
</tr>
<tr>
<td><strong>TOTAL TANGIBLES</strong></td>
<td>74.1</td>
<td>70.1</td>
<td>104.0</td>
<td>102.1</td>
<td>115.9</td>
<td>92.7</td>
</tr>
<tr>
<td>MSGVA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without intangibles</td>
<td>393.8</td>
<td>485.1</td>
<td>642.0</td>
<td>812.4</td>
<td>946.2</td>
<td>900.0</td>
</tr>
<tr>
<td>with NA intangibles</td>
<td>403.4</td>
<td>500.2</td>
<td>663.9</td>
<td>836.7</td>
<td>974.7</td>
<td>928.2</td>
</tr>
<tr>
<td>with all CHS intangibles</td>
<td>442.0</td>
<td>549.8</td>
<td>735.7</td>
<td>928.1</td>
<td>1074.7</td>
<td>1024.2</td>
</tr>
</tbody>
</table>

Note to table. Data are investment figures, in £bns, current prices: italicised data are sub-totals for broader asset definitions. ‘Design’ refers to architectural & engineering design. MSGVA is presented with no intangibles capitalised; with only NA intangibles capitalised (software, mineral exploration and artistic originals); and with all CHS intangibles capitalised. Market Sector refers to sectors A to K plus OP, excluding residential real estate.

Source: ONS data for tangibles, this paper for intangibles.
In Figure 4.2 we report tangible and intangible investment as shares of MSGVA, where output has been adjusted for the capitalisation of all intangibles. There are three main points to note. First note the steady consistent decline in market sector investment across all assets as a share of value-added, falling from approximately 27% in 1999 to 21% in 2009. Looking at data from before the recent recession, the aggregate share stood at 23% in 2007. Second, within total investment, tangible investment as a share of MSGVA has fallen very sharply. After the recession in the early 1990s tangible investment recovered to almost 15% of value-added in 1998, and then declined to around 11% in 2007, and to 9% in 2009. Third, intangible investment as a share of value-added rose steadily throughout the 1990s, peaking at almost 13% in 2001 and declining very slightly since then to 12% in 2009. It is worth noting that although the decline in tangible investment is somewhat compensated for by the steady profile of intangible investment, assets in the latter category tend to have much higher depreciation rates than tangibles, with implications for the level and growth of the UK market sector aggregate capital stock.

**Figure 4.2: Market Sector tangible and intangible investment as a share of (adjusted) MSGVA, 1990-2009**

Note to figure: Solid line in intangible investment as a share of MSGVA. Dashed line is tangible investment as a share of MSGVA. Dotted line is total investment as a share of MSGVA. MSGVA has been adjusted for the capitalisation of all CHS intangibles for all three series’. Intangible investment data also incorporate all CHS intangibles.
Although not presented here, one point to note on the data within tangibles is that ICT as a share of tangible investment has declined since the ICT investment boom in the late 1990s, as has plant and machinery, with strong growth in investment in buildings\textsuperscript{92} as a share of tangible investment even in the most recent years.

4.5.2. \textit{Industry intangible investment}

Table 4.3 reports tangible and intangible investment by industry and for the market sector over the years 1997 to 2007. Finance and manufacturing invest very strongly in intangibles relative to tangibles: in both sectors, intangible investment is three times that in tangibles. It is interesting to note in passing that this raises important questions on how to classify manufacturing since it is undertaking a good deal of intangible activity (manufacturing own-account intangible investment is 17\% of value added by 2007 for example).

Table 4.4 is based on the same data as that presented in Table 4.3 but presents a breakdown by both asset and industry for 2007. It shows the prevalence of R&D investment in manufacturing; design and training in construction; software, training and organisational investments in distribution and communications; software and organisational investments in finance; training in business services; and creation of artistic originals in recreational services.

\textsuperscript{92}Note that here buildings refers to commercial property. Residential dwellings are excluded from our data since they do not form part of the productive capital stock.
Table 4.3: Tangible and Intangible investment, by industry, Current Prices £bns

<table>
<thead>
<tr>
<th>Year</th>
<th>Agriculture and Fishing; Mining</th>
<th>Manufacturing</th>
<th>Utilities</th>
<th>Construction</th>
<th>Retail &amp; Wholesale; Hotels &amp; Restaurants; Transport &amp; Comms</th>
<th>Financial Services</th>
<th>Business Services</th>
<th>Community, Social and Personal Services</th>
<th>Market Sector (A-K &amp; OP)</th>
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</thead>
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<tr>
<td>1997</td>
<td>6.98</td>
<td>2.66</td>
<td>18.11</td>
<td>23.65</td>
<td>4.98</td>
<td>1.50</td>
<td>1.80</td>
<td>3.25</td>
<td>28.43</td>
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<tr>
<td>1998</td>
<td>7.76</td>
<td>2.22</td>
<td>18.47</td>
<td>25.48</td>
<td>5.26</td>
<td>1.65</td>
<td>1.70</td>
<td>3.48</td>
<td>33.14</td>
</tr>
<tr>
<td>1999</td>
<td>6.22</td>
<td>2.01</td>
<td>16.54</td>
<td>26.69</td>
<td>5.56</td>
<td>1.74</td>
<td>1.89</td>
<td>3.84</td>
<td>33.94</td>
</tr>
<tr>
<td>2000</td>
<td>5.04</td>
<td>1.82</td>
<td>16.18</td>
<td>26.98</td>
<td>5.06</td>
<td>1.80</td>
<td>1.99</td>
<td>4.13</td>
<td>38.60</td>
</tr>
<tr>
<td>2001</td>
<td>6.13</td>
<td>1.91</td>
<td>14.67</td>
<td>28.18</td>
<td>5.33</td>
<td>1.87</td>
<td>2.15</td>
<td>4.39</td>
<td>38.13</td>
</tr>
<tr>
<td>2002</td>
<td>7.24</td>
<td>2.05</td>
<td>12.26</td>
<td>27.74</td>
<td>4.77</td>
<td>1.80</td>
<td>3.12</td>
<td>5.01</td>
<td>38.11</td>
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<tr>
<td>2003</td>
<td>6.88</td>
<td>2.09</td>
<td>11.93</td>
<td>27.90</td>
<td>4.82</td>
<td>1.72</td>
<td>3.11</td>
<td>5.51</td>
<td>35.08</td>
</tr>
<tr>
<td>2004</td>
<td>6.81</td>
<td>2.01</td>
<td>11.78</td>
<td>28.15</td>
<td>2.68</td>
<td>1.79</td>
<td>3.63</td>
<td>5.83</td>
<td>36.65</td>
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<tr>
<td>2005</td>
<td>6.63</td>
<td>2.19</td>
<td>11.57</td>
<td>29.08</td>
<td>3.73</td>
<td>2.03</td>
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<td>35.58</td>
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<tr>
<td>2006</td>
<td>7.04</td>
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<td>11.16</td>
<td>28.98</td>
<td>5.04</td>
<td>2.34</td>
<td>3.20</td>
<td>6.78</td>
<td>35.81</td>
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<tr>
<td>2007</td>
<td>8.26</td>
<td>2.52</td>
<td>11.98</td>
<td>29.46</td>
<td>6.92</td>
<td>2.46</td>
<td>3.15</td>
<td>7.42</td>
<td>39.81</td>
</tr>
</tbody>
</table>

Source: authors’ calculations using EUKLEMS data for tangibles and methods in this paper for intangibles.
Table 4.4: Intangible investment, by asset and industry, 2007, Current Prices £bns

<table>
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<tr>
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</thead>
<tbody>
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<td>Agriculture; Mining</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.5</td>
<td>0.5</td>
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<td>Manufacturing</td>
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<td>11.8</td>
<td>3.8</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>3.8</td>
<td>4.9</td>
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<td>0.0</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Construction</td>
<td>0.4</td>
<td>0.0</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>2.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Distribution; Hotels; Transport</td>
<td>6.1</td>
<td>1.6</td>
<td>3.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4.6</td>
<td>8.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Finance</td>
<td>4.7</td>
<td>0.0</td>
<td>1.6</td>
<td>0.0</td>
<td>1.2</td>
<td>0.0</td>
<td>0.0</td>
<td>2.4</td>
<td>1.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Business Services</td>
<td>5.1</td>
<td>0.0</td>
<td>2.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.6</td>
<td>0.0</td>
<td>1.4</td>
<td>10.1</td>
<td>5.2</td>
</tr>
<tr>
<td>Personal Services</td>
<td>1.3</td>
<td>0.0</td>
<td>1.0</td>
<td>5.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.1</td>
<td>2.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Source: authors’ calculations.
Figure 4.3 shows the ratios of total investment in all intangible categories to industry value added (where industry value added equals conventional value added plus additional intangible investment not officially capitalised). Note the initial very high level in financial services due to the software boom in the late 1990s, especially in the run up to Y2K. Since, then it is worth noting that manufacturing and personal services are the most intangible investment intensive, at 17% and 16% of industry-value-added respectively in 2007.

**Figure 4.3: Ratio of investment to (adjusted) value-added ratios, by industry (1997-2007)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Ag, Fish, Mining</th>
<th>Mfring</th>
<th>Elect, Gas, Water</th>
<th>Constr’n</th>
<th>Retail, Hotels, T’port</th>
<th>Fin Svcs</th>
<th>Bis Svcs</th>
<th>Pers Svcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Which particular intangible assets are most important in which industries? Table 4.5 shows the asset share of total intangible spending by industry (in 2007, the shares are very stable over time). Starting with manufacturing, the largest share of all intangible spending is innovative property (53%), with software 10%. Compare with financial intermediation, where innovative property accounts for only 17% whereas “ecom” (training, branding and organization building) accounts for 54%, whilst software is 28%. Similarly, in distribution/communications, software and economic competencies are more important than innovative property. In our new industry, Community and Personal Services, innovative property accounts for 52% of intangible investment. Note here that innovative property here includes the creation of new
artistic originals in film, television, music, literary and miscellaneous works. Software and economic competencies account for 11% and 36% respectively.

To shed light on the importance of non-R&D spend outside manufacturing, the lower panel sets out some detail on selected individual measures. As the top line shows, R&D accounts, in manufacturing, for 40% of all intangible spend, but 0% in all services with the exception of 5% in distribution & communications. Training, line 2, accounts for 13% in manufacturing, 26% in distribution & communications and 8% in finance, but 41% in business services. Investment in organisational capital, line 3, is 17% in manufacturing, 25% in distributive trade and a considerable 32% in finance. Finally, branding is almost twice as important in distribution and finance as in manufacturing. Thus we can conclude that the “non-R&D” intangible spend, outside manufacturing, is mostly due to software, training, organisational capital and branding.

Table 4.5: Shares of total industry intangible investment accounted for by individual intangible asset categories (for 2007)

<table>
<thead>
<tr>
<th>Shares</th>
<th>AgrMin</th>
<th>Mfr</th>
<th>Utilities</th>
<th>Constr</th>
<th>RtHtTrs</th>
<th>FinSvc</th>
<th>BusSvc</th>
<th>PersSvc</th>
</tr>
</thead>
<tbody>
<tr>
<td>soft</td>
<td>0.08</td>
<td>0.10</td>
<td>0.23</td>
<td>0.06</td>
<td>0.20</td>
<td>0.28</td>
<td>0.20</td>
<td>0.11</td>
</tr>
<tr>
<td>innop</td>
<td>0.47</td>
<td>0.53</td>
<td>0.16</td>
<td>0.31</td>
<td>0.15</td>
<td>0.17</td>
<td>0.13</td>
<td>0.52</td>
</tr>
<tr>
<td>ecom</td>
<td>0.44</td>
<td>0.37</td>
<td>0.60</td>
<td>0.63</td>
<td>0.65</td>
<td>0.54</td>
<td>0.67</td>
<td>0.36</td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Individual Assets:</th>
<th>R&amp;D</th>
<th>Training</th>
<th>Organisational</th>
<th>Branding</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D</td>
<td>0.04</td>
<td>0.22</td>
<td>0.20</td>
<td>0.03</td>
</tr>
<tr>
<td>Training</td>
<td>0.40</td>
<td>0.13</td>
<td>0.17</td>
<td>0.08</td>
</tr>
<tr>
<td>Organisational</td>
<td>0.02</td>
<td>0.26</td>
<td>0.28</td>
<td>0.07</td>
</tr>
<tr>
<td>Branding</td>
<td>0.00</td>
<td>0.35</td>
<td>0.22</td>
<td>0.06</td>
</tr>
</tbody>
</table>

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

4.6.1. Growth accounting results for the market economy

Our growth accounting results are set out in Table 4.6, which reads as follows. The first column is labour productivity growth (LPG) in per hour terms. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times the share of labour in MSGVA. Column 3 is growth in computer capital services times the share of payments for computer services in MSGVA. Column 4 is growth in telecommunications capital services times share in MSGVA. Column 5 is growth in other tangible capital services (buildings, plant, vehicles) times share in MSGVA. Column 6 is growth in intangible capital services times share in MSGVA. Column 7 is TFP, namely column 1 minus the sum of columns 2 to 6. Column 8 is the share of labour payments in MSGVA. Columns 9 to 12 are the shares of particular contributions, shown in the table heading, to form alternative versions of the ‘innovation index’.

Consider first the top panel of data, which reports the contributions to growth in a standard framework that does not include intangibles. LPG was steady in the 1990s and then slowed strongly in the 2000s. Note that were it not for the introduction of a new methodology for FISIM and other methodological changes in the 2008 and 2009 National Accounts, see Haskel, Goodridge et al. (2011), labour productivity growth in the late 1990s especially would have been measured as substantially lower. The contribution of labour quality, column 2, rose in the late 1990s. Computer capital input grew quickly in the 1990s, but fell in the 2000s. The opposite profile occurs for other tangibles (buildings, plant and vehicles) leaving the overall contribution of tangible capital stable in the 1990s but falling in the 2000s. Therefore the overall contribution of tangible capital as a share of LPG was also stable in the 1990s at 39% of LPG but grew strongly in the 2000s to 66% of LPG. Thus the overall TFP record was a small fall in the second half of the 1990s and then a strong fall in the 2000s to a low rate of 0.17% p.a.

Consider now the second set of results in panel 1, where we include intangibles officially capitalized in the SNA, namely software, mineral exploration, and artistic originals, where software is by far the largest category in terms of investment. Their inclusion raises output growth in the 1990s but has much less impact in the 2000s. Other contributions are also changed due to the changes in factor income shares, and TFP growth is lowered slightly.

The third set of results in panel 1 add in R&D as a capitalised asset, and thus provides a guide as to the impact of the upcoming capitalisation of R&D on the UK productivity picture. As we have previously

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93 In contrast to previous work (Haskel, Goodridge et al, 2011) where LPG rose in the 1990s. The difference is down to the addition of sector O which has very low productivity growth and thus drags down the aggregate, particularly in the late 1990s.

94 FISIM added around 0.5 pppa to growth in GDP in selected years in the late 1990s (Akritidis 2007), all of which adds to TFPG almost directly since no new inputs are involved. Thus even without intangibles, the productivity picture changes.
argued, scientific R&D is actually a small component of the total investment in knowledge undertaken by firms. Therefore the impact of capitalizing R&D is small, adding between -0.04% to +0.01% p.a. to labour productivity growth depending on the period considered. The reduction to TFP growth is in a similar range. We stress however that this result is dependent on the use of a market sector output deflator to estimate real R&D investment. There is no reason to believe that the price of R&D follows general output prices. We discuss this in more detail later, and provide an alternative result using improved estimates of changes in R&D asset prices.

The fourth set of results are for a decomposition that incorporates all intangibles identified by CHS. The inclusion of intangibles in output raises productivity growth in the 1990s, with little effect in the 2000s. The latter effect is due to a decline in intangible investment growth in the 2000s, following the boom in intangible investment in the preceding years. The contribution of labour quality, column 2, falls due to the fall in the labour share. The contributions of tangible capital, columns 3, 4 and 5, fall somewhat relative to the upper panel, as the inclusion of intangibles alters the factor income shares of these inputs. In column 6 we see the contribution of intangible inputs; stronger in the 1990s and weaker – though still important – in the 2000s. Thus the overall TFPG record in column 7 is acceleration in the late 1990s and then virtually zero growth in the 2000s, with TFPG in the 2000s even weaker than in the “without intangibles” or “national accounts” models.

Columns 9 to 11 set out the shares of LPG of various components and column 12 presents the total contribution of private intangible capital and TFPG combined. What are the main findings? First, the inclusion of intangibles lowers TFPG as a share of LPG. Consider column 9 in the upper panel. TFPG as a share of LPG is around 10-15 percentage points less with intangibles compared to without intangibles. Second, the contribution of the “knowledge economy” to LPG is very significant, whether measured as in column 10 or 11. Looking at column 10, TFPG and intangible capital deepening are between 61-64% of LPG in the 1990s and 26% in the 2000s. Column 11 adds the contribution of labour quality taking the figure to around 68-71% and 45% respectively. Note how high this contribution is in the late 1990s when intangible capital deepening was very fast.
Table 4.6: Growth accounting for market sector with and without intangibles
1
DlnV/H

2
sDln(L/H)

3
sDln(K/L)
cm p

4
sDln(K/L)
telecom

5
sDln(K/L)
othtan

6
sDln(K/L)
intan

7
DlnTFP

8
M emo:
sLAB

9

10

11

12

InnIndex1

InnIndex2

InnIndex3

InnIndex4

7/1

(6+7)/1

(2+6+7)/1

(6+7)

1) Baseline Results: With and w ithout intangibles
Without all intangibles
1990-95

3.07%

0.24%

0.33%

0.01%

0.85%

0.00%

1.64%

0.66

0.53

0.53

0.61

1.64%

1995-00

3.06%

0.30%

0.73%

0.08%

0.39%

0.00%

1.57%

0.65

0.51

0.51

0.61

1.57%

2000-09

1.44%

0.31%

0.24%

0.03%

0.68%

0.00%

0.17%

0.68

0.12

0.12

0.34

0.17%

National Acc's Intangibles: just software (ONS); mineral exploration (ONS); artistic originals (GH)
1990-95

3.26%

0.23%

0.32%

0.01%

0.84%

0.24%

1.63%

0.65

0.50

0.57

0.64

1.86%

1995-00

3.29%

0.29%

0.71%

0.07%

0.37%

0.26%

1.59%

0.63

0.48

0.56

0.65

1.85%

2000-09

1.47%

0.30%

0.23%

0.02%

0.64%

0.11%

0.16%

0.66

0.11

0.18

0.39

0.27%

National Accounts plus R&D
1990-95

3.22%

0.23%

0.32%

0.01%

0.83%

0.28%

1.56%

0.64

0.48

0.57

0.64

1.84%

1995-00

3.30%

0.28%

0.70%

0.07%

0.36%

0.29%

1.60%

0.62

0.48

0.57

0.66

1.89%

2000-09

1.47%

0.30%

0.23%

0.02%

0.63%

0.15%

0.14%

0.65

0.09

0.19

0.40

0.28%

All CHS Intangibles
1990-95

3.36%

0.21%

0.29%

0.01%

0.78%

0.68%

1.38%

0.59

0.41

0.61

0.68

2.06%

1995-00

3.57%

0.26%

0.64%

0.07%

0.33%

0.73%

1.54%

0.57

0.43

0.64

0.71

2.27%

2000-09

1.43%

0.27%

0.21%

0.02%

0.56%

0.38%

-0.01%

0.59

0.00

0.26

0.45

0.37%

2) Baseline: alternative periods
Without all intangibles
1990-95

3.07%

0.24%

0.33%

0.01%

0.85%

0.00%

1.64%

0.66

0.49

0.49

0.59

1.64%

1995-00

3.06%

0.30%

0.73%

0.08%

0.39%

0.00%

1.57%

0.65

0.54

0.54

0.63

1.57%

2000-05

2.36%

0.19%

0.39%

0.04%

0.57%

0.00%

1.17%

0.68

0.45

0.45

0.55

1.17%

2005-09

0.28%

0.47%

0.05%

0.01%

0.82%

0.00%

-1.07%

0.67

1.35

1.35

1.24

-1.07%

All CHS Intangibles
1990-95

3.36%

0.21%

0.29%

0.01%

0.78%

0.68%

1.38%

0.59

0.41

0.61

0.68

2.06%

1995-00

3.57%

0.26%

0.64%

0.07%

0.33%

0.73%

1.54%

0.57

0.43

0.64

0.71

2.27%

2000-05

2.45%

0.16%

0.34%

0.03%

0.48%

0.48%

0.96%

0.60

0.39

0.59

0.65

1.44%

2005-09

0.17%

0.41%

0.04%

0.01%

0.66%

0.25%

-1.21%

0.59

-7.27

-5.76

-3.28

-0.96%

3) Altering Depreciation rates
All CHS Intangibles: Halve intangible dep rates
1990-95

3.36%

0.21%

0.30%

0.01%

0.83%

0.66%

1.35%

0.59

0.40

0.60

0.66

2.01%

1995-00

3.57%

0.26%

0.64%

0.07%

0.34%

0.68%

1.57%

0.57

0.44

0.63

0.71

2.25%

2000-09

1.43%

0.27%

0.21%

0.02%

0.55%

0.52%

-0.15%

0.59

-0.10

0.26

0.45

0.37%

All CHS Intangibles: Double intangible dep rates
1990-95

3.36%

0.21%

0.29%

0.01%

0.75%

0.67%

1.43%

0.59

0.42

0.62

0.69

2.10%

1995-00

3.57%

0.26%

0.64%

0.07%

0.33%

0.77%

1.50%

0.57

0.42

0.64

0.71

2.27%

2000-09

1.43%

0.27%

0.21%

0.02%

0.57%

0.23%

0.13%

0.59

0.09

0.25

0.44

0.36%

4) Excluding 75% of Organisational ow n-account
All CHS Intangibles: Org own-account conversion factor = 0.25
1990-95

3.25%

0.22%

0.30%

0.01%

0.79%

0.55%

1.39%

0.60

0.43

0.60

0.66

1.94%

1995-00

3.52%

0.26%

0.65%

0.07%

0.34%

0.63%

1.57%

0.58

0.45

0.63

0.70

2.20%

2000-09

1.42%

0.28%

0.21%

0.02%

0.57%

0.31%

0.02%

0.60

0.02

0.24

0.43

0.34%

5) Without Tax adjustm ent factors for tangible and intangible capital
All CHS Intangibles: TAF=1
1990-95

3.36%

0.21%

0.27%

0.01%

0.77%

0.70%

1.40%

0.59

0.42

0.62

0.69

2.10%

1995-00

3.57%

0.26%

0.59%

0.06%

0.33%

0.74%

1.57%

0.57

0.44

0.65

0.72

2.32%

2000-09

1.43%

0.27%

0.19%

0.02%

0.55%

0.39%

0.00%

0.59

0.00

0.28

0.47

0.40%

183


Notes to table. Data are average growth rates per year for intervals shown, calculated as changes in natural logs. Contributions are Tornqvist indices. First column is labour productivity growth in per hour terms. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times share of labour in MSGVA. Column 3 is growth in computer capital services times share in MSGVA. Column 4 is growth in telecommunications capital services times share in MSGVA. Column 5 is growth in other tangible capital services (buildings, plant, vehicles) times share in MSGVA. Column 6 is growth in intangible capital services times share in MSGVA. Column 7 is TFP, namely column 1 minus the sum of columns 2 to 6. Column 8 is the share of labour payments in MSGVA. Columns 9-12 are alternative version of the innovation index.

4.6.2. Growth accounting: further details and robustness checks

As we have seen, we necessarily make a number of assumptions when implementing the growth accounting exercise. How robust are our findings to key assumptions? This is shown in the rest of the table. First we look at the 2000s in additional detail. The strong slowdown in labour productivity and TFP in the 2000s are driven partly by a general slowdown throughout the period and also by the collapse that occurred in the recession that followed the financial crisis. Therefore panel 2 breaks the 2000s into two separate periods. As can be seen, the data show a significant slowdown in labour productivity in the early 2000s. Features of the data for the later 2000s include a strong increase in the contribution of labour composition. This is partly driven by the increased labour share as wages have held up in comparison to profits, and partly by the hoarding of experienced workers.

Panel 3 tests the robustness of the results to changes in intangible depreciation rates, where we first halve and then double the geometric rates for intangible capital. Halving the depreciation rates causes the contribution of intangibles to rise in the 2000s as would be expected. In the 1990s this halving causes the contribution to fall slightly, but this difference simply reflects the intangible investment boom that took place in the late 1990s forming much of the stock. That is, intangible investment prior to the late 1990s was much smaller, so the change in the stock depends more on the previous level of the stock. And the previous level of the stock is larger if the depreciation rate is smaller, making the change in the stock and therefore contribution, smaller, if depreciation rates are halved as in this scenario. Doubling the depreciation rates has a similar impact but in the opposite directions, as would be expected. The changes in the contributions more or less directly affect ΔlnTFP, so that, if for example, intangibles depreciated half as fast as we have assumed, ΔlnTFP falls from -0.01%pa to -0.15%pa in 2000-09.

Since estimation of own account organizational capital is particularly uncertain, panel 4 reduces such spending by 75% (that is, managers are assumed to spend 5% of their time building organizational capital,

\[95\] The change in the stock is \(\Delta K_t = I_t - \delta K_{t-1}\). In the case of smaller \(\delta\), \(K_{t-1}\) can be larger to the extent that the increase outweighs the reduction in \(\delta\) causing \(\Delta K_t\) to be lower.
as opposed to 20% in the baseline estimates). In this case in 2000-09 the contribution of intangible capital falls from 0.38%pa to 0.31% pa and ΔlnTFP rises from -0.01%pa to +0.02%pa.

One way of checking the robustness of the results regarding the innovation index is to calculate the fraction of overall ΔlnV/H accounted for by intangibles, ΔlnTFP and ΔlnL/H under the various different scenarios. It is in fact quite robust giving similar results in the models: without intangibles; with national accounts intangibles; with national accounts intangibles plus R&D. With intangibles, the fractions for just ΔlnTFP (column 9) fall, but once we take account of the intangibles contribution (column 10) the fraction is raised. But the interesting thing to note is that these fractions are almost identical with the experiments on depreciation and organizational capital. Thus the inclusion of the full range of intangibles lowers the share of the contribution of ΔlnTFP, but consistently raises the share of the summed contributions of ΔlnTFP plus intangible capital deepening plus labour composition, such that the latter sum of contributions has accounted for 45% of ΔlnV/H over this century.

In panel 5 we look at the impact of incorporating new tax adjustment factors for all tangible and intangible assets, by excluding those factors and comparing the results with the (fourth set of) baseline estimates in panel 1. Note that our previous work in this area did not include tax adjustment factors for either tangible or intangible assets.

Looking first at the contributions for tangibles, in the case of computers, applying a tax adjustment factor incorporating the impact of capital allowances and corporation tax increases the contribution of capital deepening in that asset by around 8% across all periods. For other tangibles (plant & machinery, buildings and vehicles) the contribution is reduced by 2% in the early 1990s and 2000s, but is unaffected in the late 1990s. As with other tangibles, incorporating tax adjustment factors reduces the contribution of intangible capital deepening, by 3% in the early 1990s, 2% in the late 1990s and by 5% in the 2000s. This reduction added to that of other tangibles, is largely offset by the increased contribution for IT equipment. In the 1990s it is also partly offset by an increased estimate for ΔlnTFP. In the 2000s the introduction of tax adjustment factors slightly reduces the estimate for ΔlnTFP.

The reasoning for these changes is as follows. Incorporation of tax adjustment factors results in better estimation of asset rental prices and the cost of capital since they account for both the rate of corporation tax plus any asset-specific capital depreciation allowances that firms are allowed to expense for tax purposes. The intent of these allowances is to reduce the cost of capital to firms, and their size varies by asset. However, since the impact of corporation tax still outweighs such allowances, the incorporation of

96 The formula for tax adjustment factors was set out in Chapter 1. They can be estimated as τ=(1-u.v)/(1-u) where u is the rate of corporation tax and v is the proportion of the asset value that can be deducted from taxable income (capital allowances). With tax adjustment factors incorporated, the user cost relation is: P^K=P^I(ρ+δ−π)τ, where P^K is the rental price, P^I the asset price, ρ the net rate of return, δ a geometric rate of depreciation and π a capital gains term.
adjustment factors increases the rental prices and relative factor incomes for tangible assets compared to our previous work. In the case of intangibles, there is also an allowance for purchased software, the R&D tax credit, and tax relief on mineral exploration and the production of film originals. For all other intangibles no capital allowances are available but firms are able to expense their expenditures leaving the cost of capital unaffected by the presence of corporation tax. In other words, the tax adjustment factors for these other intangibles are equal to 1. The result is that tax adjustment factors increase the rental prices, factor income shares and therefore the contributions of capital deepening in tangibles relative to most intangibles. Investment and capital stocks remain as previously measured. So although, ex ante, we would expect changes in the tax adjustment factors to impact the rate of investment, any impact on investment had already been picked up in our previous work. However our incorporation of tax adjustment factors specific to each asset means that our growth accounting decomposition is more accurate than that presented previously.

4.6.3. Annual Contributions and the impact of recession

All results in the table above are annual averages. For completeness we also provide a full annual decomposition below. We stress however that annual TFP estimates are inherently volatile, and care should be taken in interpreting annual movements in unsmoothed annual estimates of TFP or the Innovation Index. In particular annual changes in the contributions reflect changes in ex-post rental prices, due to the inability to accurately observe the utilisation of capital.

The annual data show more clearly the collapse in labour productivity growth that occurred in 2008 and particularly 2009. Rises in the labour income share and the wagebill share of experienced and skilled worked resulted in an increase to the contribution of labour composition. This combined with the strong contributions of other tangible capital (buildings, plant and vehicles) and intangible capital results in large negative estimates for the TFP residual. The former is driven by revisions to ONS investment deflators and their impact on growth in tangible capital services.
The above table presents a decomposition of labour productivity, with all terms expressed in terms of per hour worked. Obviously the recent recession has been associated with a strong fall in hours worked. Therefore to better understand how the raw capital services data is behaving, the following table is a decomposition of growth in value-added, unadjusted for hours worked. The contribution of labour therefore includes the volume of hours worked plus the impact of labour quality or composition.

**Table 4.7: Annual Decomposition, ‘National Accounts model’ compared to ‘All CHS intangibles’**

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<tbody>
<tr>
<td><strong>DlnV/H</strong></td>
<td>-5.09%</td>
<td>-2.82%</td>
<td>0.00%</td>
<td>-0.40%</td>
<td>1.47%</td>
<td>0.19%</td>
<td>-5.20%</td>
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<td>-5.02%</td>
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<td><strong>sDln(L/H)</strong></td>
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<td>0.60%</td>
<td>0.66%</td>
<td>0.00%</td>
<td>1.44%</td>
<td>0.56</td>
<td>0.52</td>
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<td>0.82%</td>
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<td>0.64</td>
<td>0.57</td>
<td>0.57</td>
<td>0.62%</td>
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<tr>
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<td>0.42%</td>
<td>1.26%</td>
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<td>0.57%</td>
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**All CHS intangibles**

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The data show that the UK market sector suffered a 0.69% decline in adjusted value-added in 2008, followed by a massive 7.5% fall in 2009. Strong falls in market sector investment were enough to cause estimates of growth in capital services to turn negative. The exception is buildings, where the stock...
continued to grow. This reflects the fact that the rate of depreciation of buildings is lower than for other assets and the existing stock has a higher value. This means that a much sharper fall in investment is needed to generate a fall in the capital stock. It is likely however that in very severe recessions we do not measure the actual fall in capital that likely comes about due to premature scrapping and underutilisation and since TFP is a residual, this renders TFP negative. Thus we should be careful about interpreting year-to-year movements in the innovation index.

4.6.4. Contributions of individual intangible assets

Contributions of each tangible and intangible asset are set out in Table 4.9. Column 8 shows that software is an important driver of LPG, with a very strong contribution in the 1990s of between 0.18% and 0.23% p.a., but less so this century, contributing 0.10% p.a.. Columns 9 and 10 show a small negative contribution for mineral exploration and a small positive contribution for artistic originals, although the latter are around double those when we use official ONS estimates. Columns 11 and 12 show the contribution of design to be above that of R&D in all periods, at around 0.06%pa with R&D at 0.03% p.a. in 2000-2009 (note R&D in this table includes R&D in financial services (financial product development) and social sciences, as well as scientific R&D). In columns 13 to 15, we show the contributions of brand, training and organisational capital. Organisational capital is the most important here, with the contributions from all three declining in the 2000s.
Table 4.9: Contributions of individual assets: Detailed breakdown

| Year     | DlnV/H | Dln(L/H) | sDln(K/L) | telecom | sDln(K/L) | buildings | P&M | sDln(K/L) | vehicles | sDln(K/L) | software | sDln(K/L) | min | sDln(K/L) | cop | sDln(K/L) | aed | sDln(K/L) | rd | sDln(K/L) | brand | sDln(K/L) | train | sDln(K/L) | org | DlnTFP | Memo: sLAB |
|----------|--------|----------|-----------|----------|-----------|-----------|-----|-----------|----------|-----------|----------|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|------|-----------|------|----------|-----|---------|------|---------|
| 1990-95  | 3.36%  | 0.21%    | 0.29%     | 0.01%    | 0.41%     | 0.35%     | 0.02%| 0.18%     | 0.00%    | 0.03%     | 0.07%    | 0.04%     | 0.05%| 0.09%     | 0.21%| 1.38%     | 0.59 |
| 1995-00  | 3.57%  | 0.26%    | 0.64%     | 0.07%    | 0.20%     | 0.08%     | 0.06%| 0.23%     | -0.02%   | 0.03%     | 0.06%    | 0.03%     | 0.09%| 0.13%     | 0.18%| 1.54%     | 0.57 |
| 2000-09  | 1.43%  | 0.27%    | 0.21%     | 0.02%    | 0.31%     | 0.21%     | 0.04%| 0.10%     | -0.01%   | 0.01%     | 0.06%    | 0.03%     | 0.01%| 0.06%     | -0.01%| 0.11%     | -0.01% | 0.59 |

Notes to table. Data are average growth rates per year for intervals shown. First column is labour productivity growth in per hour terms. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times share of labour in MSGVA. Column 3 is growth in computer capital services per hour times share in MSGVA. Column 4 is growth in telecommunications capital services per hour times share in MSGVA. Column 5 is growth in capital services from buildings per hour times share in MSGVA. Column 6 is growth in capital services from plant & machinery (excluding computers and telecoms equipment) per hour times share in MSGVA. Column 7 is growth in capital services from vehicles per hour times share in MSGVA. Column 8 is growth in software capital services per hour times share in MSGVA. Column 9 is growth in capital services from mineral exploration per hour times share in MSGVA. Column 10 is growth in capital services from copyright (artistic originals) per hour times share in MSGVA. Column 11 is capital services from design per hour times share in MSGVA. Column 12 is growth in broadly defined R&D (including non-scientific R&D and financial product development) capital services per hour times share in MSGVA. Column 13 is capital services from advertising and market research per hour times share in MSGVA. Column 14 is capital services from firm training per hour times share in MSGVA. Column 15 is organisational capital services per hour times share in MSGVA. Column 16 is TFP, namely column 1 minus the sum of columns 2 to 15. Column 17 is the share of labour payments in MSGVA.
4.6.5. Impact of alternative deflators for intangible assets

Whilst a great deal has been done to improve estimates of investment in knowledge assets, less has been done on estimation of their prices. Such estimation is difficult as a feature of these assets is that they are rarely acquired via market transactions. Indeed the benefit of ownership/investment is the access to knowledge unavailable to market competitors. Therefore much investment takes place in-house and no market price can be recorded. For this reason the standard approach for deflating investment in most intangible assets has been to use a value-added deflator, implicitly assuming that their prices closely follow a weighted average of prices in the rest of the economy. Another approach is to form estimates of prices based on the prices of inputs to knowledge production, as applied in Chapter 3 of this thesis in the context of own-account software.

Corrado, Goodridge and Haskel (CGH, (2011)) use industry productivity data to show that the implied price of R&D assets has been falling strongly over time due to technical progress in the upstream, or knowledge production, sector. Their final estimate of a price index for R&D falls at 7.5% p.a. on average between 1985 and 2005. Obviously replacing a value-added deflator, which typically rises at a rate of 4-5% p.a., with the CGH R&D deflator has a considerable impact on measures of real R&D investment, the R&D capital stock, and the contribution of R&D capital deepening to growth in labour productivity, as shown below in Table 4.10. Panel 1, column 8 presents estimates of the contribution of R&D capital deepening where R&D has been deflated using a value-added price index. Panel 2 presents estimates which use the CGH R&D deflator, with contributions as much as six times greater in the early 1990s.

That result is based on estimated strong productivity growth in the creation of R&D assets. It could of course be the case that productivity growth has also been growing strongly in the creation of other knowledge assets. Consider own-account software. The official ONS own-account software deflator is based on the wages of software professionals with a small downward adjustment based on labour productivity growth in the wider service sector. However if productivity in the creation of own-account software has been rising faster than productivity in the wider service sector, then the software asset price index will over-estimate price changes and underestimate growth in real investment and software capital services. Chapter 3 presented some evidence that productivity in the creation of own-account software has indeed been growing faster than the rate assumed in the construction of the official price index, and also presented new estimates of the contribution of software capital deepening to labour productivity growth.

Instead of using an adjusted wage index for software professionals as in the official ONS methodology, one option for deflating own-account software investment would be to use the same deflator as used for purchased software. After all it would seem reasonable to assume that growth in the productivity of creating
own-account software is similar to that in creating software that is sold in the marketplace. That is what we use in Panel 3, resulting in an increase in the contribution of total software of around a quarter.

Another option available is to use the own-account and purchased software deflators produced by the BEA. Doing that produces the estimates presented in Panel 4, with the impact on the total contribution of software capital deepening slightly greater than that in Panel 3.

Table 4.10: Alternative deflators for intangible assets

<table>
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<tr>
<th></th>
<th>1) Baseline</th>
<th>2) CGH R&amp;D deflator</th>
<th>3) Using UK purchased software deflator for own-account</th>
<th>4) Using US (BEA) software deflators for purchased and own-account</th>
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<tr>
<td></td>
<td>DlnV/H</td>
<td>sDln(L/H)</td>
<td>sDln(KL comp)</td>
<td>sDln(KL telecom)</td>
</tr>
<tr>
<td>All CHS Intangibles</td>
<td></td>
<td></td>
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<tr>
<td>1990-95</td>
<td>3.36%</td>
<td>0.21%</td>
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<td>1995-00</td>
<td>3.43%</td>
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<td>2000-09</td>
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<td>1.43%</td>
<td>0.27%</td>
<td>0.21%</td>
<td>0.02%</td>
</tr>
<tr>
<td></td>
<td>3.36%</td>
<td>0.21%</td>
<td>0.29%</td>
<td>0.01%</td>
</tr>
<tr>
<td></td>
<td>3.57%</td>
<td>0.26%</td>
<td>0.64%</td>
<td>0.07%</td>
</tr>
<tr>
<td></td>
<td>1.43%</td>
<td>0.27%</td>
<td>0.21%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

Note to table. Panel 1 are baseline estimates as presented previously. Panel 2 uses the R&D deflator developed in Corrado, Goodridge and Haskel (2011). Panel 3 uses the deflator for purchased software to also deflate own-account, with the implicit assumption being that productivity in the creation of own-account software is similar to that in the software industry itself. Panel 4 uses official US BEA deflators for purchased and own-account software, where the latter includes a productivity adjustment based on the purchased software data.

4.6.6. Comparison with previous estimates

This paper is an update on previous work. The following table compares results with those in a previous publication of the Innovation Index (Haskel, Goodridge et al. 2011). The results differ for a number of reasons which are expanded on further in Appendix 2. In short there have been changes to:
• estimated growth in labour services (and underlying hours) and (tangible and intangible) capital deepening, and labour productivity growth, due to the addition of a new industry to our market sector definition\(^{97}\);
• estimated growth in tangible capital services due to revisions to ONS asset price deflators and Gross Operating Surplus
• estimated rentals due to updated deflators and the introduction of tax adjustment factors to the estimation, and
• estimated growth in intangible capital deepening due to improved methodologies to remove potential double-counting in purchased investments, and to better estimate investments in artistic originals (as detailed in Chapter 2).

As a result of these changes, relative to previous work our data show stronger growth in labour productivity in the 1990s but weaker growth in the 2000s; stronger growth in labour composition in all periods; stronger growth in tangible capital deepening in all periods and stronger growth in intangible capital deepening throughout the 1990s, but weaker growth in the 2000s. TFP is also estimated as weaker in the late 1990s and 2000s relative to previous work. The increase in the contribution of tangible capital deepening is largely a result of incorporating new tax adjustment factors as described above, increasing the factor income shares of tangible assets relative to intangible assets compared to previous results. The reduction in estimated TFP is largely due to the introduction of the personal services (‘O’) industry into our dataset. Estimated TFP in this industry is consistently strongly negative. Since this industry makes up 7% of market sector value-added and 8% of total hours worked in the market sector, and invests relatively heavily in intangible assets, we consider the inclusion of this industry a significant development in our dataset. However, the industry data also suggest there may be significant issues with official measures of prices and quantities which could hamper analysis.

\(^{97}\) Additionally, our dataset remains based on SIC03. To maintain compatibility we therefore do not use real output data based on SIC07, as published in BB2011. Instead we use output data up to 2009 based on BB2010. Whilst this means our data do not reflect the revisions to growth published in BB2011, due to changes in industry output deflators, it also means our data does not suffer from a break in series at the time of the switch between use of retail (RPIs) and consumer (CPIs) price indices in the late 1990s.
Table 4.11: Comparison with previous results

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DlnV/H</td>
<td>sDln(L/H)</td>
<td>sDln(K/L)</td>
<td>intang</td>
<td>DlnTFP</td>
</tr>
<tr>
<td>1990-95</td>
<td>3.36%</td>
<td>0.21%</td>
<td>1.09%</td>
<td>0.68%</td>
<td>1.38%</td>
</tr>
<tr>
<td>1995-00</td>
<td>3.57%</td>
<td>0.26%</td>
<td>1.04%</td>
<td>0.73%</td>
<td>1.54%</td>
</tr>
<tr>
<td>2000-08</td>
<td>1.97%</td>
<td>0.23%</td>
<td>0.73%</td>
<td>0.37%</td>
<td>0.63%</td>
</tr>
<tr>
<td>NESTA (2010) All CHS Intangibles (SIC03: A-K)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990-95</td>
<td>2.94%</td>
<td>0.17%</td>
<td>0.95%</td>
<td>0.64%</td>
<td>1.19%</td>
</tr>
<tr>
<td>1995-00</td>
<td>3.53%</td>
<td>0.25%</td>
<td>0.74%</td>
<td>0.67%</td>
<td>1.87%</td>
</tr>
<tr>
<td>2000-08</td>
<td>2.69%</td>
<td>0.17%</td>
<td>0.68%</td>
<td>0.55%</td>
<td>1.30%</td>
</tr>
</tbody>
</table>

Note to table. For comparison, data are based on the same periods. The top panel are our most recent results that incorporate a new industry and tax adjustment factors for all assets. The bottom panel includes neither of these features, hence the differences in productivity growth and the factor contributions.

4.7. Growth accounting results: industry-level

Our industry growth accounting is feasible between 2000-07.98 Thus we start with comparing our aggregated market sector results with those using ONS data to check the two are closely comparable. Then we look more closely industry by industry.

4.7.1. Comparing aggregated KLEMS industry data with ONS data

Table 4.12 sets out our results. The top row shows the use of ONS data, with intangibles, 2000-07. The second row shows the results for 2000-07, with intangibles, using the aggregated EUKLEMS industry data. DlnV/H is 15 percentage points higher with EUKLEMS. There are also bigger differences to some of the contributions compared to our previous work. The reasons are as follows. First, ONS data on tangible capital have been revised, increasing real investment and the contribution of capital deepening for other tangibles. Second, our series on labour composition was only produced using ONS hours and we have not produced a version based on KLEMS hours for the industry decomposition. Third, we have incorporated an additional industry into our decomposition. Fourth we have incorporated tax adjustment factors for all assets.

4.7.2. Results by industry

To build up the industry contributions to these overall figures we start with the industry-by-industry results in Table 4.13, also presented graphically in Figure 4.4. These are on a gross output basis: we show how they relate to the whole economy value-added level below.

---

98 We have data based on the Supply-Use Tables back to 1992, but due to uncertainty about initial capital stocks for intangible assets we confine ourselves to growth accounting starting in 2000.
Table 4.12: Growth accounting: comparison of ONS market sector and Domar-weighted Market Sector Aggregates, 2000-07

<table>
<thead>
<tr>
<th>ALPG</th>
<th>Total Computers &amp; Telecoms</th>
<th>Other tang</th>
<th>Intangibles</th>
<th>Labour Composition</th>
<th>DlnTFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>DlnV/H</td>
<td>sDln(K/H)</td>
<td>sDln(K/H) cmp</td>
<td>sDln(K/H) othtan</td>
<td>sDln(K/H) intan</td>
<td>sDln(L/H)</td>
</tr>
<tr>
<td>ONS data, with all CHS intangibles</td>
<td>2.39%</td>
<td>1.16%</td>
<td>0.29%</td>
<td>0.46%</td>
<td>0.41%</td>
</tr>
<tr>
<td>KLEMS, with all CHS intangibles</td>
<td>2.54%</td>
<td>1.09%</td>
<td>0.33%</td>
<td>0.35%</td>
<td>0.35%</td>
</tr>
</tbody>
</table>

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

Table 4.13: Industry level gross output growth accounting, 2000-2007, including intangibles

<table>
<thead>
<tr>
<th>Industry</th>
<th>DlnY/H</th>
<th>sDln(K/H)</th>
<th>sDln(K/H)ICT</th>
<th>sDln(K/H) othtan</th>
<th>sDln(K/H) intan</th>
<th>sDln(L/H)</th>
<th>sDln(M/H)</th>
<th>DlnTFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgrMin</td>
<td>0.74</td>
<td>1.16</td>
<td>0.01</td>
<td>1.27</td>
<td>-0.11</td>
<td>0.65</td>
<td>1.29</td>
<td>-2.37</td>
</tr>
<tr>
<td>Mfr</td>
<td>3.77</td>
<td>0.67</td>
<td>0.07</td>
<td>0.15</td>
<td>0.45</td>
<td>0.23</td>
<td>1.82</td>
<td>1.05</td>
</tr>
<tr>
<td>Utilities</td>
<td>-3.55</td>
<td>0.11</td>
<td>0.17</td>
<td>-0.14</td>
<td>0.07</td>
<td>0.05</td>
<td>-3.44</td>
<td>-0.27</td>
</tr>
<tr>
<td>Constr</td>
<td>2.17</td>
<td>0.35</td>
<td>0.02</td>
<td>0.25</td>
<td>0.07</td>
<td>0.08</td>
<td>1.67</td>
<td>0.07</td>
</tr>
<tr>
<td>RHTTrs</td>
<td>2.73</td>
<td>0.71</td>
<td>0.23</td>
<td>0.28</td>
<td>0.21</td>
<td>0.01</td>
<td>1.25</td>
<td>0.75</td>
</tr>
<tr>
<td>FinSvc</td>
<td>1.60</td>
<td>-0.06</td>
<td>0.35</td>
<td>-0.28</td>
<td>-0.13</td>
<td>0.00</td>
<td>-0.01</td>
<td>1.66</td>
</tr>
<tr>
<td>BusSvc</td>
<td>2.46</td>
<td>0.61</td>
<td>0.25</td>
<td>0.03</td>
<td>0.33</td>
<td>0.36</td>
<td>0.59</td>
<td>0.89</td>
</tr>
<tr>
<td>PersSvc</td>
<td>-0.98</td>
<td>0.22</td>
<td>0.08</td>
<td>0.29</td>
<td>-0.14</td>
<td>-0.11</td>
<td>0.35</td>
<td>-1.45</td>
</tr>
</tbody>
</table>

Note to table: All figures are average annual changes in natural logs. The contribution of an output or input is the growth rate weighted by the corresponding average share. Columns are: column 1, real gross output per hour, column 2, contribution of total capital (which is the sum of the next three columns), column 3, contribution of ICT (computer & telecoms) capital, column 4, contribution of other non-ICT tangible capital, column 5, contribution of intangibles, column 6, contribution of labour quality per person hour, column 7, contribution of intermediates, column 8, TFP, being column 1 less the sum of column 2, 6 and 7. Note also that Health & Safety and induction training are excluded from the investment figures used for the above calculation in the case of the service sector but not in the production sector. Source: authors’ calculations
Figure 4.4: Decomposition of industry-level gross output, 2000-07

Note to figure: Data as presented in Table 4.13. Data are annual average changes in natural logs for 2000-07. All CHS intangibles capitalised. Labelled data points are growth in real gross output per hour. Stacked bars are contributions from labour composition, capital deepening (for broad asset definitions) and intermediate inputs, all expressed in terms of per hour worked, and TFP.
We just report the results including all intangibles. Column 1 shows ΔlnY/H, growth in gross output per employee-hour. It is negative in Electricity, Gas, Water, and Personal Services, otherwise positive particularly in manufacturing, business services, and trade and communications. Column 2 shows total capital deepening per employee-hour, being strongly positive in those same industries, but negative in financial services. Columns 3, 4 and 5 shed some light on this. The contribution of computer hardware is strongest in financial and business services, and note particularly weak in manufacturing. The contribution of other tangibles (buildings, vehicles etc.) is actually negative in financial services, as is the contribution of intangibles in that industry. It is worth nothing that employee-hours are growing very fast in financial services (the second largest growth in the market economy behind business services) and that intangible capital is falling after the massive investment in the late 1990s. So capital deepening per hour is falling, thus rendering the contribution of growth in capital per hour negative. However, this also slows down ΔlnY/H, so it turns out that ΔlnTFP still falls in financial services when we add intangibles (see table Appendix 1, without intangibles, ΔlnTFP=1.84%): thus intangibles do help account for the TFP residual. Columns 6 and 7 show the contributions of labour composition and intermediates, and column 8 shows ΔlnTFP. ΔlnTFP grows particularly fast in finance and manufacturing.

Looking at Personal Services in the final row we see that growth in labour productivity is negative over the period considered, as is ΔlnTFP and the contribution of intangibles. The contribution of tangibles however is stronger. Measured ΔlnTFP is higher in the Appendix table (Appendix 1), where no intangibles are included. This result is a consequence of the measured falls in labour productivity, forcing a negative contribution from ΔlnTFP and intangible capital deepening, and suggests potential issues with the measurement of prices and quantities in this sector. There are a number of reasons for this.

First the industry does include a significant amount of non-market activity. It also includes a lot of ‘cultural’ activity which is in fact heavily subsidised, including museums, galleries and theatres. These features raise numerous issues for the measurement of output. Second, it is notoriously difficult to accurately measure prices and quantities in the service sector. Despite suspicions on the accuracy of the real output and TFP measures for this sector, we felt it important to include the industry as it does house some important investors in UK knowledge assets, such as those in film, television, media, artistic creation etc.. Given that this is a significant industry in size in terms of both nominal value-added and employment, and includes activity where the UK is considered to have a comparative advantage, improving measurement of its output is a first order issue. In terms of presentation, we expect our future work to benefit from the improved classification of the service sector in SIC2007.

So the overall picture of intangibles at the industry level is as follows. In manufacturing, labour productivity is high, particularly with a lot of labour shedding. About 28% of that LPG is due to TFPG, with 12% due to intangible growth and 6% due to labour quality. In financial services, measured labour productivity is lower,
in fact less than half the rate of manufacturing, but TFP is growing faster than labour productivity in that sector, with the overall contribution of capital negative but a positive contribution from computers. So manufacturing is very much driven by within-industry intangible investment, whilst finance is very much driven by TFP (would could of course reflect within-industry spillovers of intangible investment). In the distributive trades, together computers and intangibles account for around 16% of LPG and in business services they account for 24%.

Finally, the Appendix 1 shows the impact of adding intangibles, which is that \(\Delta \ln \frac{Y}{H}\) is higher and \(\Delta \ln \text{TFP}\) is lower than without intangibles. Thus for example, without intangibles one would conclude \(\Delta \ln \text{TFP}=1.62\%\) instead of 1.18\% here with.

### 4.7.3. Contributions of individual industries overall performance

The contribution of each industry to the overall market economy is a combination of their contributions within each industry and the weight of each industry in the market sector. Thus for example, there may be much innovation in manufacturing but it might be a small sector in the market sector as a whole. Table 4.14 sets this out.
### Table 4.14: Industry contributions to growth in aggregate value added, capital deepening, labour quality and TFP (growth rates and contributions are %pa per employee hour, 2000-07)

<table>
<thead>
<tr>
<th>Industry</th>
<th>VA weight</th>
<th>DlnVA/H</th>
<th>contrib to agg va/h</th>
<th>Cap weight</th>
<th>Contrib to agg K/H</th>
<th>Contrib to agg ICT K/H</th>
<th>Contrib to agg non-ICT K/H</th>
<th>Contrib to agg intan/H</th>
<th>Lab weight</th>
<th>Contrib to agg lab qual per hr</th>
<th>Domar weight</th>
<th>DlnTFP</th>
<th>Contrib to agg TFP</th>
<th>Memo: % total hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture; Mining</td>
<td>0.04</td>
<td>-0.80</td>
<td>-0.03</td>
<td>0.03</td>
<td>0.08</td>
<td>0.00</td>
<td>0.09</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.04</td>
<td>0.07</td>
<td>-2.37</td>
<td>-0.16</td>
<td>3%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.20</td>
<td>4.81</td>
<td>0.98</td>
<td>0.07</td>
<td>0.35</td>
<td>0.04</td>
<td>0.08</td>
<td>0.23</td>
<td>0.14</td>
<td>0.11</td>
<td>0.51</td>
<td>1.05</td>
<td>0.52</td>
<td>17%</td>
</tr>
<tr>
<td>Utilities</td>
<td>0.02</td>
<td>-0.65</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.07</td>
<td>-0.27</td>
<td>-0.02</td>
<td>1%</td>
</tr>
<tr>
<td>Construction</td>
<td>0.08</td>
<td>1.21</td>
<td>0.09</td>
<td>0.02</td>
<td>0.07</td>
<td>0.00</td>
<td>0.05</td>
<td>0.01</td>
<td>0.06</td>
<td>0.01</td>
<td>0.19</td>
<td>0.07</td>
<td>0.01</td>
<td>10%</td>
</tr>
<tr>
<td>Distribution; Hotels; Transport</td>
<td>0.30</td>
<td>2.76</td>
<td>0.83</td>
<td>0.10</td>
<td>0.40</td>
<td>0.13</td>
<td>0.15</td>
<td>0.12</td>
<td>0.20</td>
<td>0.01</td>
<td>0.56</td>
<td>0.75</td>
<td>0.42</td>
<td>36%</td>
</tr>
<tr>
<td>Finance</td>
<td>0.09</td>
<td>3.37</td>
<td>0.30</td>
<td>0.04</td>
<td>-0.02</td>
<td>0.06</td>
<td>-0.05</td>
<td>-0.03</td>
<td>0.05</td>
<td>0.00</td>
<td>0.19</td>
<td>1.66</td>
<td>0.32</td>
<td>5%</td>
</tr>
<tr>
<td>Business Services</td>
<td>0.19</td>
<td>2.92</td>
<td>0.55</td>
<td>0.06</td>
<td>0.18</td>
<td>0.07</td>
<td>0.01</td>
<td>0.10</td>
<td>0.13</td>
<td>0.11</td>
<td>0.29</td>
<td>0.89</td>
<td>0.26</td>
<td>20%</td>
</tr>
<tr>
<td>Personal Services</td>
<td>0.07</td>
<td>-2.09</td>
<td>-0.15</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.03</td>
<td>-0.02</td>
<td>0.06</td>
<td>-0.01</td>
<td>0.11</td>
<td>-1.45</td>
<td>-0.17</td>
<td>8%</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>1.00</strong></td>
<td><strong>2.54</strong></td>
<td><strong>1.09</strong></td>
<td><strong>0.33</strong></td>
<td><strong>0.35</strong></td>
<td><strong>0.41</strong></td>
<td><strong>0.27</strong></td>
<td><strong>1.99</strong></td>
<td><strong>1.18</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>%ages of summed contributions</th>
<th>Memo: % total hrs</th>
<th>(8 + 13)/(18+113)</th>
<th>(8+10+13)/(18+113+110)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture; Mining</td>
<td>-1%</td>
<td>16%</td>
<td>-14%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>38%</td>
<td>41%</td>
<td>44%</td>
</tr>
<tr>
<td>Utilities</td>
<td>-1%</td>
<td>1%</td>
<td>-2%</td>
</tr>
<tr>
<td>Construction</td>
<td>4%</td>
<td>5%</td>
<td>1%</td>
</tr>
<tr>
<td>Distribution; Hotels; Transport</td>
<td>32%</td>
<td>3%</td>
<td>35%</td>
</tr>
<tr>
<td>Finance</td>
<td>12%</td>
<td>0%</td>
<td>27%</td>
</tr>
<tr>
<td>Business Services</td>
<td>22%</td>
<td>40%</td>
<td>22%</td>
</tr>
<tr>
<td>Personal Services</td>
<td>-6%</td>
<td>-5%</td>
<td>-14%</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

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

**Source:** authors' calculations
In the left panel columns 1, 2 and 3 show respectively the industry weights in MSGVA, average $\Delta \ln V/H$ and the industry contribution to aggregate value added (which is not quite the product of columns 1 and 2, since the average of a product is not the product of two averages). In the final row, the value-added weights sum to unity and the sum of contributions equals the market-sector total in row 2 of Table 4.12. The middle panels show the factor contributions which again sum to the market sector total. The right panel shows industry $\Delta \ln TFP$ and its Domar weight, each industries contribution and confirms the weighted sum duplicates the aggregate. Finally, as a memo item, column 14 shows actual hours worked as a fraction of the total. The lower panel shows the contributions as a proportion of the total.

What do we learn about the economy from this table? Let us start by considering manufacturing. As the top panel shows, column 1, its value added weight in the market sector is 20%, and column 14 shows its employment share is 17% (note these are higher than the whole economy shares usually quoted). Column 5 shows the contribution of manufacturing capital deepening to aggregate capital deepening is 0.35% p.a., which is, lower panel, 32% of the total. Column 8 shows that the contribution of intangibles in manufacturing is significant: 56% (see lower panel) of the total intangible contribution. Columns 10 and 13 show the contribution of labour quality and $\Delta \ln TFP$, 41% and 44% respectively of the total. Thus manufacturing, accounting for 20% of value added and 17% of employment, accounts for 56% of total intangible capital deepening and 44% of $\Delta \ln TFP$.

What of other industries? The other large contributions of capital deepening are from the distributive trades which are also grouped with communications, and business services. Within these, ICT capital deepening is very important in distribution and communications, accounting for 39% of the total. Intangible capital deepening in business services and distribution/communications account for 24% and 29% of the total.

Turning to labour composition, manufacturing and business services alone account for 81% of it. Finally, on $\Delta \ln TFP$, after manufacturing, trade and communications account for 35%, so that just these two sectors combined account for 79% of market sector $\Delta \ln TFP$. Finance and business services account for 49%. Note that whilst $\Delta \ln TFP$ in finance exceeds that of for all other industries including manufacturing, the Domar weight for finance is smaller than that for manufacturing, business services, and distribution/communications, so the contribution to total $\Delta \ln TFP$ is smaller too.

Finally, one might summarise these results by asking what industries account for the contribution of knowledge or innovation to $\Delta \ln V/H$? If we define the contribution of innovation as the contributions of $\Delta \ln TFP+s\Delta \ln K/H(\text{intang})$ to the total, we see that manufacturing accounts for 47%, trade & communications 34%, business services 22% and financial services 18% (the numbers are very similar if we add $s\Delta \ln L/H$, namely 46%, 29%, 25% and 15%). This same data is presented in graphical form below, highlighting the contribution of manufacturing to total UK market sector innovation.
Figure 4.5: Industry contributions to UK market sector innovation

Note to figure: data as presented in Table 4.14. All figures are weighted annual averages. Contributions are the product of the weights and the input growth averaged over years. Weights depend on the industry share in aggregate value-added, the input share in gross output and the share of industry value-added in gross output.
One important question, we believe, is to ask how these results compare to those without intangibles? The results without intangibles are set out in Appendix 1, but the main results are as follows. First, without intangibles, $\Delta \ln TFP$ is 1.62% p.a. (against 1.18% p.a. above). But note that the contribution above of $\Delta \ln TFP$ and intangible capital deepening is $1.18 + 0.41 = 1.59\%$, very close to $\Delta \ln TFP$ without intangibles, which accounts for $1.59/2.54 = 63\%$ of economic growth against $1.62/2.70 = 60\%$ without intangibles. So in this calculation the total “innovation” contribution turns out to be about the same, but intangibles accounts for a quarter of the residual. Second, the industry contributions are different. As we have seen here with intangibles, manufacturing and financial services account for 47% and 18% of final innovation. Without intangibles, manufacturing and financial services $\Delta \ln TFP$ account for 40% and 25% of innovation. So without intangibles financial services $\Delta \ln TFP$, and its contribution to innovation, is overstated.

4.8. Conclusions

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

1. Investment in knowledge.
   a. Investment in knowledge, which we call intangible assets, is now greater than investment in tangible assets, at around, in 2009, £124bn and £93bn respectively, 12% and 9% of (adjusted) MSGVA, quantifying the UK move to a knowledge-based economy.
   b. In 2009, R&D was about 11% of total intangible investment, software 18%, design 12%, and the largest categories (21%) training and organizational capital. Approximately 70% of intangible investment is own account.
   c. The most intangible-intensive industry is manufacturing (intangible investment as a proportion of value added =17%), closely followed by personal services (=16%), a new addition to our dataset. Manufacturing, financial services and business services all invest about 3:1 on intangibles:tangibles. In personal services the ratio is around 1:1 in what is a capital intensive sector.
   d. The effect of treating intangible expenditure as investment is to raise growth in market sector value added in the late 1990s (the internet investment boom), but have little impact in the 2000s.

a. For the most recent period of 2000-2009, intangible capital deepening accounts for 26% of growth in market sector value added per hour (ΔlnV/H), a larger contribution than ICT tangibles (computer hardware and telecommunications) (16%) and labour quality (19%), . The 2000s have seen a close to zero contribution from ΔlnTFP, driven by large declines in the last two years.

b. With (without) intangibles ΔlnV/H 1.43%pa (1.44%pa) and ΔlnTFP is -0.01%pa (0.17%pa). Thus adding intangibles to growth accounting lowers ΔlnTFP and ΔlnV/H is almost unaffected.

c. Capitalising R&D relative to the current practice of capitalizing software (plus mineral exploration and artistic originals) adds 0.04% to input growth and reduces ΔlnTFP by 0.02%, with ΔlnV/H unaffected.

d. If innovation is measured as ΔlnTFP plus the contribution of intangible capital deepening, then innovation has contributed 26% of growth in labour productivity with intangibles and 12% without. Adding the contribution of labour composition gives 45% of ΔlnV/H with intangibles and 34% without.

3. *Contribution by industries to growth.* The main finding here is the importance of manufacturing, which accounts for around half of innovation (measured either as the contributions of intangible capital deepening plus TFP, or intangible capital deepening plus TFP plus labour quality) in the UK market sector. This is due to a combination of its high intangible investment (56% of the total intangible contribution) and TFP (44% of the total contribution), even though manufacturing is a comparatively small sector in terms of employment share (17% of market sector hours worked). We also find important contributions from retail/hotels/transport/communications, accounting for 34% of innovation, business services which contributes 22% and finance 18%.

In future work, we hope to improve the measures of all variables. We also wish to explore policy and the total contributions of various assets by looking for spillovers. So, for example, it is quite conceivable that R&D spillovers will greatly amplify the contribution of R&D.
Appendix 4.1: Excluding Intangibles

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

<table>
<thead>
<tr>
<th>Industry</th>
<th>VA weight</th>
<th>DlnVA/H</th>
<th>contrib to agg va/h</th>
<th>Cap weight</th>
<th>Contrib to agg K/H</th>
<th>Contrib to agg ICT dlnK/H</th>
<th>Contrib to agg non-ICT dlnK/H</th>
<th>Contrib to agg Intan/H</th>
<th>Lab weight</th>
<th>Contrib to agg lab qual per hr</th>
<th>Domar weight</th>
<th>DlnTFP</th>
<th>Contrib to agg TFP</th>
<th>Memo: % total hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture; Mining</td>
<td>0.04</td>
<td>-0.93</td>
<td>-0.04</td>
<td>0.03</td>
<td>0.11</td>
<td>0.00</td>
<td>0.11</td>
<td>0.01</td>
<td>0.05</td>
<td>0.08</td>
<td>-2.59</td>
<td>-0.20</td>
<td>-3</td>
<td>3</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>0.20</td>
<td>4.70</td>
<td>0.91</td>
<td>0.04</td>
<td>0.13</td>
<td>0.04</td>
<td>0.09</td>
<td>0.16</td>
<td>0.13</td>
<td>0.58</td>
<td>1.14</td>
<td>0.65</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td>0.02</td>
<td>-0.52</td>
<td>-0.01</td>
<td>0.02</td>
<td>0.00</td>
<td>-0.01</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.08</td>
<td>-0.15</td>
<td>-0.02</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>0.09</td>
<td>1.28</td>
<td>0.10</td>
<td>0.01</td>
<td>0.08</td>
<td>0.01</td>
<td>0.07</td>
<td>0.07</td>
<td>0.02</td>
<td>0.22</td>
<td>0.06</td>
<td>0.01</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Distribution; Hotels; Transport</td>
<td>0.31</td>
<td>2.84</td>
<td>0.87</td>
<td>0.07</td>
<td>0.31</td>
<td>0.14</td>
<td>0.16</td>
<td>0.23</td>
<td>0.01</td>
<td>0.64</td>
<td>0.87</td>
<td>0.56</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Finance</td>
<td>0.09</td>
<td>4.92</td>
<td>0.40</td>
<td>0.03</td>
<td>0.01</td>
<td>0.08</td>
<td>-0.08</td>
<td>0.06</td>
<td>0.00</td>
<td>0.22</td>
<td>1.84</td>
<td>0.40</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Business Services</td>
<td>0.19</td>
<td>2.93</td>
<td>0.55</td>
<td>0.04</td>
<td>0.10</td>
<td>0.09</td>
<td>0.01</td>
<td>0.15</td>
<td>0.12</td>
<td>0.34</td>
<td>0.99</td>
<td>0.33</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Personal Services</td>
<td>0.07</td>
<td>-1.34</td>
<td>-0.10</td>
<td>0.00</td>
<td>0.03</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td>-0.02</td>
<td>0.13</td>
<td>-0.83</td>
<td>-0.11</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>1.00</strong></td>
<td><strong>2.70</strong></td>
<td><strong>0.76</strong></td>
<td><strong>0.38</strong></td>
<td><strong>0.37</strong></td>
<td><strong>0.32</strong></td>
<td><strong>2.29</strong></td>
<td><strong>1.62</strong></td>
<td><strong>100%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

%ages of summed contributions

<table>
<thead>
<tr>
<th>Industry</th>
<th>% of which</th>
<th>Value added</th>
<th>Capital contributions</th>
<th>Labour contrib</th>
<th>TFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture; Mining</td>
<td>-2%</td>
<td>16%</td>
<td>-13%</td>
<td>3%</td>
<td>-3%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>34%</td>
<td>41%</td>
<td>40%</td>
<td>17%</td>
<td>40%</td>
</tr>
<tr>
<td>Utilities</td>
<td>0%</td>
<td>1%</td>
<td>-1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Construction</td>
<td>4%</td>
<td>5%</td>
<td>1%</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Distribution; Hotels; Transport</td>
<td>32%</td>
<td>3%</td>
<td>34%</td>
<td>36%</td>
<td>29%</td>
</tr>
<tr>
<td>Finance</td>
<td>15%</td>
<td>0%</td>
<td>25%</td>
<td>5%</td>
<td>21%</td>
</tr>
<tr>
<td>Business Services</td>
<td>21%</td>
<td>40%</td>
<td>20%</td>
<td>20%</td>
<td>24%</td>
</tr>
<tr>
<td>Personal Services</td>
<td>-4%</td>
<td>-7%</td>
<td>8%</td>
<td>7%</td>
<td>-6%</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

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

**Source:** authors' calculations
Appendix 4.2: A note on changes since previous work (Haskel, Goodridge et al. 2011)

The main changes are as follows.

1. Improved Industry Breakdown

We now apply a more complete definition of the market sector, in line with that used in EUKLEMS, and a dataset more representative of the UK economy. The new industry is labelled ‘OP’, defined as “Other Community, Social and Personal Service Activities”; “Private households employing staff” in the 2003 Standard Industrial Classification. In the body of this work, for simplicity, we sometimes refer to this sector as personal services. Actually the coverage is much wider than that. The following table provides a more complete overview of industry activity.

Appendix Table 2.2: Personal Services: Industry Description

<table>
<thead>
<tr>
<th>SIC(03) Section</th>
<th>Subsections (two digit)</th>
<th>Divisions (three digit)</th>
<th>Industry Description</th>
<th>Including:</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td></td>
<td></td>
<td>OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICE ACTIVITIES</td>
<td></td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>900</td>
<td>Sewage and Refuse Disposal, Sanitation and Similar Activities</td>
<td>collection / treatment of household / industrial waste; street cleaning</td>
</tr>
<tr>
<td></td>
<td>91</td>
<td>911</td>
<td>Activities of Membership Organisations Not Elsewhere Classified</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>912</td>
<td>Activities of trade unions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>913</td>
<td>Activities of other membership organisations</td>
<td>religious; political and other membership organisations</td>
</tr>
<tr>
<td></td>
<td>92</td>
<td>921</td>
<td>Recreational, Cultural and Sporting Activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>922</td>
<td>Motion picture and video activities</td>
<td>production; distribution and projection of film / video</td>
</tr>
<tr>
<td></td>
<td></td>
<td>923</td>
<td>Radio and television activities</td>
<td>artistic and literary creation and interpretation; live theatrical presentation; arts facilities; amusement parks; dance halls/instruction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>924</td>
<td>Other entertainment activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>925</td>
<td>News agency activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>926</td>
<td>Library, archives, museums and other cultural activities</td>
<td>preservation and reconstruction; botanical and zoological gardens</td>
</tr>
<tr>
<td></td>
<td></td>
<td>927</td>
<td>Sporting activities</td>
<td>arenas/stadia; ice rinks; racehorse owners; leisure centres; marinas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>930</td>
<td>Other recreational activities</td>
<td>gambling; lottery; coin operated video games</td>
</tr>
<tr>
<td></td>
<td></td>
<td>930</td>
<td>Other Service Activities</td>
<td>washing and dry cleaning; hairdressing; funeral and related activities; physical well-being activities; pet care</td>
</tr>
<tr>
<td>P</td>
<td></td>
<td></td>
<td>PRIVATE HOUSEHOLDS EMPLOYING STAFF AND UNDIFFERENTIATED PRODUCTION ACTIVITIES</td>
<td></td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>950</td>
<td>Activities of Households as Employers of Domestic Staff</td>
<td>domestic personnel such as maids, cooks, gardeners, babysitters, etc.</td>
</tr>
<tr>
<td></td>
<td>96</td>
<td>960</td>
<td>Undifferentiated Goods Producing Activities of Private Households for Own Use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>97</td>
<td>970</td>
<td>Undifferentiated Services Producing Activities of Private Households for Own Use</td>
<td></td>
</tr>
</tbody>
</table>
As can be seen, although this addition gives us better coverage of market activity, it also means we include some non-market activity which we may prefer to exclude. For instance, although some activities have been outsourced, local authorities still provide many of the above services for sewage and refuse; sporting activities (leisure centres etc.). We also end up including some activity on the boundaries of market and non-market provision by organisations such as the BBC and museums. The former is officially defined as a public corporation, so ought to be included in the market sector, and is a significant investor in knowledge assets in an industry that we consider important to include in our dataset. It is also worth noting that unlike official market sector data produced by the ONS, our definition of the market sector as does not include private provision of health and education services, with sections L (Public Administration and Defence), M (Education) and N (Health and social work) entirely excluded from our estimation.

We consider this addition a step forward. As well as capturing additional investments in assets such as software, design, training, business process improvement, as outlined above this industry includes film production; television and radio activities; and artistic and literary creation and so includes the creators of artistic originals which we now properly account for at the industry level.


Data on tangible investment have been revised, see Appleton and Wallis (2011). Broadly the revisions are due to: revisions to estimates of real investment; the use of updated data to separate computers from plant and machinery; and downward revisions to Gross Operating Surplus in 2006 and 2008. Overall this has raised growth in volume of capital services by around a percentage point on average in the 2000’s, quite a substantial revision. The overall effect in our work, relative to previous data, has been

a. To raise the contribution of computers in the early 2000s, and lower it in the late 2000s
b. To raise the contribution of buildings throughout. Buildings and non-computer plant had a roughly equal income share of value added (13-15% each in the early 1990s). The share of non-computer plant then rose sharply and fell back from 1996, whereas buildings did the opposite, rising very strongly from 2001, so that they both converged again around 2008. The building share remains just above that of plant and machinery.

3. Measurement of Intangible investment

We have updated our estimates using official sources as much as possible e.g. for software, mineral exploration and R&D. These numbers look very similar to before. The main changes are:

a. Design. As before, we have used the IO tables for purchased design and occupational methods for own account. In the data, in 2008, total (market sector) design purchases are around £32.3bn. Business services (excluding dwellings), was by far the largest purchaser, at £13.6bn. Of that £13.6bn, £10.1bn were purchased by SIC74, a subdivision of business services, “other business
activities”. This is the industry where design firms are located, and hence is it plausible that at least part of this £10.1bn is the purchase of design services by design companies i.e. the outsourcing of design by design companies to, for example, independents. To be conservative therefore, we excluded all of this £10.1bn to avoid double-counting. This is why total design investment is about £8bn less than previous work (the 2008 figure last time was £23bn, now it is £15.5bn). The additional £2bn is due to the addition of consumer and personal services (section O) to our dataset.

b. **Advertising and Market Research.** Here we have applied the same adjustment as that for purchased design, to avoid the double-counting of sub-contracted or outsourced activity, which has reduced branding spending from around £15bn to £13bn, after accounting for the inclusion of an additional industry in our dataset.

c. **Artistic originals.** We have conducted a major revision of this whole asset class using industry data on film production, TV, books, music, art and other spending. This has raised investment by about £2bn relative to previous numbers. The ONS have recently incorporated the new estimates into the National Accounts. Details on the data and method were presented in Chapter 2.

d. **Training.** In previous work we subtracted spending on health and safety training. In the latest version of the NESS firms are asked to provide the proportion of training expenditure that is either health and safety or induction training. In this run, we noted that health and safety and induction is above 30% of training spending for the production industries (agriculture and mining; utilities; and manufacturing). Thus we added this back in for these industries, since one would imagine that such spending in oil and gas mining builds long term knowledge more than, say, health and safety and induction in accounting and other service industries.

e. **Organisational capital.** In Haskel, Goodridge et al. (2011), purchased organisational capital was based on interpolated numbers from a 2005 benchmark from the Management Consultancies Association (MCA). We have now obtained actual MCA data for the latest years, which shows a fall in spend rather than a rise, reducing overall organisational spend from £31bn in 2008 as previously reported to £27bn, after accounting for the inclusion of an additional industry in our dataset.

It is worth re-iterating that our dataset is still classified using SIC 2003. Blue Book 2011 was the first to be produced using SIC 2007. As a result much of our data remains based on either Blue Book 2010 or National Accounts publications in the year 2011 prior to the release of Blue Book 2011. Some Blue Book 2011 data has been mapped back to SIC 2003, to ensure consistency. We aim to fully update our dataset in accordance with SIC 2007 in future work. Improved classification of the service sector in the new SIC will aid the measurement and analysis of knowledge-intensive activity.
4. **Tax-adjustment factors**

We have adjusted our estimation to properly account for appropriate tax adjustment factors in the calculation of capital compensation and rentals, by asset type. In the case of tangibles assets, this also includes the relevant capital depreciation allowances. Most intangible assets do not receive such allowances but the expenditure to generate the intangible asset can be expensed leaving the cost of capital unaffected by the presence of corporation tax. The exceptions are scientific R&D, purchased software, mineral exploration and some types of artistic originals. Purchased software cannot be expensed in most cases but qualifies for the plant and machinery capital allowance. Scientific Research Allowances (SRA), called Research & Development Allowances since 2000, were introduced after the second world war and are a 100 per cent first-year allowance on capital expenditure for R&D purposes (expensing treatment). Following Bloom, Griffith et al. (2002) we assume that prior to 2000 the relevant capital allowance for firms was the general plant and machinery allowance due to the narrow coverage of the SRA. The R&D Corporate Tax Relief, which most people call the R&D Tax Credit, was introduced in 2002 to provide an allowance for ‘revenue expenditure’. In essence this tax relief is a 125 per cent first-year allowance (130 per cent from April 2008 onwards) on revenue expenditure for R&D purposes. The net present value of depreciation allowances for R&D is then a weighted average of the present value of these two different allowances where the weights are given by the shares of capital and revenue expenditure in total R&D spending.

As explained in the main text, the impact of incorporating new tax adjustment factors has been to raise the estimated rental prices and factor income shares for tangible assets relative to intangible assets. The following chart presents income shares for broad asset categories with and without tax adjustment factors. As can be seen the main impact is to the group “other tangibles” where the factor income share rises. Since aggregate capital compensation remains the same, this rise is compensated for by a fall in the factor income share for intangibles. We also present the income share for R&D which clearly shows the impact of the tax credit subsidising the cost of R&D capital, especially post-2002 when the R&D tax credit was introduced.
Appendix Figure 2.4.1: Shares of total capital compensation, by asset

Note to figure: All CHS intangibles treated as capital assets. Labels “wi” and “wo” refer to the incorporation and absence of tax adjustment factors respectively. For asset categories: “ICT” refers to computer hardware plus telecommunications equipment; “othtan” refers to buildings, plant & machinery and vehicles; “soft” refers to software; “innprop” refers to innovative property, that is R&D, mineral exploration, artistic originals, design, non-scientific research and financial product innovation; and “ec” refers to economic competencies, that is branding, organisational capital and training.

Appendix Figure 2.4.2: Share of total capital compensation, R&D
Appendix 4.3: Comparisons of income shares, by asset: Tangible and Intangible

Estimated growth-accounting contributions are derived using a) estimates of growth in capital deepening and b) the asset share of compensation in aggregate income. The following charts present data for the total factor income shares in Appendix Figure 4.3.1, and the asset shares in Appendix Figure 3.2.

Appendix Figure 4.3.1: Labour and Capital (standard NA capital definition) income shares

Note to figure: Capital defined as in the National Accounts i.e. buildings, plant and machinery, vehicles, ICT tangible capital, software, mineral exploration and artistic originals.

The above chart shows that since the mid-90s the labour share as typically defined in the National Accounts has risen. The final two data points show a sharp rise in the labour share in 2009, helping explain the increase in the contribution of labour composition, and decrease in the contribution of capital deepening, as a share of LPG toward the end of our study. This feature is driven by a relatively smaller fall in labour compensation than value-added due to the stickiness of nominal wages and firms hoarding labour.
Appendix Figure 3.2: Capital (standard NA capital definition) income shares for selected assets

Note to figure: Total ICT share is defined as Computer Hardware; Telecommunications Equipment; Software (own-account and purchased)

Appendix Figure 3.2 looks more closely at some of the individual asset shares within the capital share. The respective shares for ‘buildings’ and ‘plant and machinery’ are striking. The income share for buildings declined strongly throughout the 1990s before rising sharply in the 2000s and then falling again in 2009. We conjecture that this profile may be at least partly be explained by infrastructure investments prior to the 2012 Olympics. The pattern is mirrored by the series for plant and machinery, where the income share rose in the 1990s before exhibiting a steady decline. The share for total ICT capital (defined here as computer hardware, telecommunications equipment and software) tended to gradually rise in the 1990s before declining slightly following the late 1990s ICT investment boom. The total ICT share has tended to be relatively stable throughout the 2000s.
Appendix 4.4: Discussion of depreciation and discard, and the conversion from expenditure to investment

The following table presents the depreciation rates applied to each asset. In the case of intangible assets we also present the conversion factors used to move from expenditure to investment. The two concepts are related. The purpose of the conversion factor is eliminate expenditure which creates a good that lasts for less than twelve months. The remaining expenditure is therefore counted as building an asset which provides services for a period beyond one year.

As discussed above and in Chapter 1, geometric rates may not be appropriate for knowledge assets. Data on the revenues earned by artistic originals show that on average such assets depreciate quickly in first few years of life and much slower thereafter (Soloveichik 2010a). Application of a conversion factor can help accounts for fast depreciation in early years by effectively applying a very fast depreciation rate to the first year after any expenditures are made. If conversions factors were not applied, it is likely that the appropriate depreciation rates for most knowledge assets would be greater than those presented below.

Appendix Table 4.1: Geometric depreciation rates and conversion factors, by asset

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Appendix 4.5: Annual growth-accounting results by industry

For completeness the following table presents annual growth-accounting results by industry. We stress that care should be taken in interpreting annual changes in contributions and the innovation index, but feel such data are useful for understanding the period averages presented in the main text.

### Appendix Table 5: Annual growth-accounting results by industry

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<th>Industry</th>
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<td>-0.04</td>
<td>-0.33</td>
<td>-2.62</td>
<td>-1.63</td>
<td>-0.13</td>
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<td></td>
<td>2004</td>
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<td>0.49</td>
<td>0.06</td>
<td>0.63</td>
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<td>-0.31</td>
<td>1.81</td>
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</tr>
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<td></td>
<td>2005</td>
<td>1.21</td>
<td>0.79</td>
<td>0.07</td>
<td>0.74</td>
<td>-0.02</td>
<td>0.59</td>
<td>0.80</td>
<td>-0.96</td>
</tr>
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<td></td>
<td>2006</td>
<td>-3.14</td>
<td>0.11</td>
<td>0.02</td>
<td>0.36</td>
<td>-0.27</td>
<td>-0.52</td>
<td>-0.64</td>
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</tr>
<tr>
<td></td>
<td>2007</td>
<td>0.25</td>
<td>0.57</td>
<td>0.06</td>
<td>0.48</td>
<td>0.03</td>
<td>0.98</td>
<td>0.57</td>
<td>-1.87</td>
</tr>
</tbody>
</table>
Chapter 5: Spillovers from R&D and other intangible investment: evidence from UK industries*

ABSTRACT

Many agree that evidence exists consistent with spillovers from R&D. But is there any evidence of spillovers from a broader range of knowledge/intangible investments, such as software, design or training? We collect investment data for this wider intangible range for a panel of 7 UK industries, 1992-2007. Using the industry-level method in the R&D literature, Griliches (1973) for example, we regress industry TFP growth on lagged external knowledge stock growth, where the latter is outside industry knowledge stock growth weighted by matrices based on (a) flows of intermediate consumption or (b) workers. Our main new result is that we find (controlling for time and industry effects) statistically significant correlations between TFP growth and knowledge stock growth in (a) external R&D and (b) total intangibles (excluding R&D). We expand our framework to allow for imperfect competition and non-constant returns and show our results are robust; likewise they are robust to including foreign R&D, and other controls, and various lags.

*This chapter is an extension on co-authored work of the same title, by myself, Jonathan Haskel and Gavin Wallis. Sections on public R&D and foreign R&D are new. I am grateful for financial support from ESRC (Grant ES/I035781/1) and the NESTA Innovation Index project. This work contains statistical data from ONS which is crown copyright and reproduced with the permission of the controller HMSO and Queen's Printer for Scotland. The use of ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. All errors are of course my own.
5.1. Introduction

An extensive literature studies private and spillover returns to R&D. The recent survey by for example, Hall, Mairesse et al. (2009), and an earlier one by Griliches (1973), suggests that for R&D, social returns likely exceed private returns.

However it is well acknowledged that R&D is only a subset of the actual investments made in researching, designing, developing and commercialising innovations. A framework for estimating a broader range of “intangible” investments is set out in Corrado, Hulten and Sichel (2005) and has been applied in this thesis, in particular in the previous chapter.99

This chapter therefore asks: is there any evidence that other intangible investments, besides R&D, have social returns above private returns? It is, for example, perfectly possible that a broader range of intangible investments might accompany R&D, but only R&D has spillover effects. Thus the intangible approach might offer a more complete measure of investment but the key policy insights from the spillover effects of R&D remain perfectly valid.

To the best of our knowledge, evidence for intangible spillovers (over and above R&D) is very thin on the ground. As Griliches (1992) pointed out many years ago, the lack of direct measures for knowledge flows makes gathering evidence very difficult. One important stream of the R&D literature has been to use patent citations (see e.g. Jaffe, Trajtenberg et al. (2002), for a survey and citations), but this is unavailable in our case since non-R&D intangibles, such as software, design and training are not patentable (for example, UK software is not patentable, except under very special circumstances). Griliches (1992) therefore sets out the indirect methods used, going back to Schmookler (1966) and Scherer (1982), which are essentially to correlate TFP with some measure of external knowledge, with that external knowledge weighted in some way that might correspond to the possible transfer of knowledge to the firm or industry under analysis. A series of papers have used this approach for R&D using a variety of weights, see Eberhardt, Helmers et al. (2010) and Hall, Mairesse et al. (2009) for a survey.

What of non-R&D intangible assets? At the firm-level, Greenhalgh and Rogers (2007) find spillovers from firm-level productivity and industry-level trademark activity: since trademarks likely are generated by non-R&D intellectual property investment, this is suggestive of non-R&D spillovers. At a cross-country level, Van Ark, Hao et al. (2009) and Corrado, Haskel et al. (2011) find a correlation between TFP growth and

99 The broader set of knowledge investments are: (a) software and databases (b) innovative property (scientific and non-scientific R&D, design, mineral exploration, financial product development and artistic originals) and (c) economic competencies (branding, training, organizational capital). If this spending devotes current resources to the pursuit of future returns, it would meet the official definition of investment and hence such spending is being incorporated into National Accounts as investment: the UK National Accounts currently count as investments software, artistic originals and mineral exploration, and, in 2014, will count R&D.
intangible investment for a sample of countries. Dearden, Reed et al. (2006) compare industry and individual level wage equations and find that the results suggest that the industry level analysis may capture externalities from training since industry wages, by aggregation, capture external influences on wages absent from individual data.

This chapter attempts to complement this evidence base by studying the relation between TFP growth and intangible investment at the industry level. We use the data in Goodridge, Haskel and Wallis (2012) and Chapter 4 of this thesis,¹⁰⁰ for 7 UK industries, 1992-2007.¹⁰¹ We adopt the industry-level method used in the R&D literature by, for example, Griliches (1973) and Griliches and Lichtenberg (1984) which relies on weighting external measures of the knowledge stock: in their case, R&D, in our case, R&D, a range of other intangible asset categories, and total intangibles. We create two alternative sets of weights based on (1) flows of intermediate consumption built using the input-output (IO) supply use tables; and (2) labour transition flows between industries, constructed from the Labour Force Survey (LFS) (in robustness checks we also examine foreign R&D weighted by import purchases).¹⁰²

Such a method is of course subject to a number of criticisms. In particular, we have only industry data. It would of course be of great interest to have firm-level data with a long run of intangible spending on software, marketing, R&D etc. To the best of our knowledge such data are not available: for example, O’Mahony and Vecchi (2009) are forced to merge firm data on R&D with industry data on advertising, skills and the like, due to lack of data. In addition, firm-level data raises its own problems e.g. lack of firm-specific deflators (Hall, Mairesse et al. 2009). We comment below on the possible biases due to lack of firm-level data. In addition, like other studies, we have noisy data and lack a natural experiment (Greenstone, Hornbeck et al. (2008) and Kantor and Whalley (2013) for example, use (quasi-)experiments). Of course, future work will improve methods and data, but here we describe how we try to control for these issues as best we can.

At this stage we believe there are four main reasons for this work to be of interest. First, to the best of our knowledge, looking for non-R&D spillovers using the R&D spillovers approach has not been adopted for intangibles so as a first-pass at the data we believe it is worth exploring. Indeed, Hall, Mairesse et al. (2009)

¹⁰⁰ Goodridge, Haskel and Wallis (2012) and Chapter 4 of this thesis are based on 8 market sector industries, the eighth composed of personal, social and recreational services (SIC03 sector O). That industry is excluded from this work due to issues in measurement of output (and inclusion of non-market services and seemingly implausible estimates of TFP).

¹⁰¹ Goodridge, Haskel and Wallis (2013) use time series data for the UK market sector and find strong evidence for positive externalities from the conduct of publicly funded scientific research as well as telecommunications capital. That work relies on 23 time series observations, this work herein uses variation at the industry level. Economy-wide variables such as public R&D and are subsumed into time dummies.

¹⁰² We are extremely grateful to Richard Jones (ONS) for constructing these weights for us. They use labour flows in 2007, so we are implicitly assuming that the pattern of movements in 2007 is reflective of those in other years. In future work we hope to gain access to other cross-sections of LFS data.
in the conclusion to their recent survey, call for exploring possible spillovers from wider innovation spending rather than just R&D, which is what we do.

Second, and related, Hall, Mairesse et al. (2009) also point out that much of the existing work has been done on manufacturing and suggest widening the focus to services and the non-R&D innovation spending therein: we do this as well (Anon Higon (2007) uses 8 two-digit UK manufacturing industries 1970-97 for example: her Table 1 lists the preceding most recent UK industry panel study as ending in 1992).

Third, many TFP-based studies have been conducted using underlying data that has not been appropriately adjusted for the treatment of intangibles as capital, thus introducing potentially large additional bias into measured output, factor shares and TFP as pointed out for instance in Schankerman (1981). Our data correct for this.

Fourth, we examine our results for robustness to imperfect competition and non-constant returns. Our key results turn out to be robust and we think the proposed robustness method is new.

We look at the relation between industry TFP growth and lagged “outside” knowledge stocks (lagged changes in other industry knowledge stocks weighted by the weighting matrices). All findings are controlling for industry and time effects. Thus our results are not based on contemporaneous correlations between TFP growth and changes in outside capital stocks, which could be due to unmeasured utilization and imposes instant spillover transmission. Rather, we examine if more exposure to outside capital growth, over and above that industry’s average exposure and the average exposure across all industries in that period, is associated with above industry/time average TFP growth in future periods. What do we find?

First, as a benchmark, we estimate a positive statistically significant correlation between industry TFP growth and outside R&D knowledge, when controlling for internal industry knowledge capital, using both outside weighting methods. This does not of course imply causation, but is consistent with spillovers of R&D, with the magnitudes in line with other studies. Second, we find a correlation between TFP growth and outside total intangible knowledge, again with controls, but only statistically significant using the intermediate-consumption weights. Multi-collinearity problems make exploring very detailed intangible categories very hard, but we find some correlation with outside firm competencies (branding, training and organisational capital) and outside software, although the latter correlations are less robust. Thus we conclude that, on the basis of these data and methods, our findings are consistent with (a) spillovers from R&D (b) potential spillovers from other intangible categories, but depending somewhat on method. These findings are robust to non-constant returns and imperfect competition and foreign R&D.
The rest of the chapter is set out as follows. The next section sets out the conceptual framework and measurement, section 3 the data, section 4 the results and robustness checks and section 5 concludes.

5.2. Conceptual framework and measurement

5.2.1. Model

Suppose an industry \( i \) has a production function of the form:

\[
Y_{it} = A_{it} F(L_{it}, K_{it}, R_{it}, R_{it})
\]

(9)

where \( Y_{it}, L_{it} \) and \( K_{it} \) are output, labour input and tangible capital input respectively. \( R_{it} \) is intangible capital for the industry and \( R_{it} \) is intangible capital outside the industry, some of which might be useful in production (or more precisely, yield a flow of productive services). It might include publically financed R&D; knowledge produced elsewhere in the world etc. \( A_{it} \) is any increase in output not accounted for by the increase in the other inputs.

Denoting \( \varepsilon \) as an output elasticity we can write, for any form of (9):

\[
\Delta \ln Y_{it} = \Delta \ln A_{it} + \varepsilon_{M,i} \Delta \ln M_{it} + \varepsilon_{K,i} \Delta \ln K_{it} + \varepsilon_{L,i} \Delta \ln L_{it} + \varepsilon_{R,i} \Delta \ln R_{it} + \varepsilon_{R,\text{external}} \Delta \ln R_{it}
\]

(10)

In this section we assume perfect competition and constant returns to focus on spillovers. In the robustness section we extend the framework to allow for non-constant returns and imperfect competition and show our results are robust. Proceeding, to convert (10) into something estimable we make the following assumptions. First, \( \Delta \ln A_{it} \) is industry-specific and includes an i.i.d. error term:

\[
\Delta \ln A_{it} = a_i + \nu_{it}
\]

(11)

where \( \nu \) is an i.i.d. error. Second, under perfect competition and no spillovers, the \( \varepsilon \) terms equal factor shares, since this is simply what cost-minimising firms will choose. With spillovers, industries get extra output than that due to their own choice of capital and so the output elasticity differs from the factor share. Following Stiroh (2002b) we therefore write

\[
\varepsilon_{X,\text{it}} = s_{X,\text{it}} + d_{X,\text{it}}, X = M_{it}, K_{it}, L_{it}, R_{it}
\]

(12)
where $s_{X, it}$ is the share in output, $Y$, of spending on factor $X$ and $d$ a term to account for either deviations from perfect competition, increasing returns or spillovers due to that factor (a formal demonstration of this is set out in the robustness section). Third, observed TFP growth is defined as:

$$\Delta \ln TFP_{it} \equiv \Delta \ln Y_{it} - \sum_{X=L, K, R} \bar{s}_{X, it} \Delta \ln X_{it}$$

(13)

Where the bar above $s_{X, it}$ denotes a time average.

Fourth, we turn to the “outside knowledge term”, $\varepsilon_{R} \Delta \ln R_{it}$ in (10). Consider $\varepsilon_{R}$. If outside knowledge that affects $\Delta \ln Y$ is free, $\varepsilon_{R, it} > 0$, but cannot be measured in a factor share. Thus we must determine it econometrically in this framework or by case studies. Second, consider $\Delta \ln R_{it}$. Some proportion of this would be economy-wide information, such as publically subsidised R&D and/or knowledge in other countries (these elements will be considered later). Some other proportion, our focus here, will be in other industries. With $n-1$ other industries, we have then potentially $t(n-1)$ data points for $\Delta \ln R_{it}$ for each industry $n$, which would provide insufficient degrees of freedom with $t$ observations. Thus as in other papers, we have to devise some sort of weighting matrix to combine these exterior sources of free knowledge. Hence our tests are joint tests of the hypotheses of (a) spillovers and (b) the correct form of the weighting matrix. Denoting this matrix by $M$ we can write:

$$\varepsilon_{R, it} \Delta \ln R_{it} = \alpha_{i} \left( M \Delta \ln R_{it} \right) + \lambda_{i}$$

(14)

Where $\lambda_{i}$ measures any common economy-wide knowledge e.g. on the internet, from universities, from abroad etc. (we experiment below with more measures of this). All this gives us:

$$\Delta \ln TFP_{it} = \alpha_{i} \left( M \Delta \ln R_{it} \right) + \lambda_{i} + \sum_{X=L, K, R^{PRV}} d_{X} \Delta \ln X + v_{it}$$

(15)

which has the following intuition. Measured industry TFP growth\(^{103}\) will be driven by the following: (a) the first term on the right-hand side is freely available knowledge from external domestic industries (b) the second term is freely available knowledge originating from other sources, such as publicly funded research or foreign knowledge, (c) the third term, which is industry technical change (d) by the influence of spillovers or departures from perfect competition or increasing returns accruing to within-industry inputs, in the

\(^{103}\) We allow for industries to have different output elasticities via the construction of TFP as in (5). But (7) does impose the same elasticities with respect to weighted outside intangibles, $\alpha_{1}$. However, the effect of a unit increase in outside knowledge varies by industry, since this effect is $\alpha_{1}$ times the sum of outside weights, and this sum varies by industry: see section 5.4b.
penultimate term, and (e) any residual mismeasurement captured here by $v_t$, which may for instance incorporate unmeasured changes in capital utilisation. With a limited number of observations our central empirical exercise is to test for spillovers due to knowledge investment by other industries. Since we use UK market sector data, any other sources of knowledge e.g. public sector originating spillovers, such as public R&D, or foreign knowledge, should be captured by the time dummies. In a later section we seek to estimate the contributions of public R&D and foreign knowledge directly.

It is worth noting the different interpretations of the right hand side depending on whether or not $\Delta \ln \text{TFP}$ includes the contribution of industry-intangible capital. To interpret $d_X$ as the excess return to industry-specific knowledge investment requires computing $\Delta \ln \text{TFP}$ including the contribution of intangibles, that is to say, using (5), which is what we do here. If we do not, as is noted in the literature, e.g. Schankerman (1981), then $d_{R&D}$ includes of course both the private and social returns to R&D, and the biases can be very large.

What biases might be induced by our use of industry data in the presence of firm heterogeneity? Consider a firm-level production function where $\text{firm ln } Y_j$ depends upon within and outside firm inputs ($\ln X_{j}$ and $\ln X_{-j}$). Heterogeneity raises at least two issues. First, available industry data is $\sum_j Y_j$. However, the log of industry data, $\ln(\sum_j Y_j)$ is not the same as $\sum (\ln Y_j)$. For log normally distributed variables $\log(\sum_j X_j) = \sum_j (\log X_j) + (1/2)\sigma^2_{\log X}$. Hence log industry TFP data (derived from $\ln(\sum_j Y)$ less terms in $\ln(\sum_j X)$) introduces a “mix” term being the standard deviation of inputs less outputs in the industry. We have no information on this and so our outside spillover results are biased to the extent that changes in such terms are not controlled for by industry/time and are correlated with the outside spillover measures. Second, when we use industry data we implicitly sum over the firm-specific “outside” terms. If we suppose the outside terms are those outside the firm (a) but within the industry and (b) outside the industry, industry data gives two outside firm terms: (a) an outside term but within the industry and (b) an outside term summing across firms outside the industry. The first of these is measured in the $d_i$ and the second is the outside term that we measure. If the coefficient on these outside spillovers depends upon firm characteristics, we will again omit a “mix” term. Thus we should be cautious in the interpretation of our outside industry terms as spillovers.

5.2.2. Other studies and discussion of framework
As pointed out in Griliches (1973) and Hall, Mairesse et al. (2009) many industry studies are based on something like (7), using as weights, for example, intermediate inputs (Terleckyj 1980), flows of patents (Scherer 1984) or survey-measures of innovations (Sterlacchini 1989). As is usual in all indirect knowledge flow measures, such measures need to be interpreted carefully. If they track free use of knowledge, they might be knowledge spillovers. But, if they reflect mispricing, they might be rent spillovers. For example, using intermediates as weights, there might have been growth in intermediate quality, unaccounted for by
measured intermediate prices. This shows up as higher measured TFP growth in the using industry, creating a direct link between innovation in one industry and measured TFP in another.

One example of this mispricing effect may arise through branding. Suppose the manufacturing industry builds reputation by branding (cars for example). Thus demand rises for manufacturing and, downstream for retailing. Manufacturers, if they are doing the branding, would hope to appropriate returns from their investment in reputational capital by charging more to retailers. If we do not measure that, then the rise in retail car sales comes without any apparent increased payments for the better reputation goods retailers are selling on, which shows up as an increase in measured retailer TFP. So the spillover is a rent induced spillover, which might lead one to wrongly presume there ought to be a move to subsidise branding, if vertical relations between manufacturers and retailers internalise any externality present. Without detailed information for each industry this remains a caveat in our, and other, results.

Hall, Mairesse et al. (2009) also point out that spillovers might be negative if they incorporate market-stealing effects from rival R&D (Bloom, Schankerman et al. 2007) and that results tend to vary depending upon the weighting matrix used. Nonetheless, in their summary (Table 5) the elasticity with respect to external R&D is positive and between 0.68 (on firm data) and 0.006 (on country data).

5.3. Measurement

5.3.1. Industries

We base this work on our industry-level dataset of UK market sector investment in intangible assets, for a full discussion of data derivation and detailed sources see Goodridge, Haskel and Wallis (2012), also presented in the previous chapter. This work uses the seven broad industries as set out in Table 5.1. We use the seven broad industries due to limited industry detail in the intangible data. We have data from 1992 to 2007. We start in 1992 due to the IO tables not being available earlier. We end in 2007 since we rely on EUKLEMS data, and more up to date real industry intermediates are not available from the ONS. We exclude real estate from SIC K which therefore excludes imputed rents due to owner-occupied housing which is not counted as capital in our data.

Table 5.1: Industry Breakdown

<table>
<thead>
<tr>
<th>SIC(2003)</th>
<th>Industry Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC</td>
<td>Agriculture, Forestry and Fishing</td>
</tr>
<tr>
<td>D</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>E</td>
<td>Electricity, Gas &amp; Water Supply</td>
</tr>
<tr>
<td>F</td>
<td>Construction</td>
</tr>
<tr>
<td>GHI</td>
<td>Distribution; Hotels &amp; Restaurants; Transport, Storage &amp; Communications</td>
</tr>
</tbody>
</table>
Since our work is at the industry-level, some adjustments present measurement problems for certain industries. First, output in some industries is simply not well-measured, notably in financial services. This is clearly an area for more work, see e.g. Burgess (2010) for a discussion, but for the moment we note that the bulk of the measurement problems due to ‘Financial Intermediation Services Indirectly Measured’ (FISIM) in the crisis are at the end of our data. In Agriculture and Construction land is a major factor of production, but is not treated as a capital asset in the National Accounts framework by (European) national accounting convention. This makes TFP difficult to interpret and in fact we find it to be measured as negative for agriculture over much of our data period. Industry TFP can also be hard to interpret in Electricity, Gas and Water due to the use of natural resources and likely increasing returns to scale. That said, Basu, Fernald et al. (2004) estimate close to constant returns to scale for US industries: 1.07 for durable manufacturing, 0.89 for nondurable manufacturing and 1.10 for non-manufacturing.\footnote{Better data is clearly desirable, but we note that we use industry and time dummies. So if for example, true agricultural $\Delta \ln TFP$ is positive but we incorrectly mis-measure it by a constant industry or time factor, we are controlling for this. That is, for measurement error to be driving all our results, it would have to be measurement error that is causing deviations of $\Delta \ln TFP$ from its industry and time means.}

Second, the quality of most of our industry-level intangible investment data improves greatly from 1992, the first year of published IO analyses. Data are extended further back but there is inevitably some imputation for earlier years. We estimate initial capital stocks in 1990 using the standard method (e.g. as in Oulton and Srinivasan (2003)). So that estimates are not too affected by initial values problems, we conduct our analysis over the period 1995 to 2007.

### 5.3.2. Data on output and tangible investment

Our output and tangible capital data come from EUKLEMS which is based on UK National Accounts and uses a consistent set of real and nominal output variables which sum to the aggregate. In computing TFP we adjust both the input and also the output data. All the input shares sum to one and the rental prices are calculated consistently using the ex post method so that the sum of capital rental payments, including intangibles, equals total capital payments. Because we are working at the industry level, TFP is calculated on a gross output basis, which does not impose restrictions on the form of the production function that value added would.

### 5.3.3. Data on intangible investment, by asset

We now review the major categories of intangible investment. Table 5.2 provides an overview of the intangible assets included following the definitions developed by Corrado, Hulten and Sichel (2005) and first
applied to the UK in Giorgio Marrano, Haskel and Wallis (2009). The sections below describe the data construction. For a fuller description of the data and robustness checks see Goodridge, Haskel and Wallis (2012), also presented in Chapter 4: (e.g. $\Delta \ln TFP$ is quite robust to changes in depreciation rates for intangible capital).

The CHS framework for measuring intangible investment breaks spending down into three broad categories: i) software and computerised databases; ii) innovative property; and iii) economic competencies. Investment in Innovative property can be regarded as the spend on the development of the innovation, and so includes activities such as scientific or non-scientific R&D; mineral exploration; design and the creation of blueprints, and the development of artistic originals and financial products. Economic competencies can be thought of as the co-investments that are essential to commercialising the innovation, and therefore includes activities such as: branding; improvement of organisational structures and business processes; and the training of the workforce in order to apply the newly acquired knowledge. It is therefore sensible to consider the data in these broader categories, as below.

### Table 5.2: Intangible asset categories

<table>
<thead>
<tr>
<th>Broad category of intangible asset</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computerised information</td>
<td>Computer software, computer databases</td>
</tr>
<tr>
<td>Intellectual property</td>
<td>Artistic originals, Scientific R&amp;D, Non-scientific R&amp;D, Mineral exploration, Financial product innovation, and Architectural and engineering design</td>
</tr>
<tr>
<td>Economic competencies</td>
<td>Branding: Advertising and market research, Firm-specific human capital, and Organisational Structure</td>
</tr>
</tbody>
</table>

Notes to table: Source: Corrado, Hulten and Sichel (2005)

**I. Computerised information**

Computerised information comprises computer software, both purchased and own-account, and computerised databases. Software is already capitalised in the National Accounts, and our main source for computer software investment is contained in the ONS work described by Chamberlin, Clayton et al. (2007).
II. Intellectual property

Artistic originals

Previous estimates for investment in Artistic Originals were based on official ONS estimates recorded in the National Accounts. We have since improved those estimates in terms of both data and methodology (details in Chapter 1). Using a variety of sources we construct new estimates of investment in the categories of Film, TV & Radio, Books, Music and Miscellaneous Artwork. Official estimates are soon to be improved based on that work.

Scientific R&D

For Scientific R&D performed by businesses in the UK, expenditure data are derived from the Business Enterprise R&D survey (BERD). To avoid double counting of R&D and software investment, R&D spending in “computer and related activities” (SIC 72) is subtracted from R&D spending, since this is already included in the software investment data. One component of BERD expenditure data is the spend on tangible assets used in R&D production. In estimating R&D investment we convert estimates of the tangible stock used in R&D production into terms for the user cost of capital. Note too that in the BERD data one product category is R&D in R&D products, which is the R&D conducted by the R&D services industry (SIC 73) that is sold to outside industries. In accounting for this, we allocate own-account expenditure on production of R&D products to the industries that purchase R&D products from SIC73, using shares constructed from the IO tables. Thus our spillovers, if any, from the business services industry, do not reflect these measured purchases.

Non-scientific R&D

This is estimated as twice the turnover of R&D in the “Social sciences and humanities” industry (SIC 73.2), where the doubling is assumed to capture own-account spending (this number is very small).

Mineral exploration

Data on mineral exploration are already capitalised in the National Accounts and the data here are simply data for Gross Fixed Capital Formation (GFCF) from Blue Book 2011.

Financial product innovation

The measurement methodology for New product development costs in the financial industry follows that of own-account software, used by the ONS, and is based therefore on financial service occupations; further details are in Haskel and Pesole (2010). In practice these numbers turn out to be rather small: spending is
about 0.52% of industry gross output in 2005 (note that reported R&D in BERD is 0.01% of gross output in this industry).\textsuperscript{105}

*Architectural and engineering design*

For new *architectural and engineering design* we use the software method for own-account, and purchased data are taken from the IO tables. Full details are set out in Galindo-Rueda, Haskel et al. (2008). To avoid over-estimating, based on industry discussions we assume that 50% of such expenditure represents long-lived investment, thereby excluding one-half of the expenditure figure. As described in Chapter 4, we also subtract purchases of design made by and from the design industry itself, to avoid any possible double-counting due to intra-industry outsourcing.

*III. Economic competencies*

*Branding: advertising and market research*

*Advertising expenditure* is estimated from the IO Tables by summing intermediate consumption on advertising (product group 113) across all industries. Market research is estimated with data on market research from the IO tables. Of course not all expenditure on advertising and market research constitutes investment. Following CHS we subtract off 40% of expenditure. Again, as with design, intra-industry purchases are removed to account for outsourcing and potential double-counting.

*Firm-specific human capital (training)*

*Firm specific human capital*, that is training provided by firms, was estimated using cross sections from the National Employer Skills Survey for 2004, 2007, 2009 and 2010. We also have data for 1988 from an unpublished paper by John Barber. The series is backcast using the EU KLEMS wage bill time series benchmarking the data to five cross sections.

*Organisational structure*

For purchased organisational capital we use data from the Management Consultancy Association (MCA). To measure own-account investment in organisational structure we use the now standard assumption in the intangibles literature that 20% of the wage bill of managers, where managers are defined using occupational definitions, is investment in organisational structure. Wage bill data are taken from the ASHE for all those classified as managers, excluding IT and R&D managers to avoid double counting.

\textsuperscript{105} In brief, we interviewed a number of financial firms to try to identify the job titles of workers responsible for product development and mapped these titles to available occupational/wage data from the Annual Survey on Hours and Earnings (the occupational classification most aligned with the job titles was ‘economists, statisticians and researchers’). We asked our interviewees about time spent by these workers on developing new products that would last more than a year, noting that some firms based their estimates on time sheets that staff filled out, and on
5.3.4. *Industry weights: outside knowledge*

We have constructed two alternative sets of weights. Each provides some measure of ‘industry closeness’ and the appropriateness of each may depend on the asset type being considered. The first are based on data for intermediate consumption (IC), by product and industry, as recorded in the IO tables. The second are based on inter-industry labour force transitions (TR), estimated using Labour Force Survey (LFS) micro data. Due to data availability, labour transition weights only apply to movements between 2006 and 2007 whilst the intermediate consumption weights are produced using a full set of published data from 1992.

*Weights: inter-industry trade (Intermediate Consumption)*

We use data from the official IO datasets, available for 1992-2007, which contain information on industry intermediate consumption by product, and we use that data to form a matrix of inter-industry flows, as in for example Griliches and Lichtenberg (1984). In doing so we assume that products purchased correspond to producing industries. IO data is aggregated to a broad seven-industry breakdown, and each cell is transformed into an industry share, where the shares sum to unity (i.e. across products or “selling industries”). In the case of Business Services, we appropriately exclude data for dwellings (both actual and imputed rents) since dwellings are not part of the productive capital stock and were excluded from the calculation of TFP.

*Weights: Labour force transition*

Based on LFS micro data we have data on the flows of workers into each industry and which industry they have moved from, and again the data are constructed into industry shares.

Our final dataset consists of a series of vectors for both forms of industry-weight, where the weights in each sum to one. We then apply these weights to our industry estimates of knowledge stocks, by asset type. For each industry and asset we construct a term for growth in available outside knowledge as the industry weight multiplied by growth in the relevant capital stock from the other six industries. Therefore, say for example, 50% of IC in industry X comes from within the industry, the weights for other industries will sum to 0.5.

5.4. Results

5.4.1. *Graphs and raw correlations*

We have potentially many assets and, it turns out, they are very collinear in the time series (although not in the cross section e.g. R&D is concentrated in manufacturing, software in financial services).

---

overhead costs. Own-account investment in product development is therefore that occupation wage bill, times a mark-up for capital, overheads etc., times the time fraction spent on long-term projects.
Thus we work with the following asset groups: just R&D since that is studied so much in the literature, all intangibles, all intangibles excluding R&D, computerised information, innovative property, innovative property excluding R&D and economic competencies. We also smooth TFP growth, as is done in many studies, since it is so noisy. We do so using forward weights of 0.25, 0.5 and 0.25 for t+2, t+1 and t respectively. Our explanatory variables are dated t, implying a lagged relation between outside knowledge and ΔlnTFP, which seems reasonable. The results for unsmoothed TFP growth, with explanatory variables dated t-1 or t-2, are similar.

Figure 5.1 plots smoothed TFP growth and growth in the weighted (IC) outside stock, all in terms of deviation from time and industry means. Each point is an industry (1=agriculture and mining, 2 = manufacturing, 3=utilities, 4=construction, 5= distribution, 6 = finance and 7 = business services). Each panel corresponds to a different outside measure.

**Figure 5.1:** ΔlnTFP$_i$ against MΔlnR$_i$ (outside industry ΔlnR, weighted by intermediate consumption of industry $i$, by the industry $i$), all in deviation from industry and time mean terms, ΔlnTFP smoothed (t+2, t+1, t).

**Notes to figure:** outside ΔlnR are, clockwise from top left, rd = R&D; TTIN= total intangibles, sof= software and computerised databases; IP = innovative property (scientific and non-scientific R&D; mineral exploration, design, new
products in finance, and artistic originals); EC = economic competencies (market research branding; improvement of organisational structures and business processes; and firm-provided training). Aggregation of $\Delta \ln R$ is by rental share of each intangible. Outside industry $\Delta \ln R$ weighted using the intermediate consumption-based weighting matrix, see text. Each point in graph is an industry (1 = agriculture and mining, 2 = manufacturing, 3 = utilities, 4 = construction, 5 = distribution, 6 = finance and 7 = business services). All points are deviations from time and industry means.

Consider then the upper left panel for R&D. The points labelled “3” show the 13 observations for the utilities industry, 1995-2007. Consider the points on the left-hand side of the graph. They lie below both the zero horizontal and vertical axes. This shows that for periods where utilities was relatively less exposed to outside R&D stock growth, subsequent $\Delta \ln TFP$ (recall outside variables are dated t, $\Delta \ln TFP$ smoothed t+2, t+1, t) was low (these and later statements are relative to the industry and time average). Now consider the points, again for utilities, on the right-hand side of the chart. These lie above the zero horizontal and vertical axes, showing that following periods where utilities were relatively more exposed to outside R&D growth, subsequent TFP growth was higher.

The figures seem to suggest a positive relation with each category, although that for software appears weakest. The relation appears strongest for R&D and economic competencies. Note that manufacturing (2), consistently clustered around zero, is exposed to a relatively low amount of outside capital growth relative to the average because a) much of its intermediate consumption comes from within manufacturing and b) much of the growth in intangible capital takes place in manufacturing itself. Therefore weighted growth of external knowledge is low for manufacturing.

Less of a correlation is found with the labour transitions weighting scheme, as shown in the Appendix chart (Figure A1). Indeed for total innovative property and economic competencies the correlation appears negative.

5.4.2. Regression results
To estimate (7) we proceed as follows. Even at these broader asset categorisations, the degree of collinearity between our independent variables remains rather high. We therefore first run separate regressions for different asset definitions and each alternative weighting scheme. Growth in internal stocks is included to control for the effects of market power and/or increasing returns. The interpretation follows equation (7), namely that the internal variable should appear in a regression even with that effect accounted for in $\Delta \ln TFP$ if there is some deviation of the output elasticity from its factor share, which could be due to within-industry spillovers, industry imperfect competition, non-constant returns to scale etc. All regressions use data for 1995 to 2007, as data for the early 1990s are considered to be of much lower quality and data post-2007 were not available, and estimation uses a fixed effects model including year dummies (not reported) with robust standard errors.
Columns 1 and 2 of Table 5.3 set out the results using IC and TR weights to generate the external R&D variable. These regressions are similar to much of the previous in this area and like most of that literature external R&D is found to be statistically significant using either weighting scheme. The estimated elasticities with respect to a unit rise in all external capital growth rates, \(^{106}\) see penultimate row, are similar for each weighting scheme at 0.25 and 0.21: the survey paper by Hall, Mairesse et al. (2009) reports elasticities with respect to external R&D using a production function method between 0.006 (on country data) and 0.68 (on firm data).

Table 5.3: Fixed effects regression estimates of equation (7) (dependent variable, smoothed ΔlnTFP (t+2, t+1, t))

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<td>0.38**</td>
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<tr>
<td>Total Internal Intangibles</td>
<td>0.39*</td>
<td>0.070</td>
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<tr>
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<td>-0.16***</td>
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<td>-0.099***</td>
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<tr>
<td>R-squared</td>
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<td>0.287</td>
<td>0.228</td>
<td>0.372</td>
<td>0.273</td>
<td>0.187</td>
<td>0.161</td>
<td>0.204</td>
<td>0.170</td>
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<tr>
<td>Number of industries</td>
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<td>7</td>
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<td>7</td>
<td>7</td>
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<tr>
<td>Elasticity of external R&amp;D</td>
<td>0.25</td>
<td>0.21</td>
<td>0.30</td>
<td>0.054</td>
<td>0.22</td>
<td>0.15</td>
<td>0.26</td>
<td>0.19</td>
<td>0.22</td>
<td>0.18</td>
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<tr>
<td>Elasticity of other external variable</td>
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<td>0.0065</td>
<td>0.018</td>
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<td>0.14</td>
<td>-0.059</td>
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Notes to table: Dependent variable is dlnTFP smoothed, t+2, t+1, t. Independent variables are dated t, and are \( \sum w_\text{dlnR} \), that is weighted changes in outside intangible capital stocks, with the included intangible variables according to the row titles (see Table 5.2 for details of what is included in each broad intangible class), and dlnR the internal stock.

\(^{106}\) This is derived as follows. Consider the coefficient in the body of the table using say the IC weights. As a matter of data in 2006, the manufacturing sector purchased 69% of its intermediate consumption from inside the sector, and 31% from outside. So for manufacturing dlnTFP, we weight outside DlnX with these 6 outside weights which add up to the total share of intermediate consumption from outside: here 31%. Hence the coefficient that we then estimate is a coefficient on this “outside” DlnX variable, call it \( \sum w_\text{DlnX} \), as opposed to the DlnX variable itself. Thus the coefficient in the body of the table answers the question: what is the impact on dlnTFP of an increase in the outside variable, \( \sum w_\text{DlnX} \). This is not the same as the answer to the question: what is the impact on DlnTFP of a unit increase in all the outside DlnX’s. To answer this second question, one must multiply the body of table coefficient by the sum of the outside weights (in the case of manufacturing, 31%), for that year, then for each industry and then take a grand industry/year average. The elasticity in the bottom row is this.
Weighting schemes use intermediate consumption (IC) and labour transitions (TR). Estimation by fixed effects with time dummies. ***indicates significance at 1%, ** indicates significance at 5%, * at 10%. Final two rows show the estimated % change in TFP with respect to a 1% change in respectively, outside R&D, and other outside intangible capital. t-statistics reported in parentheses, using robust standard errors. IP = innovative property (scientific and non-scientific R&D, mineral exploration, design, new products in finance, and artistic originals); EC = economic competencies (market research branding; improvement of organisational structures and business processes; and firm-provided training).

Columns 3 and 4 report results for all intangibles weighted together (including R&D). As these columns show, statistical significance depends on the weighting matrix used, with the IC matrix significant at the 5% level, although we do generate negative and statistically significant coefficients for the within-industry intangible stock. This negative internal dlnR effect is statistically insignificant when financial services is dropped, with all external measures remaining statistically significant. The estimated elasticity also varies greatly depending on which weighting scheme is used, with the IC matrix generating a much larger elasticity. In order to check that the result is not just due to the inclusion of R&D rather than other intangible assets, columns 5 and 6 show the results of using total intangibles excluding R&D. As before, intangibles are statistically significant using the IC weighting matrix but not the TR weighting matrix. Note too that external R&D remains statistically significant using either weighting scheme.

The final six columns attempt to determine which non-R&D intangible asset(s) are driving the result in column 5. Running regressions for each asset group alongside R&D, we only generate a statistically significant result for External economic competencies, which we found to be significant at the 10% level using the IC weighting matrix but not statistically significant using the TR matrix. The results therefore suggest that spillovers from intangibles other than R&D appear to derive from investments in training, organisational capital or reputational capital. In the case of the latter, one possibility is the observation of rent spillovers as discussed above.

To explore further these variables, we entered them individually without the R&D term and found statistically significant effects for outside training and management, (coefficients 0.39 (t=4.91) and 0.33(t=2.05)) but insignificant effects for branding (0.013 (t=0.14)). However, including the R&D term renders them all insignificant (0.16, (t=1.71), 0.074(t=0.47), 0.076(t=1.08)), with the R&D term significant in all cases. It is therefore difficult to identify which asset groups other than R&D are driving some of our results. There are two possible interpretations. The first is statistical: elements of intangible investment are very collinear (as might be expected e.g. due to complementarities), hence it is hard to statistically identify separate spillovers (the correlation between demeaned ΔlnR R&D and training is 0.63; management 0.69, branding -0.21). The second is economic: spillovers arise from the bundle of non-R&D intangible investments not just each element.
Overall, our results are statistically better determined (for non-R&D assets) using the intermediate consumption model rather than the labour transition weights, with the implied elasticities to the outside variable slightly lower with labour transitions. Kantor and Whalley (2013) find spillovers from US universities seem to be mediated via labour market transitions and Greenstone, Hornbeck et al. (2008) find stronger effects of US plant-opening spillovers via labour market transitions than intermediate consumption. It is of course perfectly possible that the appropriateness of the weighting scheme would differ by asset, with IC weights preferable for some, and TR weights for others, or that the UK might be different.

5.4.3. Initial robustness checks
How robust are these results? We tried a number of different variations. First, although there is considerable collinearity between variables, Appendix Table A1 presents results for when we include all four asset groups together. The result is a weakly significant coefficient for External Economic Competencies at the 10% level when using the IC weights, and a strongly significant coefficient for R&D at the 1% level using the TR weights. We also run those same regressions but excluding the finance industry. In that case, we generate a statistically significant result for R&D at the 10% level using the IC weights, and a statistically significant result for both R&D and software, again at the 10% level, using the TR weights.

Second, to examine the absorptive capacity of firms and their ability to benefit from diffusion of outside knowledge, see for example Cohen and Levinthal (1989), we did try some specifications which included an additional interaction term between the outside stock and a measure of absorptive capacity based on industry investment intensity, with little success either in terms of statistical or economic (the coefficients for this term tended to be negative) significance. We may have insufficient cross-section variation to identify these effects.

Third, we tried a number of more econometric robustness checks. Due to the presence of measurement error in our outside stocks we estimated the regressions above using instrumental variable methods. We used lagged values of outside stocks as instruments, which are valid instruments so long as the measurement error in the outside stocks is not serially correlated. The results were similar to the regressions above: see Appendix A2.

Fourth, we added controls for utilisation, following Basu, Fernald et al. (2004), incorporating $\Delta \ln(H/N)$, where $H/N$ is hours per worker, into the industry spillover regressions. $H$ and $N$ are taken from EUKLEMS. Note that we already control for utilisation somewhat by smoothing $\Delta \ln TFP$, using ex post factor shares (Berndt and Fuss 1986; Hulten 1986) and including time dummies. So we tried this utilisation term with
unsmoothed $\Delta \ln \text{TFP}$ and dropping time dummies: the utilisation term was generally insignificant and the other effects unchanged.

So far any other outside effects have so far been relegated to time dummies. The following section examines the robustness of the results to incorporating estimates of public R&D spending (the UK science budget) and growth in foreign industry R&D capital stocks.

5.4.4. Robustness to incorporating public R&D and foreign R&D

a) Public R&D

Of course firms/industries may acquire knowledge from other sources than outside domestic industries. One possible source is public research, the results of which are freely available. Haskel and Wallis (2013) and Goodridge, Haskel and Wallis (2013), with the latter submitted as an appendix to this thesis, find a strong positive correlation between $\Delta \ln \text{TFP}$ and the UK science budget as a share of value-added (lagged) at the aggregate market sector level.

In (7), the impact of freely available knowledge from other sources is accounted for by the term, $\lambda_y$. This section extends the model to incorporate the share of the science budget in market sector value-added, where the science budget is UK government support of the UK Research Councils. On its own this share would be collinear with the time dummies. Therefore to introduce some industry variation, the term is interacted with industry R&D investment intensity, which serves as a proxy for absorptive capacity as described above. The justification is intuitive: in order for firms/industries to benefit from the knowledge contained in public research they must have the ability to exploit that knowledge, and they derive that ability from their own conduct of R&D (Cohen and Levinthal 1989). The degree to which industries can benefit commercially from the basic research of the UK Research Councils is therefore proxied by industry R&D investment intensity, as in (8):

$$
\Delta \ln \text{TFP}_i = \alpha_1 (M \Delta \ln R_{i,t}) + \alpha_2 \left( \frac{P^N N_{i,t}}{P^Y Y_{i,t}} \cdot \frac{S_i}{\Sigma P^V V_t} \right) + \lambda_y + \alpha_i + \sum_{x \in L, K, R} d_x \Delta \ln X + v_{it} \tag{8}
$$

Where terms are defined as in (7), and $P^N N_{i,t}$ is R&D investment, $P^Y Y_{i,t}$ is gross output, $S_i$ is the UK science budget and $\Sigma P^V V_t$ is market sector value-added.
Table 5.4 presents results for the specification in (8). Again estimation is using a fixed effects model, with year dummies, and with ΔlnTFP smoothed with forward weighting so that independent variables are effectively lagged.

Table 5.4: Estimation of equation (8), incorporating UK public R&D (dependent variable, smoothed ΔlnTFP (t+2, t+1, t))

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<tr>
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<td></td>
<td>0.42**</td>
<td>1.99*</td>
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<td>(1.64)</td>
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<tr>
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<td>Total External Intangibles excl. R&amp;D</td>
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<td></td>
<td>0.27**</td>
<td>-0.31</td>
<td>0.27**</td>
<td>0.22*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(3.54)</td>
<td>(-0.29)</td>
<td>(2.60)</td>
<td>(1.99)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Internal Intangibles excl. R&amp;D</td>
<td>-0.17***</td>
<td>-0.16***</td>
<td>-0.18***</td>
<td>-0.19***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-5.34)</td>
<td>(-4.49)</td>
<td>(-5.89)</td>
<td>(-6.80)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK Science Budget: (P^*N/I^<em>Y)/N</em>(S/t/P^*V)</td>
<td>331*</td>
<td>279</td>
<td>264</td>
<td>326</td>
<td>445</td>
<td>338</td>
<td>477</td>
</tr>
<tr>
<td></td>
<td>(2.00)</td>
<td>(1.27)</td>
<td>(1.91)</td>
<td>(1.64)</td>
<td>(1.86)</td>
<td>(1.76)</td>
<td>(1.69)</td>
</tr>
<tr>
<td>Observations</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>91</td>
<td>84</td>
<td>77</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.226</td>
<td>0.175</td>
<td>0.395</td>
<td>0.310</td>
<td>0.204</td>
<td>0.392</td>
<td>0.369</td>
</tr>
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<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Notes to table: Dependent variable is ΔlnTFP smoothed, t+2, t+1, t. Independent variables are dated t, and are \( \sum w\Delta \ln R \), that is weighted changes in outside intangible capital stocks, \( \Delta \ln R \), the internal stock, and the share of the science budget in market sector GVA interacted with industry R&D investment intensity. Weighting schemes use intermediate consumption (IC) and labour transitions (TR). Column 5 uses unsmoothed TFP so independent variables are lagged once. Estimation by fixed effects with time dummies. ***indicates significance at 1%, ** indicates significance at 5%, * at 10%. t-statistics reported in parentheses, using robust standard errors.

Column 1 uses the specification from column 1 of Table 5.3 and incorporates the science budget variable. External R&D remains statistically significant, although the strength of statistical significance is reduced, with an almost identical coefficient. The science budget term is just statistically significant at the 10% level.

Column 2 uses the same specification but this time using the labour transition weights on outside capital growth. The coefficient on external R&D again remains statistically significant but the magnitude of both the coefficient and the t-statistic are reduced. The term for the science budget is not statistically significant.

Columns 3 and 4 incorporate terms for total intangibles excluding R&D. Using the IC weights, column 3, both external R&D and external intangibles (excluding R&D) are statistically significant. Compared to Table 5.3 the coefficient on external intangibles is reduced but is more precisely estimated. The science budget variable is bordering on statistical significance. Using the TR weights, column 4, neither external capital nor the science budget are statistically significant.
Column 5 uses the same specification as column 1 but this time using unsmoothed $\Delta \ln \text{TFP}$. As $\Delta \ln \text{TFP}$ had been smoothed using forward weighting, dependent variables are lagged one period. External R&D remains statistically significant, with the science budget bordering on significance.

Haskel and Wallis (2013) and Goodridge, Haskel and Wallis (2013) show evidence that the marginal returns from science funding have declined as the budget has increased. This is supported by the results in columns 6 and 7 where results are estimated over the years 1995 to 2006 and 1995 to 2005 respectively. In each case removing the endpoint increases the magnitude of the coefficient on the science budget.

The results therefore provide some limited evidence that: a) public R&D and private R&D are complementary, and that the former does indeed spillover and impact industry TFP; and b) that the extent of this spillover depends on industry absorptive capacity.

b) Foreign R&D

Another potential source of knowledge for UK industries is the conduct of private R&D in other countries. This section therefore extends the specification to try and account for international knowledge flows. As with domestic R&D, some form of weighting matrix is required, both to introduce industry variation and to proxy for the connectedness of domestic industries to the source of foreign R&D.

Weighted flows from international R&D were constructed as follows. Data on R&D stocks for the G7 countries except Canada and excluding the UK were taken from Helmers, Schulte et al. (2009), constructed using the OECD ANBERD database. These include data on the R&D stocks in manufacturing and services for each of these countries, allowing us to estimate $\Delta \ln \text{R}(\text{R&D})$ in manufacturing and services for each country. So that these terms are not perfectly collinear with the time dummies, we again need some weighting scheme to introduce some industry variation. Weights were constructed using data on imported intermediates in each of the seven domestic industries from the international Supply and Use tables in the WIOD database (Timmer, Erumban et al. 2012). For each UK market sector industry we estimate what proportion of their imported intermediates from each country are of manufactured and service products respectively, and those weights are applied to changes in the sector R&D stock for that particular country. So for example, if industry A imports 100 units of intermediates from France, and of those, 60 are manufactured and 40 are services, then for industry A, growth in French manufacturing R&D is given a weight of 0.6, and growth in French service sector R&D a weight of 0.4. Using these data, the specification to be estimated is:
\[
\Delta \ln TFP_{it} = \alpha_1 (M \Delta \ln R_{t,i}) + \alpha_2 \left( \frac{P^N N_{l,j}}{P^YY_{l,j}} \cdot S_l \right) + \alpha_3 \left( w_{i,t}^{\text{MAN}} \Delta \ln R_{t,i}^{\text{MAN,FOR}} + w_{i,t}^{\text{SERV}} \Delta \ln R_{t,i}^{\text{SERV,FOR}} \right) \\
+ \lambda_i + \alpha_i + \sum_{X=L,K,R}^n d_X \Delta \ln X + \nu_{it}
\]

(9)

Where: \( w_{i,t} \) are industry weights based on the amount of intermediates from manufacturing and services as a proportion of total intermediates, from each G7 country (excluding Canada and the UK); and \( \Delta \ln R_{t,i}^{\text{FOR}} \) is growth in foreign R&D stocks in manufacturing and services for each country.\(^{107}\) All other variables are as defined previously.

Results using this specification are presented below in Table 5.5. Results presented use the IC weights to aggregate across domestic industries. The implications of results using the TR weights were similar.

Table 5.5: Estimation of equation (9), incorporating foreign industry R&D (dependent variable, smoothed \( \Delta \ln TFP \) (t+2, t+1, t))

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>95-05</th>
<th>95-06</th>
<th>95-07</th>
<th>95-06</th>
<th>95-06</th>
<th>95-05</th>
<th>95-06</th>
<th>95-06</th>
</tr>
</thead>
<tbody>
<tr>
<td>External R&amp;D</td>
<td>0.23</td>
<td>0.33**</td>
<td>0.37***</td>
<td>0.33**</td>
<td>0.32**</td>
<td>0.20</td>
<td>0.26**</td>
<td>0.25**</td>
</tr>
<tr>
<td>Internal R&amp;D</td>
<td>-0.063</td>
<td>-0.015</td>
<td>-0.014</td>
<td>-0.018</td>
<td>-0.032</td>
<td>-0.073</td>
<td>-0.016</td>
<td>-0.0044</td>
</tr>
<tr>
<td>Total External Intangibles excl. R&amp;D</td>
<td>0.41*</td>
<td>0.31**</td>
<td>0.26**</td>
<td>0.27**</td>
<td>0.32**</td>
<td>0.46</td>
<td>0.32</td>
<td>0.29</td>
</tr>
<tr>
<td>Total Internal Intangibles excl. R&amp;D</td>
<td>-0.050</td>
<td>-0.17***</td>
<td>-0.17***</td>
<td>-0.17***</td>
<td>-0.010</td>
<td>-0.19***</td>
<td>-0.20***</td>
<td>-0.20***</td>
</tr>
<tr>
<td>UK Science Budget: ((P^N N_{l,i}/P^YY_{l,i}) \cdot (S_i/\Sigma P^V V_{l}))</td>
<td>721</td>
<td>329</td>
<td>259</td>
<td>352</td>
<td>384</td>
<td>791*</td>
<td>277***</td>
<td>1.94</td>
</tr>
<tr>
<td>International R&amp;D (FRA)</td>
<td>-0.70</td>
<td>-0.69</td>
<td>-0.69</td>
<td>-0.69</td>
<td>-0.69</td>
<td>-0.69</td>
<td>-0.69</td>
<td>-0.69</td>
</tr>
<tr>
<td>International R&amp;D (GER)</td>
<td>-0.11</td>
<td>-0.047</td>
<td>-0.071</td>
<td>-0.071</td>
<td>-0.071</td>
<td>-0.071</td>
<td>-0.071</td>
<td>-0.071</td>
</tr>
<tr>
<td>International R&amp;D (ITA)</td>
<td>-0.025</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
</tr>
<tr>
<td>International R&amp;D (JPN)</td>
<td>-0.025</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
<td>-0.032</td>
</tr>
<tr>
<td>International R&amp;D (USA)</td>
<td>-0.065</td>
<td>0.0027</td>
<td>0.0057</td>
<td>0.0057</td>
<td>0.0057</td>
<td>0.0057</td>
<td>0.0057</td>
<td>0.0057</td>
</tr>
<tr>
<td>Observations</td>
<td>77</td>
<td>84</td>
<td>91</td>
<td>84</td>
<td>84</td>
<td>77</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.489</td>
<td>0.401</td>
<td>0.396</td>
<td>0.405</td>
<td>0.407</td>
<td>0.528</td>
<td>0.352</td>
<td>0.325</td>
</tr>
<tr>
<td>Number of ind</td>
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<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Notes to table: Dependent variable is \( \Delta \ln TFP \) smoothed, t+2, t+1, t. Independent variables are dated t, and are \( \sum w \Delta \ln R \), that is weighted changes in outside intangible capital stocks, \( \Delta \ln R \), the internal stock, and the share of the science

\(^{107}\) As before estimation is to be carried out from 1995. However the endpoint of the data for international R&D stocks varies. For France data are up to 2005; for Italy, 2007; and for Germany, Japan and the USA, 2006. Therefore the number of observations in each regression depends on the countries included.
budget in market sector GVA interacted with industry R&D investment intensity. Weighting schemes use intermediate consumption (IC) for domestic, and imported intermediate consumption for foreign. Estimation by fixed effects. Columns 1 to 6 with time dummies, columns 7 and 8 without. ***indicates significance at 1%, ** indicates significance at 5%, * at 10%. t-statistics reported in parentheses, using robust standard errors.

Column 1 incorporates weighted growth in French R&D, with a negative and statistically significant coefficient. In terms of the other coefficients, external domestic intangibles remains statistically significant but external domestic R&D is statistically insignificant in this specification. Note that this sample is two years shorter than results presented previously, due to the endpoint in the French R&D data. Columns 2 to 5 present results incorporating each of the other countries individually, that is for Germany, Italy, Japan and the USA respectively. In each of these cases the coefficient on the international R&D variable is negative and statistically insignificant. The coefficient on the UK science budget term is also considerably smaller than in column 1, although statistically insignificant. However, domestic external R&D and domestic external intangibles excluding R&D are both statistically significant in each column.

Column 6 includes weighted foreign R&D for all countries. Again all are negative and statistically insignificant. External domestic R&D and external domestic intangibles excluding R&D are also statistically insignificant, with the only statistically significant variable being the UK science budget interacted with industry R&D investment intensity, the t-statistic of which is very large in this specification.

The results for foreign R&D growth are not intuitive and contrary to prior expectations. One possibility is that the terms remain collinear with the time dummies. It might also be expected that the country whose R&D has most benefit for domestic industries is the USA, since it is at the technological frontier. Therefore column 7 drops the time dummies and only includes weighted US R&D growth from the international terms. The coefficient is again statistically insignificant but is positive. Of the domestic variables, terms for domestic external R&D and the science budget are statistically significant. Column 8 excludes the science budget term, which raises the magnitude of the coefficient and t-statistic for US R&D, but it remains statistically insignificant.

Therefore it is found that the results for external domestic R&D and total intangibles are relatively robust to the inclusion of foreign R&D, but little evidence is found to support the expected relationship between foreign R&D and domestic industry \( \Delta \ln \text{TFP} \), with some relationship only inferred in the case where time dummies are excluded and using the term for US R&D, which is the frontier country.
5.4.5. Robustness to imperfect competition and non-constant returns

In the above, we suppressed imperfect competition and non-constant returns into \( d \). We now set out a more formal model, based on a stream of work by Basu, Fernald et al. (2004) and summarised in, for example, Basu and Fernald (2001) Consider (2). As they point out, profit maximising implies that

\[
\varepsilon_{X,it} \equiv \frac{\partial F}{\partial X} = \mu s_{X,it}, X = M_{it}, K_{it}, L_{it}, N_{it}
\]  

(10)

Where \( \mu \) is a mark-up of output prices over marginal costs, if any and \( s_{x,it} \) as the share in output, \( Y \), of spending on factor \( X \). Note that \( \mu \) is common to all inputs, since it refers to a product market mark-up (the firm is assumed to have no monopsony power in the input market).

As they point out, imperfect competition and returns to scale are linked. We can show this by noting first the definition of returns to scale, \( \gamma \), is

\[
\gamma = \sum_{X=M_{it},K_{it},L_{it},N_{it}} \varepsilon_{X,it}
\]  

(11)

Combining (10) and (11) implies that

\[
\gamma = \sum_{X=M_{it},K_{it},L_{it},N_{it}} \mu s_{X,it}
\]  

(12)

As they point out, mark-ups over marginal costs (\( \mu>1 \)) require increasing returns (\( \gamma>1 \)) as e.g. in Chamberlinian/Robinson monopolistic competition. As it turns out we find, econometrically, that \( \mu=\gamma=1 \) (statistically speaking). We comment how perfect competition can co-exist with knowledge production below.

Given the issues with measuring \textit{ex ante} returns to capital, especially intangible capital, we adopt a residual or \textit{ex post} approach here. As Hulten (2001) points out, constant returns to scale is required if capital returns are calculated residually. We have two capital terms, \( K \) and \( R \). We have independent measures of the shares of labour and materials. Denoting our measured shares with the superscript MEAS the residual approach assumes that

\[
1 - s_{L,it} - s_{M,it} = s_{K,it} + s_{R,it}^{\text{MEAS}}
\]  

(13)
Where the bars denote Tornquist averages and $s_i$ and $s_M$ are their “true” values (if we could observe them). $\Delta \ln \text{TFP}$ is then defined in terms of these measured shares and is:

$$\Delta \ln \text{TFP}_{it} = \Delta \ln Y_{it} - \sum_{X=\text{M, L}, R_i} \bar{s}_{X, \mu} \Delta \ln X_{it} - \sum_{X=\text{K}, R_i} \bar{s}_{X, \mu} \Delta \ln X_{it}$$

Adding these new terms to the substitutions in section 5.2, we may generalise (7) to read

$$\Delta \ln \text{TFP}^{\text{MEAS}}_{it} = \alpha_i \left( M \Delta \ln R_{-i, \mu} \right) + \lambda_i + \left( \sum_{X=\text{M, L}, K, R_i} d_{X, \mu} \Delta \ln X_{it} \right) + (\mu - 1) \left( \sum_{X=\text{M, L}, K, R_i} \bar{s}_{X, \mu} \Delta \ln X_{it} \right) + (\gamma - \mu) \left( \bar{\theta}_{K, \mu} \Delta \ln K + \bar{\theta}_{R, \mu} \Delta \ln R \right)$$

where $\bar{\theta}_{K, \mu} = \frac{\bar{s}_{K, \mu}^{\text{MEAS}}}{\bar{s}_{K, \mu}^{\text{MEAS}} + \bar{s}_{R, \mu}^{\text{MEAS}}}$, $\bar{\theta}_{R, \mu} = \frac{\bar{s}_{R, \mu}^{\text{MEAS}}}{\bar{s}_{K, \mu}^{\text{MEAS}} + \bar{s}_{R, \mu}^{\text{MEAS}}}$

So the first line is exactly the same as before, but there are two new terms on the next lines. Note that these new terms all involve $\Delta \ln X$, $X = \text{inputs}$, so can be written in terms of the $d$ above, but here we use theory to place more structure on the expressions.

In (15), the second line is 0 if $\mu=1$, because if $\mu=1$ output elasticities are measured by their factor shares (Hall 1988). Note that it is a coefficient on the share-weighted input sum (the sum of the contributions) since $\mu$ is common to all inputs. The third line goes to 0 if $\gamma=\mu$ and so controls for the fact that we have imposed constant returns in order to measure our unknown (two) capital inputs residually. Basu and Fernald (2001) (their equation 9) have the second line but not the first or third. The first is absent because they do not analyse spillovers. The third is absent because they calculate returns to capital ex ante and hence do not need to impose constant returns. For them, therefore, $\mu$ is calculated econometrically using the second line as a regressor and then $\gamma$ is calculated from (12) since the shares are known ex ante. As a matter of data however, they report that the revenue shares, in practice, sum to very near one (the residual sum is at most 3% of revenue on their US industry data), and whilst their estimated $\mu$ varies it is on average very close to unity.

Table 5.6 therefore runs our key specifications with these two new terms. In column 1 we have the R&D terms and column 2 the R&D and the non-R&D intangible terms. What do we find?
Table 5.6: Fixed effects regression estimates of equation (13) incorporating imperfect competition and returns to scale (dependent variable, smoothed ΔlnTFP (t+2, t+1, t))

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum_{s} \Delta \ln X$ (coeff $\mu$-1)</td>
<td>-0.014</td>
<td>-0.043</td>
</tr>
<tr>
<td></td>
<td>(-0.22)</td>
<td>(-0.69)</td>
</tr>
<tr>
<td>$(\sum_{R} \Delta \ln R + \sum_{K} \Delta \ln K)$ (coeff $\gamma$-$\mu$)</td>
<td>-0.20**</td>
<td>-0.12</td>
</tr>
<tr>
<td></td>
<td>(-2.73)</td>
<td>(-1.54)</td>
</tr>
<tr>
<td>Internal R&amp;D stock</td>
<td>0.0075</td>
<td>-0.0014</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(-0.071)</td>
</tr>
<tr>
<td>External R&amp;D Stock</td>
<td>0.40*</td>
<td>0.44**</td>
</tr>
<tr>
<td></td>
<td>(2.20)</td>
<td>(3.47)</td>
</tr>
<tr>
<td>Internal Stock of Total Intangibles excl. R&amp;D</td>
<td></td>
<td>-0.10*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-2.06)</td>
</tr>
<tr>
<td>External Stock of Total Intangibles excl. R&amp;D</td>
<td></td>
<td>0.44*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.09)</td>
</tr>
<tr>
<td>Observations</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.383</td>
<td>0.461</td>
</tr>
<tr>
<td>Number of ind</td>
<td>7</td>
<td>7</td>
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</tbody>
</table>

Memo:
Point estimate of $\mu$: 0.986, 0.957

Test that $\mu=1$:
- F( 1, 6) = 0.05
- F( 1, 6) = 0.47
- Prob > F = 0.8330
- Prob > F = 0.5183

Point estimate of $\gamma$: 0.786, 0.837

Test that $\gamma=1$:
- F( 1, 6) = 3.57
- F( 1, 6) = 1.77
- Prob > F = 0.1076
- Prob > F = 0.2315

Notes to table: Dependent variable is dlnTFP smoothed, t+2, t+1, t. Independent variables are dated t, and are $\sum w \Delta \ln K$, that is weighted changes in outside intangible capital stocks, with the included intangible variables according to the row titles (see table 5.2 for details of what is included in each broad intangible class). Weighting schemes use intermediate consumption (IC) weights. Estimation by fixed effects with time dummies. ***indicates significance at 1%, ** indicates significance at 5%, * at 10%. Memo items report point estimates and F tests on $\mu=1$ and $\gamma=1$.

First, the R&D and non-R&D terms are very similar in sign, magnitude and significance to those reported above. So the results above are robust to non-constant returns and imperfect competition. Second, we find point estimates, in column 1 for example, of $\mu=0.986$ and $\gamma=0.786$. We find in both columns that we can reject the hypothesis that either $\mu$ or $\gamma$ are significantly different from one.
Does this mean the UK economy has no mark-up and constant returns? Romer (1991) argues that a feature of knowledge production is increasing returns. As Corrado, Goodridge and Haskel (2011) point out however, in his two sector model, increasing returns are in his upstream knowledge producing sector; the downstream sector that rents knowledge is perfectly competitive. If this is right, there are a number of possibilities. First, especially with much knowledge production in-house, each firm/industry has within it a knowledge-producing and knowledge-using sector. Available data thus merges the two together and cannot detect a mark-up. Second, analyses without intangibles implicitly assigns knowledge costs to the returns on tangible capital, which might look like mark-ups because they have omitted rental payments to knowledge. Third, we impose the same $\mu$ and $\gamma$ across industries: with more data we might be able to relax this reliably.

5.4.6. Economic significance

What is the effect of R&D, $\Delta \ln R_i$(R&D) on market sector value added, denoted $\Delta \ln V$? As Appendix 2 sets out, there are three effects which might be set out as

$$\frac{\partial \Delta \ln V}{\partial \Delta \ln R} = s_{R,V} + d_R \sum w_i + d_R \sum w_{i,j} m_{ij} (16)$$

Where $s_{R,V}$ is share of R&D capital payments in market sector value added, $w_i$ the Domar-Hulten weight, $m_{ij}$ the relevant weight in the outside weighting matrix, and $d_R$ the regression coefficient on the outside $\Delta \ln R_i$(R&D).

Looking at (16), first, there is the private elasticity of $\Delta \ln R_i$(R&D) on $\Delta \ln V$, which, since R&D is capitalised, is given by the average income share of R&D in value-added which is 0.017.

Second, there are any within-industry spillovers from $\Delta \ln R_i$(R&D) on industry $i$. These are captured by the effect of $\Delta \ln R_i$(R&D) on $\Delta \ln TFP_i$, and since we use gross output for TFP, the effect on $\Delta \ln V$ is the Domar-Hulten weighted sum of these effects. On our data, the sum of Domar-Hulten weights is 2.26 and hence the effect of a $\Delta \ln R_i$(R&D) on $\Delta \ln V$ is 0.10 or 0.17 based on the IC or TR weight coefficients from Table 5.3, columns 1 and 2.

Finally, there are outside-industry spillovers from $\Delta \ln R_i$(R&D) on industry $I$, which again have to be Domar-Hulten weighted and multiplied by the relevant outside weighting matrix element. Since $\Sigma w_i m_{ij} = 0.48$ and 0.36 for the IC and TR weights respectively, these elasticities are 0.48 and 0.36 respectively.
How do these compare with those in the literature? As mentioned, most studies do not capitalise R&D, and regress it on $\Delta \ln R_i$ and $\Delta \ln R_j$ generating “inside” and “outside” coefficients. Griliches (1992) in his survey suggests, an “inside” elasticity of 0.11 and an outside elasticity of twice that, 0.22. Since most of the papers he reviews do not capitalise R&D, our equivalent elasticities are the sum of the first two terms in (16) and the last term, which using the TR weights are 0.187 ($= 0.017+0.17$) and 0.36, almost exactly the ratio Griliches assumes (our IO weights give 0.117 ($= 0.017+0.10$) and 0.48). In the survey of more recent studies by Eberhardt, Helmers et al. (2010) “outside” effects are smaller or larger than the own effects, see their Appendix Table A-1, Panel II.2).

In sum our estimates are economically significant and in line with other studies. It is interesting too that the outside effects with the labour transition weights are about 2/3 the size of those with IC weights. If the IO weights capture some pecuniary spillovers that the labour weights avoid, then the outside effect would be lower.

5.5 Conclusions
This paper asks if there is any evidence consistent with spillovers from R&D and other wider-knowledge (or intangible) investments. We use data on 7 UK industries, 1992-2007 and adopt the industry-level method used in the R&D literature by, for example, Griliches (1973) and Griliches and Lichtenberg (1984) which relies on weighting external measures of the knowledge stock: in their case, R&D, in our case, R&D and other intangibles. We create two sets of weights: based on flows of intermediate consumption (IC) using the input-output (IO) supply use tables; and the second based on labour transition (TR) flows between industries, constructed from the Labour Force Survey (LFS). To the best of our knowledge, this approach has not been adopted for intangibles.

Our findings are based on correlations between industry TFP growth and lagged “outside” knowledge stocks (lagged changes in other industry knowledge stocks weighted by the weighting matrices), all in deviations from time and industry mean terms. Thus our results are not based on contemporaneous correlations between TFP growth and changes in capital stocks, which could be due to unmeasured utilization and imposes instant spillover transmission. Rather, we examine if more exposure to outside capital growth, over and above that industry’s average exposure and the average exposure across all industries in that period, is associated with above industry/time average TFP growth in future periods. What do we find?

First, as a benchmark, controlling for industry and time effects, we estimate a positive statistically significant correlation between industry TFP growth and lagged external R&D knowledge stock growth.

108 Terleckyji (1980) finds coefficients in the ratio (outside to inside) of 1.6 and 2.7 (Table 6.3, last two rows) using IO coefficients and R&D intensities. Sveikauskas (1980) using a similar method finds ratios of 3.5 and 2.1 (his
Second, we also find a correlation between TFP growth and outside total intangible knowledge stock growth. Third, when we enter R&D and also other intangibles, we consistently find statistically significant correlations with R&D, regardless of choice of weighting method or other regressors. Multicollinearity problems make breaking out individual components of that stock hard however. We find some occasional statistically significant correlations with other components of intangibles, but they are few and depend on choice of weighting.

Third, the framework is extended to consider potential spillovers from a) public R&D and b) foreign private R&D. The results are robust to incorporating these terms, although we find limited evidence for spillovers from public R&D, and little for spillovers from foreign private R&D.

Fourth, we have also extended the framework to test for non-constant returns and imperfect competition: our results are robust. Likewise they are robust controlling for utilisation and using instrumental variable methods.

What can we say about spillovers from these correlations? First, note of course that correlation does not imply causation. Second, our correlations are consistent with spillovers of R&D but might of course reflect assumptions such as constant returns/perfect competition or our use of aggregate data. On returns/competition we have tried to test for these and found our results robust. On the use of aggregate data, we cannot of course account for the considerable heterogeneity at the firm level. The firm-level model suggests that to the extent we have not picked up the “mix” effects that come from unobserved heterogeneity in the industry or time dummies, which are correlated with outside spillover terms, we have bias to our spillover terms. Without assumptions on heterogeneity in the firm-level spillovers term, the biases are unknown.

Third, we have been unable to estimate any absorptive capacity effects except when we use them to consider the case of public R&D. To identify them we likely need more cross-section variation e.g. between big and small industries/firms, and so this may just be an artefact of our available data. Future work with longer and wider data sets is no doubt needed.

Fourth, whilst we have a correlation with either broad non-R&D intangibles, or economic competency intangibles (the sum of training, marketing and management) we have not been able to find significant correlations within each component. This may be statistical since the elements of intangible investment are very collinear with R&D (which is as it should be if there are complementarities). Or it might be economic:

Table 2, rows 4 and 6).
spillovers arise from the bundle of outside non-R&D intangible investments not just each element. Again, future work on wider and longer datasets might help shed light on this conclusion.
Appendix 1

Figure A1 shows scatters similar to Figure 1, but with labour transition weights, see text for details. Table A1 and A2 show robustness checks on key regressions, see section 4c for discussion.

Appendix Figure A1: lnTFP, against MΔlnN, (outside industry ΔlnN, weighted by labour transitions of industry _i by the industry i), all in deviation from industry and time mean terms, ΔlnTFP smoothed (t+2, t+1, t).

Notes to figure: outside ΔlnN are, clockwise from top left, rd = R&D; TTIN= total intangibles, sof= software and computerised databases; IP = innovative property (scientific and non-scientific R&D, mineral exploration, design, new products in finance, and artistic originals); EC = economic competencies (market research, branding; improvement of organisational structures and business processes; and firm-provided training).

Aggregation of ΔlnN is by rental share of each intangible. Outside industry ΔlnN weighted using the labour transition-based weighting matrix, see text. Each point in graph is an industry (1=agriculture and mining, 2= manufacturing, 3=utilities, 4=construction, 5= distribution, 6 = finance and 7 = business services). All points are deviations from time and industry means.
Appendix Table A1: Fixed effect regression estimates (dependent variable, smoothed $\Delta$lnTFP ($t+2$, $t+1$, $t$))

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Notes to table: Dependent variable is $\Delta$lnTFP smoothed, $t+2$, $t+1$, $t$. Independent variables are $\sum w d \ln K$, that is weighted changes in outside intangible capital stocks, with the included intangible variables according to the row titles (see table 2 for details of what is included in each broad intangible class). Weighting schemes use intermediate consumption (IC) and labour transitions (TR). Estimation by fixed effects with time dummies. *** indicates significance at 1%, ** indicates significance at 5%, * at 10%. Final row shows the estimated % change in TFP with respect to a 1% change in all outside capital. t-statistics reported in parentheses, using robust standard errors.
### Appendix Table A2: Instrumental Variable estimation (dependent variable, smoothed ΔlnTFP (t+2, t+1, t))

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Note to table: Instruments are lags 1 to 3 of external and internal capital stocks. Software estimates are not instrumented. Year dummies not shown. Chi-squared 4 degrees of freedom for columns 1 to 4 and 7 and 8. 8 degrees of freedom for all other columns. Dependent variable is dlnTFP smoothed, t+2, t+1, t. ***indicates significance at 1%, ** indicates significance at 5%, * at 10%. t-statistics reported in parentheses, using robust standard errors.
Appendix 2: Calculations of inside and outside effects

Omitting fixed and time effects our model is,

$$\Delta \ln TFP_{it} = \sum_{X=L, K, M_{it}} d_X \Delta \ln X + \alpha_i \left( M \Delta \ln R_{i,j} \right)$$  \hspace{1cm} (A2.1)

Let us focus on the case where the only spillover effects are from R and denote $d_R$ the coefficient on outside industry spillovers. Thus we have

$$\Delta \ln TFP_i = d_R \Delta \ln R + d_{-R} \left( M \Delta \ln R_{-i} \right)$$  \hspace{1cm} (A2.2)

To aid intuition, let us write this out for a three-industry case, $i=1,2,3$ which gives, omitting time subscripts

$$\begin{align*}
\Delta \ln TFP_1 &= d_R \Delta \ln R_1 + d_{-R} \left( m_{12} \Delta \ln R_2 + m_{13} \Delta \ln R_3 \right) \\
\Delta \ln TFP_2 &= d_R \Delta \ln R_2 + d_{-R} \left( m_{21} \Delta \ln R_1 + m_{23} \Delta \ln R_3 \right) \\
\Delta \ln TFP_3 &= d_R \Delta \ln R_3 + d_{-R} \left( m_{31} \Delta \ln R_1 + m_{32} \Delta \ln R_2 \right)
\end{align*}$$  \hspace{1cm} (A2.3)

Which in matrix form with our seven industries can be written

$$\begin{pmatrix}
\Delta \ln TFP_1 \\
\vdots \\
\Delta \ln TFP_7
\end{pmatrix} =
\begin{pmatrix}
\Delta \ln R_1 \\
\vdots \\
\Delta \ln R_7
\end{pmatrix}
\begin{pmatrix}
m_{12} & \ldots & m_{17} \\
\vdots & \ddots & \vdots \\
m_{71} & \ldots & m_{77}
\end{pmatrix}
\begin{pmatrix}
0 \\
\vdots \\
\alpha_i \Delta \ln R_i
\end{pmatrix}$$  \hspace{1cm} (A2.4)

Let us now define aggregate $\Delta \ln TFP$ as a weighted sum, with weights $w$ to be defined later, of the industry $\Delta \ln TFP_i$

$$\Delta \ln TFP = \sum_{i=1}^{I} w_i \Delta \ln TFP_i$$

$$\Rightarrow$$

$$\Delta \ln TFP = d_R \sum_{i=1}^{I} w_i \Delta \ln R_i + d_{-R} \sum_{i=1, j \neq i}^{I} w_j m_{ij} \Delta \ln R_j$$  \hspace{1cm} (A2.5)

From which we may derive a number of “inside” and “outside” elasticities as follows.
First, from (A2.3) we note that the effect of $\Delta \ln R_i$ on $\Delta \ln TFP_i$, since TFP is capitalised including private returns, is a within-industry spillover. That is, it can be thought of as an inside effect, since it is an effect of own industry $R$ on own TFP, but is a spillover since $R$ is included in estimating TFP. This elasticity is $d_R$.

Second, turning to “outside” effects, the effect of $\Delta \ln R_1$, R&D in agriculture for example, on other industries, can been seen by reading down the columns in (A2.3) and will be

$$\frac{\partial \Delta \ln TFP_i}{\partial \Delta \ln R_i} = d_R \sum_{i=1,I,j \neq i} m_{ji} \quad (A2.6)$$

Third, the effect of other $\Delta \ln R$, i.e. R&D outside agriculture, on TFP in agriculture, can be seen by reading across the columns in (A2.3) and will be

$$\frac{\partial \Delta \ln TFP_j}{\partial \Delta \ln R_j} = d_R \sum_{i=1,J} m_{ij} \quad (A2.7)$$

Finally, from (A2.4), the total effect of $\Delta \ln R$ on total $\Delta \ln TFP$ consists of two effects, due to spillovers within the industry and outside the industry and given by summing up (A2.4) which gives

$$\frac{\partial \ln TFP}{\partial \Delta \ln R} = d_R \sum_{i=1,I} w_i + d_R \sum_{i=1,I,j \neq i} w_i m_{ij} \quad (A2.8)$$

Finally, the effect on overall market sector value added introduces in addition the effect of $\Delta \ln R$ (the private contribution) since its capitalised. We write this

$$\frac{\partial \Delta \ln V}{\partial \Delta \ln R} = s_{R,V} + d_R \sum_{i=1,I} w_i + d_R \sum_{i=1,I,j} w_i m_{ij} \quad (A2.9)$$

Where since we use gross output in computing our TFP, the appropriate $w_i$ in the second two terms are Domar-Hulten weights and the appropriate weight in the first term is the share of R&D capital payments in market sector value added, $s_{R,V}$ (Dal Borgo, Goodridge et al. 2011)(equation 5).

In our data $s_{R,V}=0.017$, $\Sigma w_i=2.26$ and $\Sigma w_i m_{ij}=0.48$ and 0.36 for the IC and TR weights respectively. Thus for the IC weights the numbers in (A2.9) are 0.017, 0.10 and 0.48 based on $d_R=0.04$ and $d_R=0.43$. For the TR weights the numbers are 0.017, 0.17 and 0.36 based on $d_R=0.07$ and $d_R=2.31$. 

A number of points are worth making. First, since we include $\Delta \ln R$ in estimating $\Delta \ln TFP$ and we work with R&D capital stocks, the latter two terms in (A2.9) correspond to net social returns, and have an elasticity of 0.58 and 0.53 based on IC and TR weights respectively.

How do these compare with those in the literature? As mentioned, most studies do not capitalise R&D, and regress it on $\Delta \ln R_i$ and $\Delta \ln R_j$ generating “inside” and “outside” coefficients. Griliches (1992) in his survey suggests these inside and outside elasticities are 0.11 and 0.22 respectively, with the latter based on a twice of the former. Our TR weights give inside and outside measures of 0.187 (≈ 0.017+0.17) and 0.36, almost exactly the ratio Griliches assumes (our IO weights give 0.117 (≈ 0.017+0.10) and 0.48). Terleckyj (1980) finds coefficients in the ratio (outside to inside) of 1.6 and 2.7 (Table 6.3, last two rows) using IO coefficients and R&D intensities. Sveikauskas (1981) using a similar method finds ratios of 3.5 and 2.1 (his Table 2, rows 4 and 6). Thus we conclude that our ratios are in line with those in the literature. (We note that Griliches (1980), Table 11.1, compares ratios based on IO weighted industry studies to those based on patent flows and technology distances; in the latter, outside effects can be about 50% of within effects. In the survey of more recent studies by Eberhardt, Helmers et al. (2010) “outside” effects are smaller or larger than the own effects, see their Appendix Table A-1, Panel II.2).

Third, our outside/inside ratios are $4.4=0.48/0.117$ and $2=0.22/0.117$ for our IC and TR weights respectively. As discussed above, the IC weights might capture pecuniary spillovers due to mispriced intermediates (though our regressions are in terms of future TFP growth and therefore lagged $\Delta \ln R_i$). Indeed, Eberhardt, Helmers et al. (2010) call the IO-based estimates “rent” spillovers. If the TR weights are less prone to this we would expect the relative spillover impact to be less which it is.

Finally, what are the implied rates of return? Our data return estimates of elasticities. Making use of the standard relation between elasticities and rates of return we can write $\rho=\varepsilon (V/R)$ where $V$ is value added which we write since we are working with Domar-Hulten aggregated sectoral productivity. The ratio of real variables $V/R$ is hard to interpret and thus we write $\rho=\varepsilon (P_V V/ P_R R)( P_R / P_V)$. Making use of the Hall-Jorgenson rental price formula $P_R=P_N(r+\delta-\pi)$ and noting that due to lack of data $P_N=P_V$ we can write

$$\rho = \frac{1}{(P_R R/ P_V V)(r+\delta-\pi)}$$

(A2.10)

Where all terms relate to R&D. Over this sample period $(P_R R/ P_V V) =0.017$. Over the same period the average value for $r$ is 0.05. The standard estimate for $\delta$ in the case of R&D is 0.15. The rate of change in value-added prices is approximately 0.04. Therefore we can estimate (10) as $(0.53/0.017)*(0.05+0.15-0.04)=4.99$, suggesting a total rate of return including private returns of 500%. This is clearly very large, but
it is worth noting our elasticities are in line with others who estimate elasticities and hence to the extent that they have similar R&D shares their implied rates of return are the same. So, for example, a private elasticity of 0.1, the central estimate quoted by Griliches (1980) would yield a private rate of return of around 100% and a social elasticity of 0.2 would imply a rate of return of 200%.

Consider, for example, Gullec and Van Pottelsbergh and la Potterie (1984). On their sample of 16 OECD countries, 1980-98, they regress ΔlnTFP’ (i.e. TFP without capitalising R&D) on ΔlnR(private) and find a coefficient of 0.13 (p.365). The average P_R/P_V/V in their sample is 2% (p.366), and hence ρ = 0.13/0.02 = 6.5 or 650%.
Chapter 6 : The “C” in ICT: Communications Capital, Spillovers and UK Growth

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ABSTRACT

Part of the ICT revolution has been the advances in communications technology, the “C” in ICT. However these advances are not reflected in official UK data for telecommunications equipment prices. Using data on telecommunications equipment prices based on Corrado (2011) we estimate two effects of “C” on UK productivity growth: the direct effect from growth accounting and the indirect effect via network effects. We find: (a) official “C” price data substantially understate quality-adjusted telecoms equipment prices; (b) using new price data doubles the growth accounting contribution of “C” to productivity growth; (c) using new price data also yields some evidence of spillover effects from investment in C capital.

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6.1. Introduction

The consequences of the ICT revolution for productivity have been extensively studied by growth accountants see e.g. Van Ark and Inklaar (2005) for EUKLEMS, Oulton (2002) in early work for the UK and Jorgenson (2001) for the USA.

The vital lesson from computer hardware was that in periods of very fast technical change standard price deflators potentially (vastly) understate the impact of nominal asset investment. The development of suitable deflators for hardware and software has rightly been a major priority.¹⁰⁹

Interestingly however the “C” part of ICT remains somewhat neglected. As pointed out by Doms (2005), Corrado (2011), Byrne and Corrado (2009) and OECD (2008),¹¹⁰ this is potentially important. For example, one way of thinking about the internet is that it is a (very large) piece of communications capital equipment, building on older telecoms capital and being augmented by broadband and mobile technologies.¹¹¹ So its contribution to growth is potentially measurable as part of the ICT contribution. In addition, if communication networks have network/spillover effects, the expansion of the communications network might show up not only in the standard contribution of ICT capital to growth, but also in MFP.

By the computer hardware logic above, the capital services derived from this communications equipment investment however needs a suitable deflator. This simple observation is the starting point for this paper. First, we document that official UK data deflates nominal telecommunications equipment investment using a non-computer plant and machinery deflator. This deflator grows at 0.58% p.a., 1984-2008.

This is in contrast to the official computer hardware deflator, which falls at around 12% p.a. over the period. This sits oddly with for example, the observation from engineering data that investment in fibre optic cable and equipment in the late 1990s increased capacity in telecoms networks by a factor of 40.¹¹² Thus our research question is whether the contribution of communications equipment might be understated in a similar fashion to that of hardware before adopting quality-adjusted deflators.

¹⁰⁹ Research databases such as EU-KLEMS (O’Mahony et al 2007) use harmonised hardware data, but not software data. A consistent software series, based on the US quality-adjusted software series but country-specific software spending compositions in set out in Corrado, Haskel et al (2012).
¹¹⁰ Indeed section 3c is called “The Impact of the “C” in “ICT””.
¹¹¹ Other methods of measuring the economic contribution of the internet include for example the Boston Consulting Group (2010) who tried to count “Internet GDP” by e.g. consumption mediated on the internet by e-commerce; parts of business investment and consumer computer spend (e.g. subscriptions to ISPs); and government spending on the internet. Greenstein and McDevitt (2009) measure consumer surplus from free goods on the internet.
¹¹² For instance, data in OECD (2008) show that DSL broadband prices fell 19% in September 2005 to October 2006, whilst speeds rose by 29% in the same time period.
Our second step is then to note that US researchers have been assembling quality-adjusted communications equipment deflators (Doms (2005), Byrne and Corrado (2009), and Corrado (2011)). These show prices falling swiftly, reflecting the use of semi-conductors in equipment at either end of the network and massive investment and technical progress in the network itself (e.g. fibre optic equipment). For example, Byrne and Corrado (2009) find an average price decline of -6.57% p.a. (1984-2008). We note further that official UK data uses US deflators for hardware and (purchased) software and so we broadly follow this by applying the US telecom deflator produced in Byrne and Corrado (2009) and Corrado (2011) to the UK data on telecommunications transmitters, for this is where the bulk of technical progress has occurred. For the other aspects of UK telecommunications investment (insulated wire and cable; receivers) we use Producer Price Indices (PPIs) from ONS. We weight together these three deflators using their investment shares in total telecoms investment. We find the following. First, the deflator falls at -4.29% p.a., as opposed to the non-quality adjusted which rise at 0.58% p.a.. Second, we derive therefore growth in the real UK telecoms capital stock of around 9.2% p.a., 1984-2008, in contrast with 3.9% p.a. using the official deflator. Third, this turns out to approximately double the standard growth accounting contribution of telecoms over the late 1990s and early 2000s. (0.14%pa as opposed to 0.07%pa in the late 1990s and 0.09%pa as opposed to 0.05%pa in the early 2000s).

Our third step is to ask if there is any evidence of spillovers from telecoms equipment. Such a question is very natural if one thinks of such equipment as building networks. We investigate this in a standard manner, by regressing lagged growth of telecoms equipment capital stock on TFP growth and find robust evidence of spillovers. With the plant and machinery deflator we find no evidence of spillovers. However the quality-adjusted deflator finds a statistically significant correlation between telecoms equipment growth rates and TFP growth four years later. It is economically significant too, accounting for 20.7% of TFP growth 1990-2008.

How is this paper related to others? The pioneering ICT work for the UK was by Oulton (Oulton (2002) for example) but this concentrated on software and hardware and used the official UK asset price index for telecoms. The EUKLEMS dataset reports a separate series for telecoms assets, but while the implied deflator used there does fall (at -1.5% p.a. over 1970 to 2007, and 3% over the more comparable period of 1984 to 2007), the changes are not as fast as those implied by the US work. Doms (2005) makes some informed guesses as to how US growth accounting would change with a different deflator, but does not formally do growth accounting (his paper is primarily concerned with price measurement). Much cross-country work follows Roller and Waverman’s (2001) method see e.g.Gruber and Koutroumpis (2011), which is to study country data on productivity growth and telecoms penetration (they were careful to subtract out telecom capital from the official cross-country
capital data); subsequent work has used mobile and broadband penetration see e.g. the survey in OECD (2008). Such work typically finds a sizable correlation, although measurement issues especially in developing country data are a challenge.

Our paper is most directly related to Corrado (2011). She presents new deflators. She then studies the telecoms industry itself, documenting capital productivity and utilisation, and presents market sector-wide contributions as well. She also finds evidence of spillovers, but using a different method. She finds a faster acceleration in post-2000 industry MFP in industries scoring highly on an index, for year 2000, of “internet-readiness” due to Forman, Goldfarb et al. (2003). Interestingly, she finds that communications capital accounts for 32% of MFP growth, 2000-07, our comparable figure is 36%.

The plan of the rest of this paper is as follows. In the next section, we set out our data and different deflators used. Section 3 shows the impact on measurement. Section 4 considers other aspects of telecoms investment. Section 5 shows growth accounting and section 6 spillover results. Section 7 concludes.

**6.2. Data**

**6.2.1. Investment data**

Historically, conventional measures of investment and capital stocks, as recorded in the UK National Accounts, have aggregated data for hardware and telecoms into the broader asset category of “Plant and Machinery” (P&M). Since 2007, in the ONS Volume Index of Capital Services (VICS), computer hardware has been separated out of P&M and treated as a distinct asset. The well-documented falls in the price of hardware, and its faster rate of depreciation compared to other P&M, meant that estimates of growth in capital services were greater than previously measured, increasing the contribution of computers in growth accounting decompositions for the UK. See Appleton and Wallis (2011) for the latest VICS data.

Communications investment however has not been separated out and hence is implicitly deflated by the aggregate non-computer plant and machinery deflator. Studies by Doms (2005), Byrne and Corrado (2009) and Corrado (2011) show that the prices of communications equipment have been in steady decline. Although the pace has not been as fast as hardware, the fall is larger than that implied by official datasets from National Statistical Institutes (NSIs) including the ONS, and this decline has not slowed in recent years as has been the case for computers. Therefore, by similarly separating out telecommunications investment and applying an improved estimate of price changes, we attempt to provide better estimates of growth in telecommunications capital, and its contribution to UK growth.
In order to do this we first must identify investment in telecommunications capital. Figure 6.1 sets out data for nominal investment in the product groups identified as telecommunications assets using Gross Fixed Capital Formation (GFCF) data in the Supply Use Input-Output (IO) tables. There are three IO product groups that fall into the telecommunications asset category: i) ‘Insulated wire and cable’; ii) ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’; and iii) ‘Television and radio receivers, sound or video recording or reproducing apparatus and associated goods’. The second product group is by far the largest in terms of investment, and largely pertains to investment in capital by the communications industry that is used to provide telecommunications services.

As Figure 6.1 shows, in 1992 and 2000, approximately 85% of telecommunications investment was in the second group. By 2008 this had fallen to 70.2%, with the third group having risen to 13.7%, from 5.2%. An interpretation of this change in the composition of investment is that the 1990s was a time of ‘network build out’ creating much of the telecoms network infrastructure with investment in fibre-optic equipment, largely by the telecommunications services industry itself. Increased investment in receivers since then appears to be reflective of increased ‘network utilisation’ by the rest of the market sector. Looking directly at the data for the ‘Post and Telecommunications’ industry (SIC03 64 or section I), investment by the telecommunications industry in 2008 accounted for 63% of total investment in telecommunications capital, compared to 47% in 1984.

**Figure 6.1: Components of telecommunications investment (£bn, Current Prices)**

Note: The full product definitions are i) ‘Insulated wire and cable’; ii) ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’; and iii) ‘Television and radio receivers, sound or video recording or reproducing apparatus and associated goods’
Source: UK Supply-Use Input-Output (IO) tables.
6.2.2. Telecommunications asset prices

To re-estimate growth in telecommunications capital services separately we must first deflate the nominal investment data to obtain real measures of investment. A suitable UK deflator does not exist. Instead we construct one from three sources. For insulated wire and cable we use the ONS PPI for this product, likewise for Receivers for TV & Radio. For Transmitters, which includes the fibre-optic and switching centre equipment where technical progress has been rapid, we use the price index presented in Byrne and Corrado (2009) and Corrado (2011), adjusted using Purchasing Power Parity (PPP) indices. We are very grateful to Carol Corrado for providing us with these data.

Doms (2005) provides an excellent, comprehensive description of the technical progress that has occurred in the production of telecommunications equipment, which underlies the price falls in the Byrne and Corrado price index. Broadly speaking, telecommunications equipment can be viewed as being made up of two main components. First, (local area) network equipment or LAN, largely being made up of the fibre-optic equipment connecting different locations to a central hub, through which information is transmitted. Second is the switching equipment, which, loosely speaking, transmits the information through the network. It includes the switching centre which acts as a central hub, receiving information and re-transmitting it to the relevant part of the network. At the ends of the network are the equipment that transmit, receive and translate that information, including semiconductors, modems, satellite and fixed line equipment. These items fall under the heading of ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’ in the UK investment data.

The prices for equipment in this category have fallen significantly due to the rapid technical progress that has occurred. The production of telecommunications equipment is a large user of semiconductors, and the transmission speed of modems has grown massively over the last twenty or so years, on a comparable scale to Moore’s Law. However even larger technical progress has occurred in the growth in capacity of fibre-optic cable and equipment which has gradually replaced traditional copper wire, resulting in huge increases in the volume of transmissions at lower cost. Doms (2005) notes that the pace of progress in fibre-optic capacity is well above that of Moore’s Law: between 1996 and 2001 the potential capacity of a glass fibre stand doubled every year.

The methodology used to construct the BC deflator is set out in Byrne and Corrado (2009) and Corrado (2011), as well as Doms (2005) which describes the construction of an earlier version. In constructing their aggregate index, Byrne and Corrado (2009) use prices for over fifty different communications products. Underlying each product are further disaggregations meaning that underlying some products are observations on dozens of varieties. The end result is an updated series for most telecommunications products for 1963 to 2009, including for wired local area network
(LAN) equipment, and the high-speed routers and switches employed in wireless wide-area networks (WAN) (Corrado 2011).

Indices for each product are then constructed as an unweighted average of the data by variety, and an index for telecommunications assets is formed as a weighted average of the products. The main differences between the official US series and the BC deflator occur in the 1948 to 1973 and 1995 to 2007 periods. Since the latter is just after the widespread introduction of the internet and in a period of significant investment in telecommunications, the implications for measurement of output and productivity growth are significant.

In the analysis that follows in this paper, we reconstruct estimates of real UK investment in telecommunications using our new deflator for the UK, largely based on the BC deflator, as described above.

To do this, we took the nominal investment data, which is under the three headings above, and matched these headings to the nearest ones for the available price deflators. In the case of ‘Insulated wire and cable’ and ‘Television and radio receivers, sound or video recording or reproducing apparatus and associated goods’ these were the ONS producer price indices. For ‘Television and radio transmitters and apparatus for line telephony and line telegraphy’ we used the BC deflator. We converted the BC deflator to UK currency using the UK:US PPP. This adjustment only affects data for years prior to 1991, due to a very stable relationship between the purchasing power of the dollar and sterling between 1992 and 2008. Our overall communications deflator is then an investment-share weighted average of the deflator for the three different categories. The price index for each category and its share in total telecoms investment are presented in Appendix 2.

It could be argued that it is not appropriate to use the US deflator as a component in our UK price index. However we note that importantly the pattern of price change is strikingly similar across a diverse range of communications products and technologies (Corrado 2011). Second, such products are internationally traded and should therefore be priced competitively across countries. Third, in the case of both hardware and purchased software, official UK indices are PPP (or exchange rate) adjusted versions of those produced by the US Bureau of Economic Analysis (BEA).

6.3. Preliminary impacts and measurement
Figure 6.2 sets out the annual changes in the ONS deflator and our new deflator, and compares them to those for hardware and purchased software. As can be seen, on average over the whole period (1982-2008), the ONS series rises at +0.9% p.a. whereas our new series falls at -4.1% p.a..
Comparable figures for UK hardware and purchased software are -11.1% p.a. and -3.8% p.a. respectively. In particular, in the late 1990s, the new deflator falls very rapidly, at a rate of -8.61% p.a. over 1995 to 2000, compared to -3.11% p.a. for the official deflator. As we see below, this has significant implications for measurement as the late 1990s were a period of very sharply rising communications investment.

**Figure 6.2: UK deflators for ICT assets**

![Graph showing deflators for UK ICT assets](image)

Note to figure: Data are annual natural log changes for each price index. The thick solid line are changes in the telecoms equipment deflator constructed for this paper. Thick dashed line are those for the general plant and machinery deflator as used by the ONS. Thin solid line are those in the official price index for computer hardware. Thin dashed line are changes in the official price index for purchased software.

Source: Official data from ONS VICS. New data based on Byrne and Corrado (2009) and ONS PPIs.

Armed with these deflators, we create a telecoms equipment capital stock using a perpetual inventory model and depreciation rate of 0.115, the same rate as used in EUKLEMS. For more details on the construction of the telecoms capital stock, please see Appendix 1.

Figure 6.3 presents estimates of growth in telecommunications capital under the old and new treatment respectively. Applying the new deflator suggests that over the period 1984 to 2008 the stock of telecommunications capital has on average grown at a rate almost 6 percentage points higher than the current treatment suggests (9.2% p.a. compared to 3.9% p.a.). In the year 2000 this differential was 11 percentage points.
Notes: Data are changes in natural logs of the telecommunications equipment stock, so e.g. 0.1 refers to a change of 10%. The dashed line is an estimate of growth in the telecommunications capital stock, where real investment has been calculated using the general plant and machinery deflator. The solid line is a comparable series generated using the new telecommunications asset deflator described in this paper.

Underestimation of the price falls for telecommunications assets also results in mismeasurement of the asset income share in value-added. Figure 6.4 presents estimates of telecommunications (Tornqvist) income shares using the new deflator, compared to the current treatment using a P&M deflator.

The faster falls in asset prices according to the new deflator result in a significantly lower income share for telecommunications. (Note that the rental prices of capital assets are adjusted using data on corporation tax and specific subsidies and allowances for each asset type including telecommunications capital). The lower income share may seem counter-intuitive but asset level capital compensation is a product of the rental price and the level of the asset stock, where the rental price is also partly determined by the asset price. Using the new deflator means the level of the capital stock in past periods is lower, as the price falls mean that past investments are not as valuable as previously estimated. The capital compensation and income share for telecommunications equipment are consequently lower using the new deflator.
Figure 6.4: Effect telecoms equipment income shares of value-added

Notes: Income shares are presented as Tornqvist averages of the annual shares in the current and previous period. For comparison, income shares for hardware and software assets are around 0.017 and 0.034 respectively in 2008. See Appendix for details on calculation of rentals and income shares. Income shares in this chart are based on the National Accounts baseline, where the only intangibles treated as assets are software, mineral exploration, artistic originals and R&D (due to be officially capitalised in the National Accounts in 2014).

We now turn to the impact of treating telecommunications as a distinct asset and applying our new deflator on aggregate estimates of UK market sector capital services. Within Figure 6.5, the solid line is the published series for VICS (Appleton and Wallis 2011) and the dashed line is a new measure of total capital services where telecommunications has been separated out and treated as a distinct asset using the deflator described above. As the graph shows, the major effects are between 1995 and 2005, with the new growth rate being as much as 0.7 percentage points per annum higher in 2000.

Figure 6.5: Growth in market sector capital services across all assets

Notes: The solid line represents growth in aggregate market sector VICS (across all assets) as calculated in
Appleton and Wallis (2011). The dashed line represents growth in VICS after treating telecommunications capital as a distinct asset and applying our new deflator with a depreciation rate specific to telecoms capital, of 11.5%. Source: Appleton and Wallis (2011) and own calculations

6.4. Private investment in spectrum rights

So far we have taken the official nominal telecommunications equipment investment figures as published. However, there is one significant aspect of investment in telecommunications not recorded in the official figures: private investment in spectrum licences. In April 2000 the UK Government conducted an auction of rights to third-generation (3G) mobile phone licences, raising £22.5bn from the sale of five licences, around 2.5% of UK GNP (Binmore and Klemperer 2002). Prior to that, payments by UK firms for 2G licences were in the thousands rather than millions. Current estimates of private investment do not include these payments. In this and the next section, we document that so incorporating them adds 0.02% to 0.06% pa to growth post 2000 and 0.0007 to the telecoms income share. The details are as follows.

Why aren’t such investments treated as such in the National Accounts? The reason is that the spectrum is a non-produced asset with rights to its use held by the state. Therefore there was no production of additional “spectrum output”, in 2001 or at any point prior to that date, and neither did the sale of spectrum rights result in any new output that generated factor incomes for labour and capital. Therefore in the context of the whole economy, the treatment is perfectly sensible, as the sale of licences simply represented an asset transfer between the government and private firms. That is, positive GFCF for the buyers (telecommunications firms), and negative GFCF for the seller (the UK Government). But we are estimating investment and growth in the market sector (given the worries on public sector output data quality). So, as outlined above, even though the auction resulted in a reduction of assets on the government balance sheet, it also meant a corresponding increase to assets on the aggregate balance sheet for private firms. Therefore we ought to treat those payments as investment when conducting a decomposition of market sector growth (if we did not, then the additional output due to the use of spectrum rights would be allocated to TFP).

In estimating the stock of spectrum rights, as well as using the observation of investment at the 2001 UK 3G auction, we also make use of data from OFCOM on payments for analogue licences from 1986 to 2001 (the analogue networks were closed in 2001). Further improvements that could be made to our data include the adding in of spectrum payments for the broadcasting and transport industries, although such spend is small in comparison to the 3G licence payments. For a deflator we apply a price index for the gross output of the (downstream) telecommunications industry, sourced from EUKLEMS (see Corrado, Goodridge and Haskel (2011) for further information on the reasoning behind this). To estimate depreciation we apply a geometric rate of as close to zero as possible, due to
the fact that there is no depreciation of the spectrum until the licence expires, making the appropriate schedule a one hoss shay model.

Incorporating investment in spectrum rights into our dataset does however present some problems. The investments required to acquire spectrum rights prior to the 3G auction in 2000 were very small, meaning the stock is almost entirely made up of the 3G licence payments. The arrangements for 2G and 3G payments were also different. Prior to 2001 2G payments were in the form of annual charges. In contrast, 3G licences, which last for twenty years, were sold for an up-front payment, after which annual charges will be incurred (in 2021). Therefore the decomposition is affected by the decision of state authorities on the nature and length of the licences to be sold. For instance, the series for the stock and the contribution of capital deepening would look very different if auctions took place every five years or every twenty years.

The result of introducing an asset with only one significant investment observation is that the series’ for growth in the ‘spectrum capital stock’ and the associated factor income share exhibit a sharp rise in 2001 and a steady decline thereafter. However, when the 3G licences were first purchased almost no 3G phones/smartphones existed in the UK and so the licences were not immediately put into productive use, that is the full extent of the rights were not part of the productive capital stock immediately after their sale/purchase. For that reason we incorporate a utilisation factor for this specific piece of telecommunications capital.

Ideally we would wish to use data which reflects actual spectrum utilisation by firms. However, aside from anecdotal suggestions that use of the 3G spectrum allocation may be nearing capacity, we have not been able to find any such data. However, we do have data on UK 3G subscriptions from the OFCOM Communications Market Report (OFCOM 2010; OFCOM 2011). Therefore to estimate a proxy for the utilisation factor we assume that spectrum utilisation was close to zero in 2000 when the licences were first purchased (mid-year), and at almost full capacity in 2011. For years in between we estimate the utilisation factor (µ) using the growth rate in 3G mobile subscriptions. Since the OFCOM CMR data begin in 2004, we impute subscription levels for the years 2001-3. All in all, incorporating spectrum in this fashion adds 0.02% to 0.06% pa to growth post 2000, and 0.0007 to the telecoms share.

This discussion raises the question of why we do not use a utilisation factor for the communications capital stock. The obvious analogy to under-utilised spectrum is fibre-optic cable. However, as Figure 6.1 shows, cable is in fact a very small part of telecommunications investment. Rather, the
bulk of the equipment investment are the transmitters that pass the signal down the cable and process messages at either end.\textsuperscript{113}

### 6.5. Growth accounting results

We apply the standard growth-accounting model to estimate the contributions of capital by asset type. Growth is in market-sector value added, 1990-2008 (we end in 2008 to avoid measurement difficulties over the recession period). TFP growth is this growth less share-weighted input growth. Capital shares are calculated using tax-adjusted rental prices (see Appendix), with the total capital share adding up to one minus the labour share. Labour inputs are adjusted for labour quality, as measured in EUKLEMS. Capital inputs are telecoms equipment, computer hardware, computer software, other tangible inputs (commercial buildings, vehicles, non-computer plant & machinery) and other intangibles already or soon to be capitalised in the national accounts (mineral exploration, artistic originals and R&D).

For all assets other than telecoms, data on GFCF, investment prices and the capital stocks are as used in the ONS VICS. Data on output/income are taken from the National Accounts. Tangible tax-adjustment factors are from Wallis (2012b) and for intangibles from Wallis (2012a). All investment categories are those already treated as capital assets in the National Accounts with the exception of R&D, which is due to be capitalised in the UK in the very near future. The asset price deflator used for R&D is the implied value-added deflator and deprecation is set at 15% p.a.

As set out in Appendix 1, our data on telecommunications investment begin in 1984. To construct reasonable estimates of the initial stock which reflect the fast falls in the price of communications equipment that took place prior to 1984, we backcast real investment data using that reported in EUKLEMS and construct the stock from 1970 using a perpetual inventory model in the usual way. Spectrum rights are included as a separate asset, and calculated as described above. Our final decomposition is presented below in Table 6.1.

\textsuperscript{113} So for example, fiber-optic communication systems require (a) an optical transmitter to convert an electrical signal into an optical signal (b) a cable (c) amplifiers to maintain signal strength and (d) an optical receiver to recover the signal as an electrical signal. Multiplexing, i.e. sending multiple signals down the existing fibre, a major increase in fibre capacity, requires enhanced transmitters and receivers.
Table 6.1: Decomposition of growth in UK value-added, 1990-2008

<table>
<thead>
<tr>
<th>Year</th>
<th>(DlnV)</th>
<th>(sDln(L))</th>
<th>(sDln(K))</th>
<th>(sDln(K))</th>
<th>(sDln(K))</th>
<th>(sDln(K))</th>
<th>(DlnTFP)</th>
<th>(Memo: sDln(L))</th>
<th>(Memo: sDln(K))</th>
<th>(Memo: sDln(K))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-95</td>
<td>1.47%</td>
<td>-0.84%</td>
<td>0.31%</td>
<td>0.20%</td>
<td>0.01%</td>
<td>0.32%</td>
<td>0.04%</td>
<td>1.43%</td>
<td>0.63</td>
<td>0.52%</td>
</tr>
<tr>
<td>1995-00</td>
<td>4.27%</td>
<td>0.78%</td>
<td>0.75%</td>
<td>0.31%</td>
<td>0.07%</td>
<td>0.49%</td>
<td>0.07%</td>
<td>1.78%</td>
<td>0.61</td>
<td>1.13%</td>
</tr>
<tr>
<td>2000-05</td>
<td>2.59%</td>
<td>0.15%</td>
<td>0.39%</td>
<td>0.12%</td>
<td>0.05%</td>
<td>0.41%</td>
<td>0.05%</td>
<td>1.40%</td>
<td>0.64</td>
<td>0.56%</td>
</tr>
<tr>
<td>2005-08</td>
<td>2.09%</td>
<td>0.47%</td>
<td>0.09%</td>
<td>0.18%</td>
<td>0.04%</td>
<td>0.57%</td>
<td>0.05%</td>
<td>0.67%</td>
<td>0.63</td>
<td>0.31%</td>
</tr>
</tbody>
</table>

1) Baseline Results: Telecoms treated as part of P&M

2) New Results: treating telecoms as a distinct asset with new deflator

3) New Results: treating telecoms as a distinct asset with new deflator and also including spectrum payments

Notes: The above decomposition is based on growth in value-added. Since our later estimates of externalities are based on growth in capital rather than growth in capital deepening (per hour), we also estimate the private contribution on the same basis. All results produced using conventional National Accounts capitalised assets plus R&D. That is, the only capitalised intangibles are software, mineral exploration, artistic originals and R&D. The first panel deflates and depreciates telecommunications capital in the conventional way as if part of Plant and Machinery. The second panel uses data where telecommunications are treated as a distinct asset, deflated using the price index described in this paper and using the depreciation rate from EUKLEMS. The third panel is the same as the second panel except spectrum rights are also introduced as a capital asset. Estimated rental prices for all assets are corrected using tax-adjustment factors. First column is growth in value-added. Column 2 is the contribution of labour services, namely growth in labour services times share of labour in MGVA. Column 3 is growth in computer capital services times share in MGVA. Column 4 is growth in software capital services times share in MGVA. Column 5 is growth in telecoms capital services times share in MGVA. Column 6 is growth in other tangible capital services (buildings, plant, vehicles) times share in MGVA. Column 7 is growth in other intangible capital services (mineral exploration, artistic originals, R&D) times share in MGVA. Column 9 is TFP, namely column 1 minus the sum of columns 2 to 8. Column 10 is the share of labour payments in MGVA. Column 11 is the total contribution of ICT capital, namely the sum of columns 3 to 6. Column 12 is the total contribution of communications capital, namely column 5 plus column 6.

\[=3+4+5+6\]

\[=5+6\]

\[DlnV = Dln(L) + sDln(K)\]

\[\Delta Dln(K)_{cmp} = \Delta Dln(K)_{software} + \Delta Dln(K)_{telecom} + \Delta Dln(K)_{spec} + \Delta Dln(K)_{oth\,intan}\]

\[DlnTFP = Dln(K)_{oth\,intan}\,\min,\,cop,\,R&D\]
One way to read Table 6.1 is to ask the following question: what is the impact of the new deflator on the estimated contributions of CT and ICT to growth in value-added? This is answered in columns 5, 6, 11 and 12. Looking at our baseline results in the first panel, conventional measurement of real investment in telecommunications (using a UK P&M deflator) suggests a contribution of CT capital of (column 5) 0.05% in 2000-05 and 0.04% in 2005-08, approximately 1.9% of ΔlnV in each period (e.g. 0.05/2.59 in 2000-05). The overall contribution of ICT capital deepening (hardware, software and telecommunications, column 11) in each of these periods is estimated at 0.56% and 0.31% p.a. respectively, 21.6% and 14.8% of ΔlnV.

Results in the second panel are based on our new treatment of telecommunications capital as a separate asset with a more appropriate price index, but without spectrum. Looking again at the periods 2000-05 and 2005-08, columns 11 and 12, we see higher estimated contributions for CT and ICT capital, at 0.09% and 0.60% p.a. in 2000-05 and 0.05% and 0.32% p.a. in 2005-08. Results in the third panel incorporate the contribution of spectrum rights into that of CT, giving higher contributions still, of 0.11% in each of the later periods, representing 4.3% and 5.3% p.a. of average annual ΔlnV. Taken together, data for 2005-08 suggests that the proposed treatments of CT as set out in this paper result in an extra 0.07 percentage points, which is 3.35% of annual average ΔlnV that can be explained by the additional contribution of CT capital compared to previous estimates.

6.6: Estimation of spillovers
Numerous studies have investigated the possibility that new communications technologies and the internet have generated network externalities or spillovers. The following section sets out a model to study this, and includes some preliminary analysis of whether the build-up of new communications equipment has had positive effects on aggregate market sector growth in TFP, above and beyond the contribution of telecommunications capital deepening to growth in labour productivity.

There are many ways in which communications capital deepening may have contributed to improved growth in TFP, for example, improved opportunity and ability for collaboration and communication that might, for example, improve supply chains; and improved access to freely available knowledge via the internet. For example, recent studies (Adams, Black et al. 2005; Ding, Levin et al. 2009) have shown a positive impact from the internet on academic collaboration and productivity.

6.6.1. Model & preliminary results
To estimate spillovers, consider the following model of market sector value added:

\[ Y_t = A_t F(L_t, K_t) \]  

(1)
where $Y_t$, $L_t$ and $K_t$ are market sector: value added, labour input and capital stocks respectively. $K$ might include tangible or intangible capital. $A_t$ is any increase in output not accounted for by the increase in the included factors of production.

Denoting $\varepsilon$ as an output elasticity we can write

$$\Delta \ln Y_t = \Delta \ln A_t + \sum_{X=L,K} \varepsilon_X \Delta \ln X$$

where $X$ denotes the inputs in the production function in (1). To convert this into something estimable we then make the following assumptions. First,

$$\Delta \ln A_t = a_o + \nu_t$$

where $\nu$ is an iid error term. We experiment with additional terms, such as public R&D in the determinants of $a_o$ below. Second, we assume the $\varepsilon$ terms are factor shares plus a term to account for either deviations from perfect competition or spillovers due to that factor

$$\varepsilon_X = s_X + d_X \quad \forall X = L, K$$

where $s_X$ is the share in $Y$ of payments to factor $X$. Third, observed TFP growth is defined as:

$$\Delta \ln TFP_t \equiv \Delta \ln Y_t - \sum_{X=L,K} s_X \Delta \ln X$$

Where note that $K$ includes tangible capital (buildings, vehicles, plant and machinery, telecoms equipment, computer hardware) and intangible capital (software, R&D, mineral exploration and artistic originals).

Since our main focus is on the effect of possible spillovers from growth in telecoms capital, we shall estimate:

$$\Delta \ln TFP_t = a_0 + d_K(\text{Comms}) \Delta \ln X^{K(\text{Comms})} + \nu_t$$

Where $d_X > 0$ implies spillovers to input $X$.

Table 6.2 sets out a first look at this model. TFP is smoothed as an equally weighted three-year moving average based on the current period ($t$) and two leading periods, ($t+1$) and ($t+2$). Smoothing removes uninformative annual noise from the data and we use leads as we are seeking to estimate network externalities derived from utilisation of capital after that capital has been built. We look at unsmoothed data below.

Columns 1 and 2 use as regressors in (6) $\Delta \ln K(\text{ICT})$ and $\Delta \ln K(\text{Comms})$ using the implicit UK deflator for Comms i.e. non-computer plant and machinery. The coefficients on both are insignificant, and is
negative in the case of ICT. The point estimate of $\Delta \ln K(\text{Comms})$ suggests a spillover coefficient of 0.0514.

Data in remaining columns are estimated using the new deflator described in this paper. Column 3 shows the coefficient for growth in ICT capital remains negative and insignificant when we use the new deflator. However column 4 shows that the coefficient for growth in CT capital is positive and significant when we use the new deflator, with an elasticity 0.0275. Column 5 shows we get the same result when we use a version of CT capital that excludes spectrum. The results in columns 4 and 5 are also statistically significant when we use two lags, although with a slightly smaller coefficient (for parsimony we only present here the third lag).

### Table 6.2: Spillover results for lagged linear model equation (6)(dependent variable: smoothed $\Delta \ln TFP$ dated t, t+1, t+2)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>ONS deflator</th>
<th>ONS deflator</th>
<th>New deflator</th>
<th>New deflator</th>
<th>New deflator</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \ln K(\text{All ICT})(t-3)$</td>
<td>-0.0353 (0.0399)</td>
<td>-0.00374 (0.0253)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \ln K(\text{tele&amp;spec})(t-3)$</td>
<td>0.0514 (0.0379)</td>
<td>0.0275** (0.0132)</td>
<td>0.0275** (0.0131)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta \ln K(\text{tele})(t-3)$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0275** (0.0131)</td>
</tr>
<tr>
<td>Observations</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.039</td>
<td>0.030</td>
<td>0.001</td>
<td>0.104</td>
<td>0.104</td>
</tr>
</tbody>
</table>

Notes: All columns have a constant. “All ICT” capital is defined as computer hardware, software, telecoms equipment and spectrum. Robust standard errors in parenthesis, ** indicated p<0.05, * p<0.1).

Before moving to the statistical robustness of these results, let us look at the economic significance. Table 6.3 shows, in column 1 unsmoothed $\Delta \ln TFP$. Column 2 shows mean growth in the CT capital stock, lagged 4 periods. We use 4 lags as the coefficient in Table 6.2 was estimated using 3 lags, plus $\Delta \ln TFP$ was smoothed using lead terms.

Column 3 shows the estimated spillover, or excess contribution, from telecommunications capital, estimated as the coefficient in Table 6.2 column 4 (0.0275) times column 2. Column 4 shows the percentage of TFP that can be explained by the excess contribution in column 3. The results show that as much as 34.3% and 42% of growth in TFP in 2000-05 and 2005-08 respectively can be
explained by the excess contribution of telecommunications capital. Over the full period, 1990-2008, 20.7% of TFP can be explained by such spillovers.

To complete the picture, column 5 sets out the private contribution of telecoms and spectrum for the periods, using Table 6.1, columns (5+6), and column 6 \( \Delta \ln V \). Finally column 7 shows the fraction of \( \Delta \ln V \) accounted for by the private and spillover contributions, i.e. columns 3+5 as a proportion of column 6. As the last row shows, over the whole period, the private and social contributions of \( \Delta \ln K(\text{comms}) \) account for 14% of \( \Delta \ln V \). These are quite considerable contributions for capital equipment which is, as Table 6.3, memo columns 8 and 9 show is 2.5% of total capital rental payments and 7.3% of VICS. Note that the contribution in the 2000s is particularly high reflecting the roll out of equipment in the late 1990s.

Finally, it is worth noting that if we used the existing deflator we obtain a statistically insignificant coefficient. Nonetheless, if we use the point estimate of that coefficient, which is much higher than that using the updated deflator, we obtain a share of TFP of 79%, 2005 to 2008. Along with the private contribution from Table 6.1, panel 1, we get a total contribution of 24% of \( \Delta \ln V \), which is similar to the figure above, but overstates the contribution to TFP and understates the private effect. Overall, we conclude that, on the basis of this first pass at the data, the results are economically significant.

Table 6.3: Accounting for TFP

<table>
<thead>
<tr>
<th>period</th>
<th>ΔlnTFP</th>
<th>ΔlnK(tele&amp;spec)(t-4)</th>
<th>Spillover</th>
<th>% of ΔlnTFP</th>
<th>sDln(K) telecom&amp;spec</th>
<th>ΔlnV</th>
<th>% of ΔlnV</th>
<th>Memo: Telecoms Share: ( \frac{Pu^xK(\text{tele&amp;spec})}{Pu^xK} )</th>
<th>Telecoms share of VICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-95</td>
<td>1.41%</td>
<td>8.86%</td>
<td>0.24%</td>
<td>17.25%</td>
<td>0.03%</td>
<td>1.47%</td>
<td>18.62%</td>
<td>1.97%</td>
<td>2.06%</td>
</tr>
<tr>
<td>1995-00</td>
<td>1.70%</td>
<td>5.24%</td>
<td>0.14%</td>
<td>8.49%</td>
<td>0.14%</td>
<td>4.27%</td>
<td>6.65%</td>
<td>2.37%</td>
<td>8.06%</td>
</tr>
<tr>
<td>2000-05</td>
<td>1.33%</td>
<td>16.58%</td>
<td>0.46%</td>
<td>34.33%</td>
<td>0.11%</td>
<td>2.59%</td>
<td>21.85%</td>
<td>2.98%</td>
<td>10.12%</td>
</tr>
<tr>
<td>2005-08</td>
<td>0.60%</td>
<td>9.14%</td>
<td>0.25%</td>
<td>42.01%</td>
<td>0.11%</td>
<td>2.09%</td>
<td>17.29%</td>
<td>2.64%</td>
<td>10.20%</td>
</tr>
<tr>
<td>1990-2008</td>
<td>1.33%</td>
<td>10.05%</td>
<td>0.28%</td>
<td>20.73%</td>
<td>0.10%</td>
<td>2.66%</td>
<td>14.14%</td>
<td>2.48%</td>
<td>7.32%</td>
</tr>
</tbody>
</table>

Note to table: Column 1 is ΔlnTFP, unsmoothed. Column 2 is mean growth in the telecommunications capital stock, lagged 4 periods. Column 3 is the estimated spillover, that is the coefficient in Table 6.2 times column 2. Column 4 is the percentage of TFP explained by telecoms spillovers, that is column 3 over column 1. Column 5 is the private contribution of telecoms capital. Column 6 is growth in market sector value-added. Column 7 is the percentage of value-added growth explained by the private and excess contributions of telecoms capital, that is, columns 3 plus 5 as a share of column 6. Memo items are in columns 8 and 9. Column 8 is the share of telecoms capital payments in total operating surplus. Column 9 is telecoms capital services as a percentage of total capital services.
6.6.2. Robustness checks

Of course the previous tables just document preliminary investigations and clearly take no account of potential omitted variables. Table 6.4 sets out the results of incorporating the above specification into our estimates for telecommunications as well as some additional robustness checks on the regressions above.

In column 1 we show that the telecoms result is not robust to incorporating an additional delta term into the dependent and independent variable, that is using an acceleration model. Another change term magnifies the measurement error so some loss of precision is to be expected. In column 2 we test the robustness to using unsmoothed TFP and instead using the logged change in hours per worker to account for capacity utilisation as in Basu, Fernald et al. (2004). However the coefficient is no longer statistically significant.

In previous work, Goodridge, Haskel and Wallis (2013) (Chapter 5 in this thesis) and Haskel and Wallis (2013), we have found some evidence of spillovers from, respectively, private and public R&D. In the former paper we use industry data and found statistically significant effects of lagged ΔlnK(R&D) in industry j on ΔlnTFP in industry i in an industry/year panel. Here we have aggregate data and so are missing the cross-sectional industry variation which is large since ΔlnK(R&D) differs between industries. So we would expect to find less effect here, and this is confirmed by the result in column 3. Regarding public R&D we found a significantly declining marginal impact from public R&D as a proportion of output (R\textsubscript{PUB}/Y) over time. Column 4 therefore adds (R\textsubscript{PUB}/Y) and (R\textsubscript{PUB}/Y)^2 and finds them significant with the magnitude and significance of ΔlnK(comms) unchanged. Column 5 adds as well ΔlnK(R&D)(t-4). Note the magnitude of ΔlnK(comms) is more or less unchanged, but the significance falls somewhat.

So we think that that statistical significance of ΔlnK(comms) remains with these experiments. Its economic significance is slightly less than in Table 6.3, that is using the coefficients in Table 6.4 with

\textsuperscript{114} As a matter of data, R\textsubscript{PUB} trebled in just three years from 2001 to 2004 and it would appear sensible to allow for diminishing rates of return from this increase, as evidence from Haskel and Wallis (2013) suggests. We recognise that there is a mismatch in the sense that our private stock incorporates a depreciation rate whereas our public measure assumes no depreciation. We feel this is justified in the sense that private R&D is applied commercial research, whereas our public science measure represents basic research. If we do apply a specification for private R&D the same as that used for public, we do find positive and significant results, also with high implied rates of return. Another possibility to include is foreign public R&D (our data on foreign is not restricted to just science funding). Again, using a non-linear specification we find large and strongly significant coefficients. Foreign R&D as a share of GDP was also tested as an instrument for UK public science research but with no success.
the methods in Table 6.3, ΔlnK(comms) accounts for 21% of ΔlnTFP, 1990-2008 (public and private R&D account for 39% and 44%).

Table 6.4: Spillovers from telecommunications capital and public R&D

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ(ΔlnK(tele&amp;spec))(t-3)</td>
<td>0.0351</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0399)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔlnK(tele&amp;spec)(t-3)</td>
<td></td>
<td>0.00340</td>
<td>0.0374*</td>
<td>0.0253**</td>
<td>0.0281*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0220)</td>
<td>(0.0206)</td>
<td>(0.00910)</td>
<td>(0.0140)</td>
</tr>
<tr>
<td>(R/Y)_PUBSCI(t-2)</td>
<td></td>
<td></td>
<td></td>
<td>344.9***</td>
<td>414.1***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(70.79)</td>
<td>(88.69)</td>
</tr>
<tr>
<td>[(R/Y)_PUBSCI(t-2)]^2</td>
<td></td>
<td></td>
<td>-67,377***</td>
<td>-81,198***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(13,622)</td>
<td>(17,525)</td>
<td></td>
</tr>
<tr>
<td>ΔlnK(priv R&amp;D)(t-4)</td>
<td></td>
<td></td>
<td>0.0625</td>
<td>0.230*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.122)</td>
<td>(0.131)</td>
<td></td>
</tr>
<tr>
<td>Δln(H/N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>22</td>
<td>23</td>
<td>22</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.057</td>
<td>0.118</td>
<td>0.121</td>
<td>0.511</td>
<td>0.619</td>
</tr>
</tbody>
</table>

Notes: All columns bar column 1 have a constant. Robust standard errors in parenthesis, (***) indicate p<0.01, (**p<0.05, * p<0.1). In Column 1 variables are in acceleration form, with a double delta term on the independent and dependent variable and with no constant. By using the public science share of GDP as an independent variable, we are implicitly assuming that the public stock of scientific capital does not depreciate. Whilst this may not be so it appears reasonable to assume that it would depreciate very slowly, with a much smaller rate of decay than say private R&D. The terms in parentheses next to variable names refer to the number of lags employed.

We also checked robustness to indirectly measured banking sector output (FISIM). The new methodology for FISIM introduced in Blue Book 2008 resulted in upward revisions to GDP, particularly in the late 1990s and mid-2000s (Akritidis 2007). It might be felt that upward revisions to

115 Whilst the main point of our work is to examine telecoms spillovers, we remark here on the remarkably robust, but very high, coefficient estimate on public R&D, implying a very high rate of return (ρ). First, the public R&D here is that won by universities in open competition with other academics. Thus it has had a competitive discipline, is freely available, and supposed to be “basic”, rather than applied. One might then expect spillovers. Second, a number of papers have documented that the UK science base is of very high quality, as measured by citations per scientist for example, and is comparatively poorly funded. Thus one might expect spillovers to be very large if funding is small and public impact is big, an impression supported by the finding that the marginal return to R&D spend has been falling as R&D spend has risen. Third, it is worth noting that if one thought that depreciation is greater than zero, this estimate of ρ would be an underestimate according to the model above. Finally, one might worry about a bias to ρ due to simultaneity, which might occur if some common factor both raised ΔlnTFP and R^PUB/Y, or if the political reaction function was such that a rise in ΔlnTFP caused a rise in R^PUB/Y and we are estimating this effect. On reverse causation, this is always possible, but given the timing of our variables it would have to be that governments allocate more R&D money in anticipation of TFP growth up to five years in the future (recall R^PUB/Y is dated t-2 and ΔlnTFP is smoothed t, t+1 and t+2). Inclusion of private and foreign public R&D does not alter our findings.

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output in the late 1990s and 2000s resulted in overestimated growth in GDP and TFP, or a cyclical effect if it was felt that measures for the 2000s reflect wider conditions of that time including loose monetary policy and the availability of credit. Therefore we include a series for growth in the volume of the component of FISIM that is a direct addition to GDP. We do not find any statistically significant effect and the coefficient is in any case negative.

6.7. Conclusions and discussion

The consequences of the ICT revolution for productivity have been extensively studied. As Corrado (2011) points out, a sizable business economics literature has developed around Metcalf’s Law, namely that the value of a network rises greatly with the number of participants. But the implications for productivity, namely of spillovers with more connected networks, have been very hard to detect. There seems no very strong evidence of spillovers to ICT equipment.

This paper follows Doms (2005), Corrado (2011), Byrne and Corrado (2009) and OECD (2007) in suggesting that a resolution of this puzzle is around the neglect of the “C” part of ICT. Researchers have long known that measurement of hardware and software quality-adjusted prices is key to understanding their effects in periods of rapid quality change. Likewise, there has been massive quality change in communications equipment technology e.g. fibre optic cable, broadband versus dial-up etc. This raises the question of whether the contribution of communications equipment is mismeasured if prices are mismeasured.

To investigate this question, this paper has taken three steps. First, we document that official UK data deflates nominal telecommunications equipment investment using a non-computer plant and machinery deflator, which grows at 0.58% p.a., 1984-2008, in sharp contrast to the official computer hardware deflator (based on US data), which falls at around 12% p.a. over the period.

Second, based on US researchers quality-adjusted communications equipment deflators (Doms (2005), Byrne and Corrado (2009), and Corrado (2011)), which show an average price decline of -6.57% p.a. (1984-2008), we construct a UK deflators that falls at -4.29% p.a. This more than doubles the growth in the real UK telecoms capital stock (9.2% p.a., 1984-2008, in contrast with 3.9% p.a. using the official deflator). And this approximately doubles the standard growth accounting contribution of telecoms over the late 1990s and early 2000s. (0.14% p.a. as opposed to 0.07% p.a. in the late 1990s and 0.09% p.a. as opposed to 0.05% p.a. in the early 2000s).

Third, we ask if there is any evidence of spillovers from telecoms equipment, by regressing three-year lagged growth of telecoms equipment capital stock on TFP growth. We find no evidence of spillovers
using the official deflator, but the quality-adjusted deflator shows a statistically significant correlation between telecoms equipment growth rates and TFP growth four years later. It is economically significant too, accounting for 20.7% of TFP growth 1990-2008.

As we have documented, communications equipment capital services have grown from 2% of total capital services in the early 1990s to 10% by the late 2000s. This increasing importance and possibility of spillovers makes future study and better data important.
Appendix 1

Our data on telecoms investment from the Supply Use tables go back to 1984. Therefore we deflate that data to get real investment and extend that back to 1970 using real investment data from EUKLEMS. The telecoms capital stock is constructed using the perpetual inventory method (PIM):

$$K_t = I_t + (1 - \delta)K_{t-1}$$  \hspace{1cm} (A1)

Where \(K_t\) is the capital stock, \(I_t\) is real investment and \(\delta\) is the geometric rate of depreciation (we use a rate of 0.115 as in EUKLEMS). Since our real investment data begin in 1970, we also require an initial value for the stock in that year, which we estimate using the formula in Appendix 1 of Guellec and Van Pottelsberghé de la Potterie (2001), which can be derived as follows. The PIM can be re-written as:

$$K_t = I_t + (1 - \delta)I_{t-1} + (1 - \delta)^2 I_{t-2} + (1 - \delta)^3 I_{t-3} + ....$$  \hspace{1cm} (A2)

Assuming real investment grows at a constant rate this becomes:

$$K_t = I_t + (1 - \delta)\lambda I_t + (1 - \delta)^2 \lambda^2 I_t + (1 - \delta)^3 \lambda^3 I_t + ....$$  \hspace{1cm} (A3)

Therefore the initial value for the capital stock can be estimated as:

$$K_t = \frac{I_t}{1-\lambda(1-\delta)}$$  \hspace{1cm} (A4)

Where \(\lambda = \frac{1}{1+g}\) and \(g\) is the mean growth rate of \(I_t\). We apply the mean growth rate in the years 1970 to 1980, giving estimates of \(g=0.38\) and \(\lambda=0.72\).

In estimating capital services, growth in the stock of each asset is weighted together by the Tornqvist share of asset rental costs in total operating surplus, where the rental cost is the rental price times the stock. Rental prices for telecoms equipment and other assets are estimated as:

$$P^k = P^i \left(r + \delta - \pi\right)\tau$$  \hspace{1cm} (A5)

Where \(P^k\) is the asset rental price, \(P^i\) is the investment price, \(r\) is the net rate of return estimated ex-post such that it is equalised across all assets and rental costs exhaust operating surplus, \(\delta\) is the geometric rate of depreciation, \(\pi\) is a capital gains term estimated using changes in the asset price deflator and \(\tau\) is an asset-specific tax adjustment factor. In the late 1990s and 2000s we estimate \(\tau\)
=1.15 for telecoms equipment, compared to \( \tau =1.03 \) and 0.95 for mineral exploration and R&D respectively.

In our growth-accounting exercise we work at the aggregate market sector level. The definition of market sector \( \Delta \ln TFP \) based on value added is

\[
\Delta \ln TFP \equiv \Delta \ln V - \bar{v}_k \Delta \ln K - \bar{v}_l \Delta \ln L
\]  

(A6)

Where the “v” terms here are shares of K and L payments in nominal value added; \( \Delta \ln K \) is growth in capital services defined to include buildings, plant & machinery, vehicles, computer hardware, telecoms equipment (including spectrum), software, mineral exploration, artistic originals and R&D; and \( \Delta \ln L \) is growth in labour services including labour composition. Note the decomposition is based on growth in value-added, and not value-added per hour.
Appendix 2

Appendix Table A.1: Shares of total investment in telecommunications, by component

<table>
<thead>
<tr>
<th>Weights</th>
<th>Insulated wire and cable</th>
<th>Transmitters for TV, radio and phone</th>
<th>Receivers for TV and radio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.11</td>
<td>0.84</td>
<td>0.05</td>
</tr>
<tr>
<td>1993</td>
<td>0.20</td>
<td>0.76</td>
<td>0.04</td>
</tr>
<tr>
<td>1994</td>
<td>0.15</td>
<td>0.80</td>
<td>0.05</td>
</tr>
<tr>
<td>1995</td>
<td>0.13</td>
<td>0.82</td>
<td>0.05</td>
</tr>
<tr>
<td>1996</td>
<td>0.12</td>
<td>0.83</td>
<td>0.05</td>
</tr>
<tr>
<td>1997</td>
<td>0.11</td>
<td>0.84</td>
<td>0.05</td>
</tr>
<tr>
<td>1998</td>
<td>0.11</td>
<td>0.83</td>
<td>0.06</td>
</tr>
<tr>
<td>1999</td>
<td>0.11</td>
<td>0.83</td>
<td>0.06</td>
</tr>
<tr>
<td>2000</td>
<td>0.09</td>
<td>0.85</td>
<td>0.05</td>
</tr>
<tr>
<td>2001</td>
<td>0.09</td>
<td>0.84</td>
<td>0.07</td>
</tr>
<tr>
<td>2002</td>
<td>0.09</td>
<td>0.82</td>
<td>0.09</td>
</tr>
<tr>
<td>2003</td>
<td>0.09</td>
<td>0.79</td>
<td>0.11</td>
</tr>
<tr>
<td>2004</td>
<td>0.11</td>
<td>0.78</td>
<td>0.11</td>
</tr>
<tr>
<td>2005</td>
<td>0.11</td>
<td>0.78</td>
<td>0.11</td>
</tr>
<tr>
<td>2006</td>
<td>0.12</td>
<td>0.76</td>
<td>0.12</td>
</tr>
<tr>
<td>2007</td>
<td>0.12</td>
<td>0.74</td>
<td>0.14</td>
</tr>
<tr>
<td>2008</td>
<td>0.15</td>
<td>0.72</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Appendix Figure A.1: Price indices for each component of telecommunications investment

- Transmitters for TV, radio and phone: Corrado (2010); PPP adjusted
- PPI: 9414032000: P&M: Radio, television & communication
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Appendix A

Measuring the creative economy?116

Peter Goodridge (Imperial College Business School)

Introduction

In the UK and elsewhere, the creative sector has been growing in both size and the attention it receives, leading policy-makers and researchers to frequently ask: “what is the contribution of the creative sector to the UK economy?” As a result a new research area has emerged that is still in the early stages of development and has employed a variety of methods. Using the UK as a case study, this chapter reviews the more popular methods used, highlights their limitations, and proposes the use of an alternative approach that is fully grounded in the economics literature and neatly overcomes those same limitations.

In assessing the contribution of creative or innovative activity, two approaches are common. The first is to compile a set of time-series indicators, often weighted to form a composite, as in the European Innovation Scoreboard (2007). But: a) interpretation of an index composed of subjectively chosen, correlated indicators is problematic; b) the choice of weights is also subjective; and c) a change in the weighting scheme can produce different results.

A second is to aggregate output across pre-selected creative industries, as in: the UK’s Department for Culture, Media and Sport annual report (DCMS 2011); a similar Office for National Statistics (ONS) study based on the Input-Output tables (Mahajan, 2006); and the World Intellectual Property Organization’s (WIPO) framework for estimating the contribution of copyright industries (2003). For want of a better term, this will be referred to as the “aggregation method”. Due to its economic approach and use of official data, the method attracts perceived

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116 The work underlying this chapter is part of a broader research programme aimed at improving the measurement of innovation and the contribution of “knowledge” (or “intangible” or “creative”) capital to growth. The approach was first outlined in the seminal paper of Corrado, Hulten and Sichel (2005). Dal Borgo, Goodridge, Haskel and Pesole (2012) and Goodridge, Haskel and Wallis (2012) undertake similar studies in a UK context. The chapter also draws upon ideas and data described in Goodridge and Haskel, (2011), who estimate the value of UK investment in Artistic Originals (Film, TV & Radio, Music, Books and Art), often considered the core of the creative sector.
credibility, but actually has severe limitations and does not truly measure what it is intended to. In highlighting why, and because it is a regular analysis so relevant to the topic of this chapter, the annual DCMS study will be used for illustrative purposes. Please note however that the limitations apply in general, and are not particular to the DCMS results.

**Limitations of the standard approach**

Within the annual DCMS report, economic estimates of the creative sector are produced using data on gross value-added (GVA) and employment. The former is the more widely cited measure and is used to illustrate the following discussion.

*Subjectivity in application: industry does not equate to activity*

The first task for this approach is to identify just which industries ought to be included. DCMS define creative industries as those:

“*which have their origin in individual creativity, skill and talent and which have a potential for wealth and job creation through the generation and exploitation of intellectual property*”;

which is ambiguous in terms of practical application. An illustration of this can be found in the latest DCMS report (2011):

“This release has had two key changes ... SIC07 codes 62.02 and 62.01/2 have been removed ... and the scaling factor that was previously applied to the GVA estimates has been dropped. The impact of these has caused a considerable reduction in the estimate of GVA, but these changes make the estimates in this release a more accurate representation of the Creative Industries”.

“Computer consultancy activities” (62.02) and “Business and domestic software development” (62.01/2) were excluded as they were considered “more related to business
software than to creative software” (DCMS 2011). But it is not clear why business software does not meet the definition of creative industries given above. Even if some threshold were used to select industries, there is: a) subjectivity in setting the threshold; and b) implicit disregard of the cumulative activity in industries that fall below the threshold, which is often substantial.

Furthermore, industries as defined by the Standard Industrial Classification (SIC) do not neatly correspond to economic activity, so there is no clear boundary between creative and non-creative activity. The DCMS definition of the creative sector incorporates the thirteen industry groups presented in Table 1. In the final column are the proportions applied to industry GVA, with the intent of removing non-creative activity.
Table 1: DCMS mapping from SIC07 to Creative Sector

<table>
<thead>
<tr>
<th>Industry</th>
<th>Sub-industry (SIC07 code)</th>
<th>Proportion applied (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Advertising</td>
<td>Advertising agencies (73.11)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Media representation (73.12)</td>
<td>100%</td>
</tr>
<tr>
<td>2. Architecture</td>
<td>Architectural activities (71.11)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Specialised design activities (74.10)</td>
<td>4.50%</td>
</tr>
<tr>
<td>3. Art and antiques</td>
<td>Retail sale in commercial art galleries (47.78/1)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Retail sale of antiques including antique books, in stores</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>(47.79/1)</td>
<td></td>
</tr>
<tr>
<td>4. Crafts</td>
<td>Majority of business too small to be picked up in business surveys</td>
<td></td>
</tr>
<tr>
<td>5. Design</td>
<td>Specialised design activities (74.10)</td>
<td>95.40%</td>
</tr>
<tr>
<td>6. Designer fashion</td>
<td>Clothing manufacture (14.11-14; 14.19-20; 14.31; 14.39; 15.12; 15.20))</td>
<td>0.50%</td>
</tr>
<tr>
<td>7. Film, Video &amp; Photography</td>
<td>Re-production of video recording (18.20/1)</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Photographic activities (74.2)</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Motion picture and video production activities (59.11/1 &amp; 59.11/2)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Motion picture, video &amp; TV post-production activities (59.12)</td>
<td>18.40%</td>
</tr>
<tr>
<td></td>
<td>Motion picture and video distribution activities (59.13/1 &amp; 59.13/2)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Motion picture projection activities (59.14)</td>
<td>100%</td>
</tr>
<tr>
<td>8 &amp; 12. (Interactive Leisure) Software Electronic Publishing: Digital &amp; Entertainment Media</td>
<td>Reproduction of computer media (18.20/3)</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Other software publishing (58.29)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Publishing of computer games (58.21)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Ready-made interactive leisure and entertainment software development (62.01/1)</td>
<td>100%</td>
</tr>
<tr>
<td>9. &amp; 10. Music &amp; Visual and Performing Arts</td>
<td>Sound recording and music publishing activities (59.20)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Reproduction of sound recording (18.20/1)</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Performing arts (90.01)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Support activities to performing arts (90.02)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Artistic creation (90.03)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Operation of arts facilities (90.04)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Motion picture, television and other theatrical casting (78.10/1)</td>
<td>0.07%</td>
</tr>
<tr>
<td>11. Publishing</td>
<td>Printing of newspapers (18.11)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Pre-press and pre-media services (18.13)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Book publishing (58.11)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Publishing of newspapers (58.13)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Publishing of journals and periodicals (58.14)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Other publishing activities (58.19)</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>News agency activities (63.91)</td>
<td>100%</td>
</tr>
<tr>
<td>13. Radio &amp; TV</td>
<td>Radio broadcasting (60.10)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Television programming and broadcasting activities (60.20)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>TV programme production activities (59.11/3)</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Motion picture, video &amp; TV post-production activities (59.12)</td>
<td>81.60%</td>
</tr>
<tr>
<td></td>
<td>TV programme distribution activities (59.13/3)</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Creative Industries Economic Estimates (DCMS, 2011), Annex A, Table 6

From Table 1 we can see that the creative sector includes the provision of services in advertising, architecture, design and leisure software. This directly implies that the output of say, a designer working in the design industry is “creative”, which is reasonable, but also that the output of a designer working in, say a manufacturing firm, is not. Why should this be the case?
Similarly for market researchers, architects, software writers or any other “creative worker” outside this narrow list of SICs.

The very value of creative output is derived from each unit being in some sense unique. To retain that value and appropriate revenue from it, firms often choose to produce it in-house rather than contract it out to the list of industries in Table 1. Continuing with the example of design, most is actually undertaken on own-account by firms outside the design industry itself (Galindo-Rueda, Haskel and Pesole, 2008). But this in-house activity is not considered in Table 1, with the notable exception of that in the fashion industry. It is not consistent to attempt to capture the design activity used in clothes manufacture but not in the production of other final goods.

A second direct implication of Table 1 is that the output of, say an administrative worker, outside this group of industries is not creative, but that of an administrative worker within this group of industries is creative. Why should the standard operational and administrative activities in these industries count as creative? Many might say they should not.

Both the DCMS (2011) and WIPO (2003) reports include recognition that: a) industries normally assigned to the creative sector also engage in non-creative activity; and b) excluded industries also produce creative output. In attempting to circumvent this problem, WIPO classify industries as ‘core’, ‘partial’, ‘interdependent’ and ‘non-dedicated support’, depending on the prevalence of creative activity in business processes. But to maintain the ability to fully appropriate revenues from unique outputs, there is often a considerable degree of vertical integration in firms and industries that produce and use creative outputs, making it difficult to separate “core” processes from other activities and introducing a further element of subjectivity into the methodology.

For the same reason, DCMS also disaggregate estimates of creative sector employment into: i) those with a creative job, working in the Creative Industries; ii) those with a non-creative job, working in the Creative Industries (support employees); iii) those with a creative job, not working in the Creative Industries. The DCMS also attempt to remove “support activity” from the GVA estimate, using the factors in the final column of Table 1:
“In certain sectors the SIC codes do not map directly to the Creative Industries. This is generally due to either the SIC code capturing non-creative elements (e.g. designer fashion SIC codes includes the manufacture of the clothes) or where elements of other non-creative industries are captured by the code (e.g. photographic activities SIC codes include elements such as ‘passport photos’). Proportions are applied to the SIC group so that only the creative elements are included” (DCMS, 2011)

But despite such adjustments, by only counting creative output from the industries in Table 1, the majority is missed and a host of non-creative output is erroneously included. Furthermore, as will be shown below in the context of the music industry, application of this method actually results in the unintended inclusion of additional non-creative output. As industries defined by the SIC differ greatly in degrees of vertical integration, and therefore the extent to which they produce, distribute and use creative output, aggregation across industries results in all three activities being treated identically, which is not appropriate. For example, the publishing industry either fully or partly includes all of the following functions: i) the creation of artistic/literary/musical works; ii) their distribution; and iii) their use.

Example: Estimating the GVA of “Music”, using the SIC

Consider the music industry but note the same argument can be made for other industry groups in Table 1. The SIC does not classify “music” as a distinct industry, instead its components are dotted around the SIC in publishing, live entertainment, artistic creation, and so on. Aggregation across these industries actually results in a severe mis-counting of what most would consider “music output”.

To highlight this, note from Table 1 that “Music GVA” includes the value-added generated in the “Operation of Arts facilities” i.e. live venues. What does this value-added equate
to? On the production-side\textsuperscript{117}, value-added is sales less intermediate expenditures. On the income side, it is the sum of incomes of employees and owners of capital that reside in the industry. Therefore from the production-side, GVA in live venues is gross revenues, largely ticket sales, less payments, including those made to the musicians that reside in “Performing Arts” and “Artistic Creation”.

So the element that acts as a return to creative output (in this case live music) is actually subtracted from GVA in live venues. What remains is used to compensate industry labour and capital, including administrators, security guards, and the owners of venues and set equipment. But the income earned by, say the owner of the venue, is simply a return to tangible capital (the building), rather than a return to creativity. The returns to creative output appear in the incomes of artists and musicians, and also of record labels and publishers who also own some share of the creative good. All of these agents reside outside the “Operation of Arts facilities”.

The DCMS estimate of music GVA also includes 25\% and 100\% of GVA in “Reproduction of sound recording” and “Sound recording and music publishing activities” respectively. But not all the value-added in music publishing is a return to creativity, and in the case of reproduction, what is being counted is the compensation to factory buildings, equipment and employees that manufacture CDs. The subtracted intermediates include the payments to labels, artists and publishers for the right to produce copies, which act as a return to the music itself.

This misidentification of creative output occurs throughout. Table 1 also includes both the production of film and its projection in cinemas. But value-added in cinemas is sales (e.g. tickets and popcorn) less intermediates. Intermediate payments include those for the right to project, which flow to the owners of the film original, usually the studio and production company. What remains are the incomes earned by cinema employees and owners of cinema capital, including the popcorn machine. It is difficult to accept that the margins earned on film projection

\textsuperscript{117}At industry-level, it is only appropriate to consider the production- or income-side measures of GVA. The expenditure-side approach can only be used at aggregate levels.
and popcorn sales represent genuine creative activity. Equally it does not seem appropriate to consider cinema ushers and ticket hall attendants as generating creative output.

Therefore, by aggregating value-added in industries in which creation takes place, with that in industries which use creative output, the DCMS method explicitly includes additional non-creative output, the very outcome it intended to avoid through the use of the proportions in the final column of Table 1.

Classification Issues

The DCMS method allocates firms to the creative sector according to the SIC. As well described in Hellebrandt and Davies (2008), the industrial classification of firms is based on their primary activity of engagement. The first point to note is that economic activity is surveyed on a reporting unit (RU) basis. Often an entire firm or enterprise is classified as a single RU even if it has several sites. Suppose an enterprise that is a single RU actually operates from two separate sites or local units (LUs). Site 1 is a factory, whilst site 2 undertakes all design activity. If site 1 is larger, the entire enterprise and its output are classified in manufacturing, even though a proportion of output is actually design. This is the ‘dominance rule’. In this scenario, none of the output produced on site 2 will feature in estimated creative sector GVA.

Now suppose the firm contracts out all design to a firm in the design industry. That same output will now fall within the DCMS definition of the creative sector, even though it is exactly the same in nature to that excluded in the previous scenario. Of course design is a specific example, the function could be any form of creative activity.

Impact of firm size on classification

For the purposes of data collection, larger enterprises are sometimes broken up into several RUs. If the two sites described above were treated as distinct RUs, RU1 and its output would be allocated to manufacturing, and RU2 to design. But this shows that the aggregation method is
more likely to capture creative activity undertaken in large firms, making the result dependent on: a) the sizes of firms that produce creative output; b) the structure of individual firms; and c) classification decisions taken by the statistical office; all of which can change over time. Small and medium sized enterprises (SMEs) make up the majority of the UK market sector and are considered important in the context of creative activity. However, the creative output of SMEs is not well accounted for in this methodology.

_Granularity and bias in the SIC_

Further classification issues arise from the greater granularity of the manufacturing breakdown compared to that for services. Let us extend the example so that a single RU operates out of three LUs. Two are plants dedicated to the manufacture of distinct products in the SIC, and the third designs both products. Employment on each site is:

**Table 2: Example of UK industrial classification procedure**

<table>
<thead>
<tr>
<th>Local Unit / Site</th>
<th>Industry (SIC)</th>
<th>SIC code</th>
<th>No. of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>LU1</td>
<td>Manufacture of basic metals</td>
<td>SIC 24</td>
<td>50</td>
</tr>
<tr>
<td>LU2</td>
<td>Manufacture of fabricated metal products</td>
<td>SIC 25</td>
<td>30</td>
</tr>
<tr>
<td>LU3</td>
<td>Specialised design activities</td>
<td>SIC 74.1</td>
<td>55</td>
</tr>
</tbody>
</table>

Source: authors example

As classification is conducted at the two-digit SIC level, even though the majority of employees are engaged in manufacturing (80 compared to 55 in design), the entire RU would be classified in the design industry. A slight adjustment of the employment numbers would result in it being classified as SIC24, even though the manufacture of SIC 25 and design form large parts of firm activity. Now suppose the manufacture of basic and fabricated metals were classified as the same industry in the SIC. Then the firm would be allocated to manufacturing, even though it
undertakes a considerable amount of design. Classification is partly a product of the differential level of detail across the SIC, and measuring the creative sector using SICs is affected by this.

*The growing servitization of the manufacturing sector*

Some of the limitations of the aggregation method are due to the fact that the nature and composition of manufacturing output is changing, and can include design, consulting and other services, that may or may not be bundled with manufactured products. Rolls-Royce is a commonly cited example, see for example Neely (2008) and Hellebrandt and Davies (2008), with the latter noting the statement on the Rolls-Royce website that 53 per cent of global annual revenues derive from the sale of services. Other firms traditionally viewed as part of the production sector that offer a range of services include Dell, IBM, BP and Shell. Manufacturing (and other) firms also produce a range of “creative outputs” for use in the production of final goods. This is particularly true of manufacturing sectors in advanced economies such as the UK.

*Potential for double-counting*

Although not inevitable, the aggregation method also introduces great potential for double-counting. Methods that seek to isolate specific activities without proper consideration of how they integrate into wider measures of output, can be easily misinterpreted. As stated in the DCMS report (2011):

> “There is considerable overlap between the Digital Industries and the Creative Industries. Therefore any estimates that attempt to measure the Digital Industries should not be compared to or aggregated with estimates of the Creative Industries”.

With regard to the digital economy, in “The Connected Kingdom” report, Boston Consulting Group (BCG, 2010) sought to measure the contribution of the Internet to UK GDP
using a variant of the aggregation method. GDP can be estimated using data from the production-side, the income side (both described above), and the expenditure side. Ignoring international trade, GDP expenditure equates to final household consumption plus business investment plus government expenditure. Summing across data for final consumption mediated by e-commerce and private/public ICT investment due to the Internet, BCG concluded that: a) £100bn, 7.2 per cent of UK GDP, was due to the Internet; and b) were the Internet an industry it would be the fifth largest in the UK.

There are many problems with this interpretation and the result actually says very little about the contribution of the Internet to UK GDP. Were we to discover that consumers spent £100bn after catching a bus to their local high street, then by adding that to the money spent on bus fares, and investments in buses themselves in the transport services industry, we could estimate the contribution of buses to GDP in a similar way. But most would recognise it would not be sensible to do so.

Furthermore, there is inherent double-counting in the BCG method. First, treatment of the Internet as a separate industry, with say Amazon implicitly part of both the retail and Internet sectors, is pure double-counting. Second, a large part of retail revenues flow back to original producers. Only the margins earned by online retailers ought to count as value-added in what BCG term the Internet sector. Again, this is double-counting.

The real question is whether the Internet has increased the volume of consumption or efficacy of production. If the Internet has increased the quantity or quality (and therefore volume) of goods and services consumed, or reduced the cost of their production, then it has made a positive contribution to GDP. Although not the focus of this chapter, it will be clear that the framework proposed further below can be applied to estimate the contribution of the telecommunications capital used to deliver Internet services, in a way that is consistent with measurement of GDP and with no double-counting.
International trade

A final limitation of the DCMS approach is the inadequate consideration of international trade. If the aim is to estimate the UK creative sector, appropriate treatment of international payments is crucial. Consider again the production and projection of film. The output of UK film production has two broad components: the first produces UK (part-)owned\textsuperscript{118} films which generate long-lived UK revenues via payment for the rights to project, distribute on DVD, broadcast on television, use on merchandise etc. over multiple years; the second produces non-UK owned films, for a one-off fee for the ‘Rest of the World’ sector.

The first is the production of a UK asset and the second is an export. By using the value-added of film production in estimation, the DCMS method makes inadequate consideration of UK asset creation (investment), implicitly treating it as equivalent to production of an asset not owned in the UK. If we are interested in the magnitude of the UK creative sector, UK ownership of creative assets surely matters.

Furthermore, UK (and worldwide) projection uses both UK- and non-UK films as inputs. As we know, payments for the right to project are subtracted from value-added in projection. What matters from the perspective of \textit{UK creative activity} is the value of payments to project/distribute/broadcast/use, which flow to \textit{UK (part-)owners (investors)} from both UK and non-UK sources. The method proposed below will properly account for this issue, and all the others described above.

\textsuperscript{118} As is the case for many forms of artistic originals, rights are split into various categories and asset ownership is often split between multiple agents, sometimes across international borders.
The “intangibles approach”

Introduction

It is clear that measurement of creative activity using the aggregation method is conceptually and practically problematic. The remainder of this chapter will present an alternative approach, grounded in the economics literature and national accounting framework, to facilitate improved understanding of the contribution of creative activity.

As already noted, and particularly for more advanced economies, much creative output is produced in-house for repeated use in final production, and therefore occurs outside the industries in Table 1. One such output is design, but consider also software, market research, product/process development as a few examples. A superior approach is therefore to consider creative activity itself, regardless of the industry it occurs in.

Where such activities contribute to production over a period greater than one year, they are usually described as intangible (or knowledge) capital in the wider literature. Where their contribution is for less than one year, they ought to be viewed as intermediates that do not appear in final value-added. By estimating investment in intangible (or “creative”) capital and treating it consistently with long-lived tangible capital (e.g. buildings, plant and machinery, vehicles), we can estimate both its share in GDP and its contribution to growth.

The symmetry between intangible capital and what is commonly described as the creative sector is clear. One element of intangible capital is the film, television, musical and literary originals used repeatedly in the production of copies and other output. Some intangible capital (software, mineral exploration, artistic originals, and soon R&D) is explicitly recognised in the measurement of GDP, but others are not so must be integrated in a way consistent with official measurement.

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\[ \text{Data and methods for estimating investment in such assets can be found in Goodridge, Haskel and Mitra-Kahn (2012) and Goodridge and Haskel (2011)} \]
The precise advantages of the intangibles approach are that: 1) the identification of investment provides a measure of output classified by asset or *activity*, rather than industry; 2) the estimated contributions of creative activity are consistent with wider measures of investment and output, and so are distinct from the contributions of other factors of production, thus avoiding the incorporation of the returns to non-creative activity and the usual inability to compare across studies; 3) all estimation is conducted within an internally consistent accounting framework with no double-counting; and 4) rather than having to make subjective judgements on what (proportions of) industries are creative, the only valuation used is that assigned by the market, as present in the estimated returns from the commercialisation of creative capital.

The first study to present a comprehensive categorisation of the intangible capital used in the generation of final output was Corrado, Hulten and Sichel (2005), summarised in Table 3. Clearly it is broader than that implicit in Table 1. For comparability purposes, the following analysis will consider two alternative measures of creative activity. The first most closely aligns with the DCMS application, and will consider Artistic Originals; Design, Advertising & Market Research as “creative intangibles”. The second will incorporate all other forms of intangible capital in Table 3.

**Table 3: Identified forms of intangible capital (CHS, 2005)**

<table>
<thead>
<tr>
<th>Computerised information</th>
<th>Innovative Property</th>
<th>Economic Competencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer software</td>
<td>Scientific R&amp;D</td>
<td>Firm-specific training</td>
</tr>
<tr>
<td>Computerised databases</td>
<td>Non-scientific R&amp;D</td>
<td>Reputation (Advertising and Market Research)</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>Organisational Capital</td>
</tr>
<tr>
<td></td>
<td>Artistic Originals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mineral Exploration</td>
<td></td>
</tr>
</tbody>
</table>

Source: Corrado, Hulten and Sichel (2005)

**Conceptual Framework**

In this proposed framework, creative activity is identified regardless of industry, so manufacturers that produce long-lived design blueprints are also considered in their role as producers of design, in addition to firms in the design industry itself. Therefore it is helpful to consider the economy in
terms of sectors of activity rather than the SIC, thus allowing estimation of distinct activities that occur in the same firm/industry.

Consider an economy broken down into two sectors: first, the creative (or upstream) sector produces creative assets such as long-lived design, artistic originals, reputational capital etc.; second, the final output (or downstream) sector uses creative assets in the production of final goods. The nominal value of creative (upstream) gross output, $P^N N$, can be expressed as equivalent to the factor and intermediate costs in the creative sector times any producer mark-up ($\mu$), as in (1).

$$P^N N = \mu(P^L L^N + P^K K^N + P^M M^N)$$

Where $P^L L^N$, $P^K K^N$ and $P^M M^N$ are payments to labour, capital and intermediates respectively and $P$ their competitive prices. The factor $\mu$ accounts for the unique nature of creative outputs and the monopoly power of creators/owners in revenue appropriation. Note this market power is sometimes legally protected by intellectual property rights (IPRs) such as copyrights, trademarks, patents or design rights.

Consider next the downstream which uses the creative asset in production. Perhaps it is a manufacturer employing some blueprint either created in-house or purchased, or perhaps an artistic original is being used to produce copies for sale. If the downstream purchases the asset (rights) outright, then the investment is equivalent to upstream (gross) output, $P^N N$. Unlike most tangible assets, the rights to creative assets are somewhat divisible, so assets can also be sold in components. For example, the full rights to a film include: cinema; DVD and television rights.

Although full (or partial) transactions for creative assets do occur, they are rare. Instead downstream users typically rent creative assets from the owners. For instance, film rights tend to be owned by the studio and production company. Payments by downstream users (e.g. cinemas

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120 Two sectors are used for simplicity, with the final goods sector modelled as producing all final consumption and tangible investment goods. More detail could easily be introduced. Similarly the upstream could be disaggregated into sectors for each type/variety of good/asset.
and broadcasters) take the form of licence fees\textsuperscript{121} that act as a return to the creative asset. Whilst payment of explicit rentals is common for artistic originals, in cases where the upstream is located in-house the rentals are unobserved and form an implicit part of firm revenues. Considering the asset value from the perspective of (implicit or explicit) rentals, upstream output can be expressed as:

\[ P^N N = \sum P^R r \frac{R}{(1 + r)^t} \]  

(2)

Which says that the asset value must equal the value of discounted rentals; where \( r \) is the real interest rate, \( R \) the stock of creative assets, \( P^R \) the rental price, and \( t \) the expected asset life-length. \( R \) can be modelled as in (3), where \( \delta \) is the rate at which the asset depreciates or decays in terms of its ability to generate revenue:

\[ R_t = N_t + (1 - \delta)R_{t-1} \]  

(3)

The downstream sector produces (gross) output, \( P^V Y \):

\[ P^V Y = P^L L^Y + P^K K^Y + P^R R^Y + P^M M^Y \]  

(4)

where \( L, K \) and \( M \) represent labour, capital and intermediates, and \( P^R R^Y \) are the (implicit or explicit) rental payments for using creative capital. The downstream is assumed competitive so there is no mark-up. The mark-up earned by the creative sector (\( \mu \)) is inherent in the rentals, \( P^R R^Y \). This framework is summarised in Figure 1 which uses the example of the film industry.

\textsuperscript{121} For example, rental payments by cinemas are typically arranged as a percentage of box office revenues.
For clarity, consider the measurement of literary originals as an alternative example. Say that in the past year, a UK resident produced one new title and over its life time, the net present value (NPV) of the books total earnings, from primary and secondary, domestic and international sources, is £10m. Those earnings form part of current and future UK income. The value of investment made in producing that title (including any mark-up generated from the unique talent and input of the writer) is equivalent, so on the expenditure-side, investment in literary originals is also estimated at £10m. Current and future UK output is also generated from the stock of originals produced in past years, of which the latest investment is a component. The contribution of that stock can be estimated by integrating the above model into standard national and growth accounting frameworks.

Practical measurement of creative output ($P^YN$)

The value of creative output/activity can be estimated in a variety of ways, but broadly speaking the methods are variants of, first, an ex-ante cost based approach exploiting the relationship in equation (1), and second, an ex-post revenue based approach exploiting the relationship in

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122 Whilst not discussed extensively here for reasons of space, it is of course important that estimation considers the residence of owners in estimation. Production or purchase of an asset owned by a UK resident is UK investment. Returns to that investment form part of UK revenues and can be earned from domestic and non-domestic sources. An asset produced in the UK but owned or purchased by a non-UK resident may be part of UK production but is not UK investment.

123 For a full description of such an integration, please see Goodridge, Haskel and Wallis (2012).
equation (2). Which method is chosen depends on the activity in question and data availability. For instance, consider ‘design’ and ‘artistic originals’. Investment in design can be in the form of: a) purchases from the design industry itself; and b) in-house (or own-account) creation by firms outside the design industry. Purchases can be identified from the official Input-Output tables. Own-account creation can be estimated using data for the terms on the right-hand side of (1), that is the labour payments to occupations that undertake design and other costs. In the case of artistic originals, production of film and TV originals can be estimated using a similar cost based approach. For music and literary originals, explicit observation of the royalties earned from sales, performance and secondary uses mean that the revenue based approach is also applicable.

UK creative activity in the context of value-added or GDP

For reasons that are now clear, the DCMS approach to estimating creative activity might produce a highly inaccurate result. The intangibles framework offers two obvious ways to consider the contribution of creative activity to GDP. First, where the output of that creative activity has a life-length greater than one year, it is an investment and therefore a direct component of GDP expenditure. Table 4 sets out estimates of investment in creative assets by the UK market sector.
Table 4: UK Market Sector Investment in knowledge assets, nominal (£bns)

<table>
<thead>
<tr>
<th>Asset</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchased Design</td>
<td>11.07</td>
</tr>
<tr>
<td>Own-account Design</td>
<td>4.39</td>
</tr>
<tr>
<td>Design</td>
<td>15.46</td>
</tr>
<tr>
<td>Film Originals</td>
<td>0.26</td>
</tr>
<tr>
<td>TV (fiction) Originals</td>
<td>1.44</td>
</tr>
<tr>
<td>TV (non-fiction) Originals</td>
<td>0.67</td>
</tr>
<tr>
<td>Total TV Originals</td>
<td>2.10</td>
</tr>
<tr>
<td>Literary Originals</td>
<td>1.02</td>
</tr>
<tr>
<td>Music Originals</td>
<td>1.33</td>
</tr>
<tr>
<td>Miscellaneous Art</td>
<td>0.37</td>
</tr>
<tr>
<td>Total Artistic Originals</td>
<td>5.09</td>
</tr>
<tr>
<td>Advertising</td>
<td>10.77</td>
</tr>
<tr>
<td>Market Research</td>
<td>2.04</td>
</tr>
<tr>
<td>Total Branding</td>
<td>12.81</td>
</tr>
<tr>
<td>Total &quot;Creative Intangibles&quot;</td>
<td>33.36</td>
</tr>
<tr>
<td>TOTAL INTANGIBLES</td>
<td>124.25</td>
</tr>
<tr>
<td>TOTAL TANGIBLES</td>
<td>92.67</td>
</tr>
</tbody>
</table>

Note to table. “Creative Intangibles” are defined as those assets that most closely match creative activity in Table 1 (Design, Artistic Originals and Branding). Total Intangibles incorporate a wider definition of intangible assets including: “creative intangibles”; and also (purchased and own-account) software; (scientific and non-scientific) R&D; mineral exploration; financial product innovation; training; and organisational capital. Tangible assets are: buildings, plant & machinery (including ICT hardware), and vehicles.

How do these compare to the DCMS estimates? DCMS estimate that in 2009 the Creative Industries contributed £36.3 billion (2.89% of UK whole economy GVA), with Publishing, Advertising and TV & Radio providing the greatest contributions. From Table 4, if we consider a very narrow range of creative capital that most closely aligns with the DCMS study (design, branding and artistic originals), we estimate UK market sector investment in creative intangibles of £33.4bn in 2009, equivalent to 3.26% of adjusted market sector GVA (MGVA)\(^{124}\), or 2.66% of the whole economy figure used by DCMS. If we include investment in software, which seems reasonable, those estimates increase to £55.9bn, 5.46% and 4.45% respectively. If we include a

\(^{124}\) This GVA figure refers to the market sector only; defined as SIC03 sections A-K & OP, consistently adjusted for the capitalisation of intangibles. The whole economy GVA figure used by DCMS incorporates the UK non-market sector, thus including government services, and is not adjusted for the treatment of intangibles as capital goods.
comprehensive range of intangible capital as in Table 3, the estimates are £124.3bn, 12.13% and 9.89% respectively, almost four times higher than the DCMS estimate due to consideration of industries outside Table 1 and a wider definition of creative activity. Note, that there is no erroneous inclusion of non-creative output associated with use, or double-counting between production and use.

A second way to consider the role of creative assets is to estimate their contribution to growth. Figure 2 sets out some brief results in the form of average contributions to labour productivity for the periods shown.

Figure 2: Contribution of creative assets UK Market Sector labour productivity

Notes to table. Data are average growth rates per year for intervals shown, calculated as changes in natural logs in Tornquist indices, with each contribution re-expressed as a percentage of average growth in labour productivity (LPG). The first bar is the contribution of labour composition or “quality”. The second is the contribution of tangible capital deepening (ICT, buildings, plant & machinery, vehicles). The third bar is divided into two components. The lower part is the contribution of “creative intangibles” (design, branding, artistic originals). The upper part is the contribution of all other intangibles defined in Table 3. The fourth column is the contribution of TFP, that part of growth unexplained by the contributions of factor inputs.

For reasons of space a description of the growth-accounting framework and methodology, and its extension to incorporating intangible assets, is not provided here. For more details please see Corrado, Hulten and Sichel (2005), Dal Borgo, Goodridge, Haskel and Pesole (2012) or Goodridge, Haskel and Wallis (2012).
In 2000-2009, the contribution of the most narrow definition of creative assets (design, marketing and artistic originals) was 0.08% p.a., or 5.5% (0.08/1.43) of annual labour productivity growth (LPG). If we consider a comprehensive range of intangible capital, which is more appropriate considering the high degrees of complementarity between intangible assets, we estimate a contribution of 0.37% p.a., or 25.6% of LPG (20.1+5.5). Therefore, in 2000 to 2009, over a quarter of UK growth can be explained by the use of intangible assets.

Of course some of the returns to creative assets cannot be fully appropriated by the owner(s) and some benefits likely diffuse to other agents. One element of Figure 2 is the contribution of the TFP residual, that is the component of growth that is unaccounted for by the contributions of factor inputs. TFP therefore incorporates the contributions of all forms of costless advance and freely available knowledge. Whether through imitation, inspiration, or some other means, part of the contribution of creative output to growth will remain in the TFP residual. The private contribution presented in Figure 2 therefore ought to be considered a lower bound.

Conclusion

Standard approaches for estimating the value, size or contribution of the creative sector potentially miss large chunks of creative activity and incorporate a host of other economic activity which is not in fact creative. Furthermore, failure to distinguish between production, distribution and use can result in mis-interpretation of the results. This chapter has argued that a superior approach is to instead identify creative activity regardless of industry classification. In 2009: a) 15.3% of aggregate UK investment was in a narrow group of “creative intangibles”, equivalent to 3.26% of adjusted MGVA; b) for 2000-09, approximately 5.5% of LPG is attributable to the use of those assets. Use of a broader definition of creative assets increases those estimates to 57.3% of UK investment and 25.6% of annual LPG.
Of course these calculations do not account for any positive externalities or cultural benefits that may arise from creative activity. The contributions are solely based on the compensation that can be directly attributed from observed market transactions. Any additional social benefits or spillovers generated by creative activity remain subsumed in the TFP residual. Furthermore creative activity may generate additional welfare beyond that measured in GDP. The estimates presented above can therefore be considered a lower bound of the true total or “social” contribution of creative activity.

It is worth noting that one element of the contribution of creativity not considered here is that of the human capital of artists. Figure 2 included an estimate for the contribution of labour composition, which includes the productivity-enhancing effects of education and experience, concepts closely linked to the idea of human capital. In principle it would be possible to break that contribution down into that from artists and other forms of labour, and incorporate the former as an additional component of the contribution of creative activity.

Finally, one element of creative activity that receives much attention is the production of film, television, musical and literary originals, sometimes referred to as copyrighted assets. This chapter features work that sought to estimate the value of investment in those assets and their contributions to growth. The results should not be interpreted as saying anything about the value of copyright protection itself. Whether investment in those assets, or their contributions, are any higher or lower than they would have been without formal IPR protection is unknown.
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Further Reading

CHS (2005) set out a clear exposition of how the measurement of intangible or “creative” capital fits into wider measures of output and GDP accounting. For a recent application of this approach in a UK setting see Goodridge, Haskel and Wallis (2012), which applies
the CHS model in the estimation of UK innovation. For a study that fits into more conventional analysis of the creative industries, see Goodridge, Haskel and Mitra-Kahn, (2012) and Goodridge and Haskel (2011), where the former provides an updated summary of a workstream described in the latter, which sought to estimate UK investment in artistic originals (film, TV & radio, music, books and miscellaneous art).
Appendix B

Constructing a Price Deflator for R&D: Calculating the Price of Knowledge Investments as a Residual*

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August 2011 (revised version)
July 2010 (original version)

ABSTRACT

We model the production and use of knowledge investment and show how the model can be used to infer the unknown price of knowledge using two approaches. The first is often used by national accounting offices and is based on costs in the knowledge-producing sector. We show this implicitly assumes no market power and no productivity in the production of knowledge. We set out an alternative approach that focuses on the downstream knowledge-using sector, the final output sector. The science policy practice of using the GDP deflator is a simple variant of this approach, while the full approach allows market power and implies backing out the price of R&D from final output prices, factor costs, and TFP. We estimate a R&D price for the United Kingdom from 1985 to 2005 using the full approach. The index falls strongly relative to the GDP deflator suggesting conventionally-measured real R&D is substantially understated.

* The authors gratefully acknowledge support from NSF’s SciSIP Grant 0830260 (Corrado) and the FP7 COINVEST Grant 217512 and UK NESTA innovation index project (Goodridge and Haskel). We thank Dennis Fixler, Shane Greenstein, and participants at the NBER/CRIW Summer 2010 workshop and 2010 CAED for comments. Errors are our own.
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Constructing a Price Deflator for R&D: Calculating the Price of Knowledge Investments as a Residual

“The value of an idea lies in the using of it.”

Thomas Alva Edison

International guidelines (SNA 2008) call for capitalizing R&D in national accounting systems, a welcome move, but one that raises vexing measurement issues. A major issue—perhaps the major issue at this point—is how to construct a price deflator for R&D. Currently there are quite a few candidates: (1) R&D often is equated with knowledge production, and an education deflator could be used. (2) Science policy analysts long have used the GDP deflator to deflate R&D, and national accountants could continue and enrich that practice. (3) National accountants could regard R&D as they regard other “hard to measure” outputs and use an input cost deflator, perhaps adjusted for productivity. (4) Finally, given the development of the R&D marketplace via the licensing of patents and the like, national accountants could obtain a price deflator by dividing revenue in the R&D marketplace by a quantity index of patents or scientists.

This paper sets out a framework that can be used to discuss and evaluate alternative price measures for knowledge investment; the framework is then used to construct a price index for private R&D in the United Kingdom from 1985 to 2005. The model and framework we develop is applicable to commercial knowledge investments more generally (i.e., investments in intangible assets as in Corrado, Hulten, and Sichel 2009, and Marrano, Haskel, and Wallis 2009, Haskel et al. 2009, Corrado and Hulten 2010, among others) and to measuring R&D price indexes for other countries.

The Edison quote above captures the basic notion behind the models and price estimates reported in this paper. We argue the four candidates can be reduced to two basic approaches: one we call the “upstream” approach in that it attempts to model and measure the knowledge production process itself, and the other we call the “downstream” approach that—in the spirit of the Edison quote—infers the price of knowledge investment from the fruits of the innovation process, total factor productivity (TFP).
Innovation arguably is a routine function within business these days (Baumol 2002). For some ongoing, existing firms, the business function devoted to innovation is explicit as the R&D or marketing or development department. In others, the function is less centralized or based on employee time, as in CEO Eric Schmidt’s famous 80/20 rule at Google. For entrepreneurial start-up businesses, almost by definition, high fractions of activity are devoted to innovation, broadly defined. Accordingly, we model aggregate business output as emanating from two sectors: one, the aggregate behavior of business functions devoted to innovation and R&D, and the other, an operations and/or producing sector consisting of all other business functions.

In the first use of the model, we show how the price of the commercially-produced knowledge is related to measured output prices, factor costs, and productivity in the operations sector. We compare and contrast this “downstream” approach to the “upstream” approach typically favored by statistical agencies, and we relate both approaches to the endogenous growth model of Romer (1990) in which markups of self-produced knowledge capital play a critical role. After considering how key aspects of innovation types (e.g., breakthrough vs. incremental innovations) and imperfect competition (e.g., markups) impact the modeling and measurement of output prices for innovation, we conclude such prices are implicitly in measured downstream sector productivity, that is, the value of resources devoted to innovative activity can be inferred from their use in business operations.

Because productivity as conventionally measured includes a contribution from the innovation sector, the second use of our model frames how to tease this contribution out of standard productivity data. Of course, conventional wisdom is that all sustained increases in TFP are due to innovation because of spillover effects. And even though data constrain us to concentrate on estimating a price index for commercial R&D investments (rather than all investments in

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126 Known as the “Pareto principle” in management, this refers to Google’s ITO (Innovation Time Out) policy that employees are encouraged to spend 80 percent of their time on core projects and 20 percent on “innovation” activities that pique their own interests.

127 Business functions are entire classes of activity within a company. See Brown (2008) for further information on the use of business functions as a classification scheme for statistics on business activity.

128 This view has its roots in the production function approach to R&D, in which all productivity growth is related to all expenditures on R&D (Griliches 1979, p. 93). Of course the view ignores the productivity-enhancing effects of public infrastructure, the climate for business formation, and the fact that R&D is not all there is to innovation, but nonetheless the view that TFP reflects the fruits of the business innovation process is acknowledged to be generally more right than wrong. The view is an important element of the approach used to develop an innovation index for the UK (Haskel, et al. 2009).
innovation), we still find that a substantial fraction of observed productivity change in the UK market sector emanates from its conduct of R&D. We obtain this result by exploiting the recursive nature of our model and the heterogeneity in R&D intensity by industry. The result impacts the estimated investment price index for UK R&D, the central estimate of which falls 7.5 percent per year from 1985 to 2005.

Our falling price index reflects both the success of industrial R&D (including spillovers) and the impact of innovations in the R&D process itself. Indeed, available evidence suggests technical progress in the “production of innovation” has been substantial. Consider how computer-enabled combinatorial chemistry has drastically lowered the costs of pharmaceutical experimentation, how computer-aided design has lowered product development times for items such as semiconductors, motor vehicles—even the British Museum’s tessellated glass ceiling—and how the Internet has promoted academic collaboration and productivity (Adams, Black, Clemmons, and Stephan 2005; Ding, Levin, Stephan, and Winkler 2010) and made huge amounts of information available more or less for free.

Why is our finding of a falling price index for R&D of interest? Many advanced industrialized countries are concerned by the stagnation of their nation’s R&D spending in relation to their GDP. But if the real price of R&D relative to GDP is falling, information in nominal terms is a misleading indicator. As we show below, with our new price index, the contribution of R&D to GDP in the UK remains substantial even though nominal R&D spending relative to GDP is flat/falling.

This paper proceeds as follows: In the next section, we set out the model and show how it can be used to infer the unknown price of commercial knowledge investments using two approaches. We then consider a host of theoretical and practical issues that confront the empirical application of each approach, and finally we turn to measurement and conclude.

1. Theoretical Framework

This section sets out a theoretical framework that can be used to discuss and evaluate alternative price measures for commercial knowledge investments such as R&D. We start with a very simple model to show the main arguments of our approach and how it compares with other
methods. We then explore the robustness of the model and approach to relaxing certain assumptions.

1.1 The model

We posit a market economy with two sectors—knowledge-producing and knowledge-using—and three factors of production—labor, capital, and knowledge. The knowledge-producing (or upstream) sector generates new knowledge \(N\) using service flows from labor \(L^N\), capital \(K^N\), and a stock of existing knowledge, denoted \(R^N\).

The stock of existing knowledge is superscripted by \(N\) because the knowledge used in the producing sector is assumed to be different from that in the using (or downstream) sector. Although we elaborate more fully on this assumption below, a simple way of thinking about the distinction is to suppose that the upstream sector uses “basic” or “unfinished” knowledge and transforms it into commercialised or “finished” knowledge. The finished knowledge is then employed in the production of goods and services by the downstream sector. We further assume that all basic knowledge is free, from universities say, and determined outside the model. In a subsequent section we relax some of these assumptions.

The production function for the upstream industry and corresponding accounting equation for factor payments is written as follows:

\[
N_i = F^N(L^N_i, K^N_i, R^N_i, t); \quad P^N_i N_i = P^L_i L^N_i + P^K_i K^N_i
\]

where \(N\) is newly-produced appropriable knowledge and \(P^L\) and \(P^K\) are prices per unit of labor and capital input, respectively. There are no payments to \(R^N\) because its services are free.

The downstream sector produces consumption and investment goods \((Y = C + I)\) by renting service flows of labor \(L^Y\), capital \(K^Y\), and a stock of finished commercial knowledge, denoted \(R^Y\). The stock of finished knowledge is the accumulated output of the upstream sector, which is assumed to grow with the production of \(N\) via the perpetual inventory model:

\[
R_t = N_t + (1 - \delta^N)R_{t-1}
\]
The term $\delta^R$ is the rate of decay of appropriable revenues from the conduct of commercial knowledge production.\(^{129}\)

The production function and flow equations in the downstream sector are

$$Y_t = F^Y (L_t^Y, K_t^Y, R_t^Y, I_t); \quad P_t^Y Y_t = P_t^L L_t^Y + P_t^K K_t^Y + P_t^R R_t^Y$$ \hspace{1cm} (18)

where $P_t^R$ is the price of renting a unit of the finished knowledge stock (e.g., a license fee for a patent or blueprint). The relationship between $P_t^N$, the price of a unit of newly-produced finished knowledge (an investment or asset price) and the price of renting a unit of the same knowledge is given by the user cost relation

$$P_t^R = P_t^N (\rho_t^N + \delta^R)$$ \hspace{1cm} (19)

where $\rho_t^N$ is the real rate of return in sector $N$ and taxes are ignored. Recalling that sector $Y$ includes the production of investment goods $I$, equations similar to (2) and (4) for tangible capital but expressed in terms of $K_t^Y, I_t, \rho_t^Y, \delta_t^K, P_t^K$ and $P_t^I$ (instead of $R_t^Y, N_t, \delta_t^R, P_t^R$ and $P_t^N$) complete the model.

We are now in a position to understand two broad approaches, upstream and downstream, to modelling R&D prices. Log differentiation of the income flow equations and dropping time subscripts gives the following price duals:

$$\Delta \ln P^N = s_N^K \Delta \ln P^K + s_N^L \Delta \ln P^L - \Delta \ln TFP^N$$ \hspace{1cm} (20)

$$\Delta \ln P^Y = s_Y^K \Delta \ln P^K + s_Y^L \Delta \ln P^L + s_Y^R \Delta \ln P^R - \Delta \ln TFP^Y$$ \hspace{1cm} (21)

The “s” terms are factor income shares for labor, capital, and knowledge calculated for each sector in the usual way from equations (1) and (3), respectively. The terms $\Delta \ln TFP^N$ and $\Delta \ln TFP^Y$ are the change in total factor productivity for each sector, i.e., the shift in each sector’s production function. The interpretation of the sector productivities and their relationship to aggregate productivity for the economy as a whole is discussed in a subsequent section.

\(^{129}\) This concept of depreciation was introduced and applied to private R&D by Pakes and Schankerman (1984).
1.2 Upstream method: data from the R&D-performing sector

Consider equation (20). Most statistical agencies have survey data on the R&D business function of R&D-performing firms; thus, existing surveys give us information on the first two terms in equation (20). But equation (20) also shows that productivity in the R&D sector $\Delta \ln TFP^V$ is needed to estimate prices for R&D, and information on this quantity is very scant indeed.

Economists long have studied the impact of R&D on productivity, but quantitative studies of productivity in the R&D process itself are fairly rare. Studies of the impact of the Internet were mentioned previously. Agrawal and Gort (2001) show that product development times shortened steadily from 1887 to 1985, suggesting improvements in R&D productivity are somewhat of a norm. And Mokyr (2007, p. 1154) states “In the past, the practical difficulty of solving differential equations limited the application of theoretical models to engineering. A clever physicist, it has been said, is somebody who can rearrange the parameters of an insoluble equation so that it does not have to be solved. Computer simulation can evade that difficulty and help us see relations in the absence of exact closed-form solutions ... In recent years simulation models have been extended to include the effects of chemical compounds on human bodies. Combinatorial chemistry and molecular biology are both equally unimaginable without fast computers.”

The upstream approach is the dominant approach used by statistical agencies.\textsuperscript{130} In its most basic form, the method assumes, in (5), that $\Delta \ln TFP^V = 0$ and uses only share-weighted input costs to measure output price change. This variant has been used by both the UK Office of National Statistics (ONS) and US Bureau of Economic Analysis (BEA) to approach the measurement of R&D prices, e.g. Galindo-Rueda (2007) and one of the approaches reported in Copeland, Medeiros and Robbins (2007).\textsuperscript{131} A more refined variant, referred to in Fixler (2009) as scenario B, assumes a rate of TFP growth that is subtracted from share-weighted change in

\textsuperscript{130} In what follows, we review recent work in statistical agencies; for a review of the earlier literature on R&D deflators, see Cameron (1996). The very recent release of the US BEA/NSF Satellite Account on June 25 is not considered.

\textsuperscript{131} Despite its drawbacks this approach has the advantage of consistency as it is widely used in recent efforts to produce R&D satellite accounts in other countries. The method also is used in areas where no market transaction data exist, such as measurement of own-account software investment in the UK, as well as much of government output and other hard-to-measure areas such as education services in many countries.
input costs, much as in equation (5). Finally, a related approach proposed by Copeland and Fixler (2009) is based on modeling the R&D services industry (US NAICS 5417, UK SIC 73.1); they suggest these “market-based” results can be used to proxy for all (i.e., in-house) private business R&D.  

The Copeland-Fixler price index increases a bit less than overall private R&D input costs and, taken literally, suggests $\Delta \ln TFP^N$ averaged 0.1 percentage point per year from 1987 to 2004. The plausibility of this result and interpretation is discussed below. More fundamentally, the premise of the approach—using the R&D services industry to generate results for all private R&D—requires scrutiny. Some NAICS 5417 industry revenues are for contract research whose character may be inconsistent with the standard definition of R&D. And the establishment-based industry classification may place a nontrivial number of company-owned R&D laboratories in the R&D services industry, in which case industry “revenue” will not be entirely market-based.

Given the development of the R&D marketplace via the sales and licensing of patents, national accountants could strengthen the upstream approach by urging statisticians to collect data on unit sales and license fees for patent and other intellectual property rights (IPRs). But one must note that such observations could correspond to $P^R$, or to $P^N$, or to $(1 - \delta^R)^T P^N$ (the latter when data are for units of $R$ of age $T$ that obsolesce at the rate $\delta^R$ per period), suggesting just some hurdles to be crossed in working with data from the IPR marketplace. Indeed, existing revenue data for the R&D services industry are likely confounded by these same issues.

1.3 Downstream Approach: data from the R&D-using sector

An alternative approach is to consider the downstream or R&D-using sector. Manipulation of equation (21) shows that it can be re-written as:

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132 The Copeland-Fixler approach is to back out price change from changes in the industry’s sales ($S$) less changes in quantities of the industry’s output. If one is willing to assume that the number of workers ($\textit{SCIENTISTS}$) and patents ($Z$) proxy for the quantity of R&D output in NAICS 5417, then their approach, expressed in our notation, is $\Delta \ln P^N = \Delta \ln S_{5417} - .5 \times (\Delta \ln Z_{5417} + \Delta \ln \textit{SCIENTISTS}_{5417})$.

133 As practical matter we also note that the result partly rests on the assumption that output per worker is unchanged over time, an assumption that is difficult to accept for a technology-intensive activity such as R&D. To improve the validity of the Copeland-Fixler approach, it may be worthwhile adjusting the number of workers for changes in composition (or “quality”) via marginal-product weighting.
\[ \Delta \ln P^R = \left( \frac{\Delta \ln P^Y - s_i^P \Delta \ln P^K - s_i^L \Delta \ln P^L + \Delta \ln TFP^Y}{s_i^R} \right) \]  

(22)

which says that the unknown \( \Delta \ln P^R \) can be inferred from final-output price changes, net of changes in other input costs and offset by the sector’s TFP. Because we have suppressed the dynamics that give rise to differences in the time paths of \( P^N \) and \( P^R \), the unknown \( \Delta \ln P^N \) will be equal to \( \Delta \ln P^R \) given constancy of \( \rho^R \) and \( \delta^R \).

In practice, we have many R&D-using industries. If R&D were a homogeneous good, the price from any one of them will do or one might combine prices from a number of downstream industries together to give a “grand” index, \( \Delta \ln P^{R*} \), a weighted average of R&D rental prices across those industries

\[ \Delta \ln P^{R*} = \sum_{i=1}^{J} \omega_i \left( \frac{\Delta \ln P^{iY} - s_i^P \Delta \ln P^{iK} - s_i^L \Delta \ln P^{iL} + \Delta \ln TFP^{iY}}{s_i^R} \right) \]  

(23)

where there are \( J \) R&D-using industries; each industry is indexed by \( i \); and \( \omega_i \) is a weight to be determined.

In its most general form, the downstream approach infers R&D prices from output prices (such as GDP prices) and is the most common approach used in analyzing R&D data for science policy analysis. It is a method that follows the Edison logic. Moreover, a specific approach in Copeland, Medeiros, and Robbins (2007) is an even closer cousin of equation (23) than the GDP deflator. This is the BEA price index for R&D used in their R&D satellite account; it is calculated as the weighted aggregate

\[ \Delta \ln P^{N} = \sum \omega_j \Delta \ln P^{jY} \]  

(24)

across the most intensive R&D-using sectors with \( \omega_j \) the \( j \)th industry’s share of total R&D investment. Equation (23) shows, however, that science-policy analysts and Copeland, Medeiros, and Robbins (2007) ignore the denominator and implicitly assume changes in the downstream sector’s share-weighted factor prices and productivity net to zero.

The downstream approach requires information on the sector’s productivity change, \( \Delta \ln TFP^Y \). This will differ from the usual productivity measure because services from the stock of
commercial knowledge are modelled as an input to the economy’s core operations. This service flow can be thought of as a Hicksian shift in the sector’s standard labor/capital production function for the period during which each unit of knowledge remains commercially viable. While a host of factors determine the size of this effect (and some will be discussed in the next section), what matters in this model is that returns to appropriable inventive activity are allocated to the upstream sector.

In terms of the salient drivers established in the productivity literature, our model views the distinction between the sectoral productivities as follows: Upstream productivity includes the appropriated returns to R&D, spillovers from public R&D, and the efficacy of the overall R&D process, whereas downstream productivity includes spillovers from freely available commercial knowledge (i.e., diffusion), as well as phenomena we associate with operations efficiency (e.g., economies of scale and services delivery improvements, etc.) that is unrelated to R&D.

2. Theoretical issues
This paper uses the downstream method. The simple model of the previous section has been designed to set out the broad intuition of the approach and illustrate its relation to other recent work. To carry on with the application requires reviewing a number of practical theoretical issues to which we now turn.

2.1. Use of knowledge in each sector
How robust is our assumption that the $N$ sector uses free “unfinished” or basic knowledge, $R^N$, and the $Y$ sector rents “finished” knowledge, $R^Y$? A number of points are worth making. First, of course, if the final-output sector also uses free unfinished knowledge (that is, in addition to renting of finished knowledge produced by the $N$ sector), nothing changes. The contribution of the free part of knowledge to production in the downstream sector shows up in $\Delta \ln TFP^Y$.

Second, one might extend the model and assume that the $N$ sector also uses “finished” knowledge, as an input for example into producing more finished knowledge. But then the problem arises of how to define the total stock of finished knowledge when both sectors draw from it. We cannot define each sector as renting from the entire pool of knowledge, because then we would implicitly be allowing the same knowledge to be “rented twice” which results in an overstatement. Although some studies suggest very large private returns to R&D, still others
suggest little more than competitive returns when consideration also is given to measuring the rate of decline in the value of the underlying R&D asset, i.e., the rate of depreciation in (2).

We have already assumed that knowledge is partially nonrival. A useful direction at this point therefore is to think about how we pay, for example, for Microsoft Office and how we might distinguish between knowledge in “platforms” and in “versions,” a form of the breakthrough versus incremental distinction in innovation analysis. Suppose the \( N \) sector uses a large quantity of resources to produce a knowledge platform from which it supplies versions to the \( Y \) sector every year (e.g., Microsoft creates Word and then leases Word 2003 version 1, version 2, etc. each year). In this case, the one-year leasing of a version does not generate any lasting asset held in the \( Y \) sector and so these payments are intermediates (just as payments by a cinema owner who rents a film to show for a month are treated as intermediates rather than rentals to the knowledge capital in the film industry).

But this does not necessarily mean that there is no stock of appropriable knowledge, or that there are just intermediate payments that net out. Rather we can think of the upstream sector as retaining ownership of the knowledge asset in its “inventory” or “product platform portfolio.” As an asset, the platform both earns a return (say at the rate \( \rho^R P^N \) per unit of \( R \) each period, equivalent to the value each unit adds to current production) plus it generates a flow of income via payments by the downstream sector for rentals of each version. If the version rentals are at the rate \( \delta^R P^N \) per unit of \( R \) (that is less than the full rental value of the stock of \( R \) ), then the knowledge asset is not being “rented twice” and the aggregate payment to \( R \) remains as given by equation (19). This argument could be made more formal, but the logic is simple: The \( N \) sector must implicitly pay something (to itself) to rent the knowledge in its platform in order to have the resources to create version after version. Equivalently, the \( N \) sector cannot charge the full rental equivalence suggested by (4) for versions because the full knowledge capital inheres in the platform, and only partially in the versions.

### 2.2 Market power in the upstream sector

This issue was considered by Romer (1990), who assumed innovators practiced monopoly pricing. Our model is similar to his: he has three sectors. The ideas sector uses all knowledge in
the economy freely as an input into ideas. Those ideas are then converted by the design sector into blueprints, knowledge which is appropriable and sold at a monopoly price to the production sector that uses blueprints as an intermediate good. Thus in our model it is the upstream, or innovation/R&D sector that can be thought of as the design sector who produces blueprints; in our language, they produce finished ideas that can be used in the output sector. Thus designs are rival and appropriable (at least for a time), and they are sold at the monopoly price to the production sector. Romer notes the “design” sector can of course be in-house.

Copeland and Fixler (2009) also state that uncertainty and market power are endemic in the research sector, by which they mean that although there is a correlation between the output and input prices of R&D, this relationship is highly non-linear and it is not possible to establish a linear approximation of R&D prices using input costs (see their Appendix B). As a concrete example, Copeland and Fixler follow Romer and model the innovator as a monopolistic competitor with respect to other innovators, which suggests the output price is above marginal production cost. In Romer the innovator’s price is given by \( P = \gamma MC \), where \( MC \) is the marginal cost of producing a new good and \( \gamma \) is the markup, a function of the good’s price elasticity of demand (Romer 1990, un-numbered equations at the top of page S87).

Romer goes on to formulate the intertemporal zero-profit constraint, whose solution equates the instantaneous excess of revenue over marginal production cost as just sufficient to cover the interest cost of the innovation investment (equations 6 and 6', page S87). How does this result relate to the framework in this paper? Let us follow Romer and assume that product market power is located in the upstream sector.\(^{134}\) In other words, the downstream sector, which uses the innovation, is competitive while the upstream sector, which produces the innovation, is a (temporary) monopolist. Under these assumptions, in our model, downstream producers are price-takers for knowledge.

If downstream marginal production costs are expressed as competitive payments to the usual factors of production \( L' \) and \( K' \), then final output prices are indeed marked up over such costs—but not necessarily because of imperfect competition. Denoting the competitive factor costs of

\(^{134}\) The same assumption is made in Aghion and Howitt (2007), among others.
core operations as $CF^Y$, then the producer markup in our model is expressed as $P^Y = \gamma CF^Y$, with the markup given by

$$\gamma = \frac{1}{1 - s^R_y}.$$  \hspace{1em} (25)

In this way, section 1’s expressions for downstream factor payments (18) and price dual (21) still hold. To see this, we move from the producer markup relation given by (25) to the downstream factor payments identity as follows:

$$P^Y Y = \gamma CF^Y$$

$$= CF^Y + P^R R^Y$$

$$= P^L L^Y + P^K K^Y + P^R R^Y.$$  \hspace{1em} (26)

This result establishes consistency of our framework with models of imperfect competition with producer markups and intertemporal zero profits, e.g., the equilibrium model of Rotemberg and Woodford (1995). Moreover, even if the knowledge price faced by the downstream sector is not the competitive price, as long as the downstream sector is a price-taker, the dual price equation for the downstream sector, which is what the downstream method relies upon, can still be written as equation (21).

If the price of knowledge faced by the downstream sector is not the competitive price due to imperfect competition in the upstream sector (innovator markups), the factor shares in that sector will be biased measures of output elasticities in which case measured $\Delta \ln TFP^N$ as conventionally calculated is a biased measure of “true” technical progress (e.g., see Hulten 2009). The implausibly small average annual percent change in $\Delta \ln TFP^N$ implied by the Copeland-Fixler upstream approach as calculated (conventionally) and reported in section 1.2 of the paper is therefore theoretically invalid in the presence of innovator markups, as Copeland and Fixler themselves would and do argue. By contrast, as we show below, the downstream approach yields a measure of $\Delta \ln TFP^N$ even in the presence of innovator markups.

**2.3 Market power in the downstream sector**

Suppose there is market power in the downstream sector as well. Recalling that $\Delta \ln TFP^\gamma$ represents the contribution of knowledge that is freely available to all competitors, a shorthand for considering imperfect competition is to modify this term in equation (21). As written, changes in TFP pass through one-for-one to changes in output prices. If factor prices are
exogenous, this is consistent with a competitive model of process innovations whereby any process innovator immediately lowers her output prices to undercut rivals, and the competitive equilibrium is that all such TFP changes are passed through 100 percent.

A simple way to represent imperfect competition in the downstream industry is to pre-multiply $\Delta \ln TFP^y$ by $(1 - \zeta)$, where $\zeta = 0$ is perfect competition (100% pass through) and $\zeta > 0$ indicates monopoly power. That is, we write:

$$\Delta \ln P^R = \left( \frac{\Delta \ln P^y - s^K \Delta \ln P^K - s^L \Delta \ln P^L + (1 - \zeta) \Delta \ln TFP^y}{s^R} \right)$$

(27)

to incorporate the impact of imperfect competition in the downstream industry. A monopolistic downstream industry with significant barriers to entry would have $\zeta = 1$ in which downstream R&D monopolist users appropriate all returns to process R&D (productivity gains) via pricing power.

In our discussion of equation (23) in section 1.3, we indicated that BEA has made use of a downstream method, but that an implicit assumption that factor costs and TFP net to zero was made via calculating an R&D price index as equation (24). Equation (27) suggests another way of thinking about the BEA index, namely, that the implicit netting may also reflect an implicit assumption about the degree of downstream monopoly power.

2.4 Product quality

Upstream production also leads to product-quality innovation in the downstream sector. If final output prices are not quality-adjusted, the true model written in terms of the quality-adjusted price, $\Delta \ln P^{y*}$, is as follows:

$$\Delta \ln P^R = \frac{1}{s^R} (\Delta \ln P^y - s^K \Delta \ln P^K - s^L \Delta \ln P^L + \Delta \ln TFP^{y*}) - \frac{1}{s^R} (\Delta \ln P^y - \Delta \ln P^{y*})$$

(28)

where true productivity change $\Delta \ln TFP^{y*}$ has been calculated using quality-adjusted prices. Equation (28) suggests that if quality is improving, $\Delta \ln P^y > \Delta \ln P^{y*}$ and a negative bias may be imparted to estimates of $\Delta \ln P^R$. 

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But the exact bias also depends the relationship between $\Delta \ln TFP^x$ and $\Delta \ln TFP^y$. In the Hulten (2009) steady-state quality ladder model,

$$\Delta \ln TFP^x = \Delta \ln TFP^y + (\Delta \ln P^y - \Delta \ln P^x). \tag{29}$$

Equation (29) says that the measurement error from not quality-adjusting $\Delta \ln P^y$ (and hence mis-measuring $\Delta \ln TFP^x$) cancels out, rendering $\Delta \ln P^y$ an unbiased steady-state measure even with unobserved product quality improvement.

### 2.5 Sector productivities and markups in the steady state

The foregoing places imperfect competition in the upstream sector. We now explore the relationship between the relative value of resources devoted to innovation—the innovation intensity $s^N_Y$—and the sector productivities $TFP^N$ and $TFP^Y$ in the presence of upstream markups.

Let the innovator markup over (competitive) upstream factor costs be given by $\mu \geq 1$.

Continuing with the simplified notation of 2.2, the value of upstream output then becomes

$$P^N N = \mu CF^N \tag{30}$$

where $CF^N$ is the cost of the conduct of innovation/R&D in terms of the standard factors of production (labor and tangible capital) at competitive factor prices ($CF^N = P^L L^N + P^K K^N$). Changes in the price and quantity elements of $CF^N$ are the share-weighted terms of section 1, denoted here as $\Delta \ln C^N$ and $\Delta \ln F^N$ respectively.\(^{135}\) Upstream productivity is then given by:

$$\Delta \ln TFP^N = \Delta \ln N - \mu \Delta \ln F^N \tag{31}$$

and downstream sector productivity is given by

$$\Delta \ln TFP^Y = \Delta \ln Y - (1 - s^R_Y) \Delta \ln F^Y - s^R_Y \Delta \ln R^Y. \tag{32}$$

The upstream price dual now becomes

$$\Delta \ln P^N = \mu \Delta \ln C^N - TFP^N \tag{33}$$

while the downstream sector’s factor payments and price dual remain as given in section 1.

\(^{135}\) The similarly defined magnitudes for the final output sector and the total economy are $CF^Y$, $\Delta \ln C^Y$, $\Delta \ln F^Y$ and $CF$, $\Delta \ln C$, $\Delta \ln F$, respectively, where $\Delta \ln F = (1 - s^R_Y) \Delta \ln F^Y + s^R_Y \Delta \ln F^N$, and so on.
How do innovator markups and sector productivities relate to (a) our previous discussion of the Romer model, (b) the literature on intangible capital that would include R&D co-investments in $P/N$, and (c) actual measured productivity growth in an economy? First, equation (32) follows from our earlier argument that treating inputs to innovation as investment produces a Romer-style framework in which revenue from the production of final output must be sufficient to cover the “interest costs” of innovation. These costs subtract from productivity as per equation (32) because they are, in fact, forgone final output.

Second, theoretical models that incorporate markups usually follow Romer and impose intertemporal zero profits by setting the markup to one in steady-state equilibrium (e.g., Rotemberg and Woodford 1995). The structure of our model also is consistent with using the parameter $\mu$ to incorporate the cost of commercializing R&D outcomes as a simple multiple of R&D (e.g., the intangible “complementary” capital in Basu et al. 2004), in which case temporal zero profits is imposed while $\mu$ is most assuredly not equal to one.\textsuperscript{136}

Finally, following standard practice, measured productivity growth $\Delta \ln TFP^{\text{measured}}$ is given by the difference between the growth rate of final output, $\Delta \ln Y$, and the growth of measured share-weighted total factor inputs (that is, including the inputs used in the innovation sector), denoted as $\Delta \ln F^{\text{measured}}$. This quantity exceeds the competitive quantity $\Delta \ln F$ in the presence of innovator markups because some of the increment to revenue is used to cover markups. We denote the real value of this increment by $\Pi$, in which case the foregone growth in final output associated with markups on the conduct of R&D is written:

$$\Delta \ln TFP^{\text{measured}} = \Delta \ln Y - \Delta \ln F^{\text{measured}} = \Delta \ln Y - \Delta \ln F - \Pi$$

Thus $\Pi$ must be added to the change in (upstream) factor inputs valued at competitive factor prices to capture the full costs of the R&D “overhead” borne by the downstream sector.

\textsuperscript{136} A rationale for this interpretation is that the R&D data only cover costs of pursuing new scientific and engineering knowledge, and a “successful” R&D outcome (a patent, say) does not necessarily imply immediate business viability, much less costless implementation. Many new product development costs are not captured in the available R&D data because they are associated with activities considered to lack sufficient experimentation to be classified as R&D but are nonetheless an inseparable aspect of the “value” of R&D.
Under steady-state conditions the growth rate of a capital stock is well approximated by the growth rate of real investment (Griliches 1980). Let \( g \) be such a growth rate for real R&D investment and its stock. As \( g \) approaches the real interest rate \( \rho^N \), the investment share approaches the capital income share (Jorgenson 1966), i.e., we can write \( s^R_Y = \tau s^N_Y \) where \( \tau \) is a discrete-time version of the Griliches (1980) term that converts gross investment to income from accumulated net investments:

\[
\tau = \left[ (\rho^N + \delta^R)(1 + g) \right] / (g + \delta^R)
\]  

(35)

The term is equal to one in the \( \rho^N \approx g \) “maximal consumption” steady state.

Substituting \( \tau s^N_Y \) for \( s^R_Y \) and \( N \) for \( R^Y \) in equation (32) and then expanding the result using equations (31) and (34) yields the following:

\[
\Delta \ln TFP^Y = \Delta \ln Y - (1 - \tau s^N_Y) \Delta \ln F^Y - \tau s^N_Y \Delta \ln N
\]

\[
= \Delta \ln Y - (1 - \tau s^N_Y) \Delta \ln F^Y - \tau s^N_Y \Delta \ln TFP^N - \tau s^N_Y \mu \Delta \ln F^N
\]

\[
= \Delta \ln Y - \Delta \ln F - \tau s^N_Y \Delta \ln TFP^N - \tau s^N_Y (\mu - 1) \Delta \ln F^N
\]

\[
= \Delta \ln TFP^{measured} - \tau s^N_Y \Delta \ln TFP^N
\]

(36)

where \( \Pi = \tau s^N_Y (\mu - 1) \Delta \ln F^N \), which goes to zero as \( \mu \) approaches one.

Rearranging terms in the last line of equation (36) yields

\[
\Delta \ln TFP^{measured} = \Delta \ln TFP^Y + \tau s^N_Y \Delta \ln TFP^N
\]

(37)

which depicts an economy’s measured productivity growth as an (approximate) Domar-weighted average (Domar 1961; Hulten 1978) of the productivities in its innovation and final output sectors. The equation highlights our modelling of the knowledge production process (not just R&D spending) as an augmenter of final output productivity. Augmentation depends on R&D spending and the productivity or “success” of the R&D activity.

3. Measurement

Our approach is as follows: We formulate the empirical growth accounting counterpart to the theoretical model of the previous sections and construct the terms on the right hand side of equation (8) to estimate price change for private R&D. For this we need estimates of input shares and final output productivity that account appropriately for the contribution of R&D to economic growth.
We cannot use the usual growth accounting terms because they are biased. We thus face three central measurement challenges: First, we need estimates of the unobserved final output productivity ($\Delta \ln TFP^Y$). Second, we need values for the unobserved capital income share for innovation assets ($s^R_Y$). Third, we need a value for the innovator markup ($\mu$). These needs are related to available measurements as follows:

$$\Delta \ln TFP^Y = \theta \ast \Delta \ln TFP^{measured}$$

$$s^R_Y = \tau \ast s^N_Y$$

$$= \tau \ast \mu \ast s^N_{measured}$$

(38)

where $s^N_{measured}$ is the R&D intensity calculated using the cost data available from R&D surveys. We further note that values for the parameters $\tau$ and $\mu$ permit calculation of the producer markup in equation (25) as $\gamma = 1/(1 - \tau \ast \mu \ast s^N_{measured})$.\(^{137}\)

### 3.1 Obtaining values for $\theta$, $\tau$, and $\mu$

Equation (37) suggests that the variation in industry-level measured TFP growth rates and R&D intensities can be exploited to decompose measured productivity for an economy into a contribution from its final output sector and a contribution from its innovation sector. In other words, assuming that downstream productivity does not vary with innovation intensity at the industry level, an industry dataset containing gross output-based TFP estimates for multiple industries and corresponding industry counterparts to $s^N_{measured}$ from R&D surveys can be used to run the following regression:

$$\Delta \ln TFP_{measured}^{G,i,t} = a + b \cdot s^N_{measured}^{G,i,t} + e_{i,t}$$

(39)

to determine the value of $\theta$. In this regression, after setting both $\tau$ and $\mu$ to one, the estimated $a$ is an estimate of $\Delta \ln TFP^Y$ and the estimated $b$ is an estimate of $\Delta \ln TFP^N$. Of course, the effects discerned by this regression will be those due to differences in resources allocated to R&D, on average, in the period of estimation. Consequently, the regression is best implemented as a long-run relationship, i.e., as a quest for trends in the two unobservable sector productivities, $\Delta \ln TFP^N$ and $\Delta \ln TFP^Y$.

\(^{137}\) Producer markups so defined are still related to the price elasticity of demand for the underlying goods as in Romer—indeed, our model connects expenditures on innovation to customer demand in this way. This is because when investments in innovation lead to products or brands with a high own-price elasticity of demand (think new Apple products vs. new brands of milk), “market power” and expenses devoted to developing and marketing new products become associated with one another and vice versa.

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A number of implementation issues nonetheless remain. First, estimating $\Delta \ln TFP$ by a constant in a regression with data for multiple industries assumes that $\Delta \ln TFP$ is constant across industries (plus an error). Determining productivity differences across industries is problematic, of course—and a problem well beyond the scope of this paper. Therefore the simple logic of equation (39), that downstream productivity trends are constant across industries, is employed in the productivity decomposition used in this paper.

Second, to capture a long run relationship we might use data averaged over a long period but this gives us rather few observations. An alternative to gain more observations would be to break the data into productivity episodes that, presumably, are roughly equal in terms of productivity growth. There is of course a tension here, because the underlying relationships might be evolving over time, in which case additional controls will be needed to capture the appropriate trends.

Third, the analysis must confront the fact that the conduct of R&D is concentrated in a handful of industries, i.e., that measured R&D must be but one aspect of innovation’s contribution to economic growth. Beyond the presence of R&D co-investments, in many advanced industrialized countries, large services industries (finance, distribution) contribute notably to economic growth but perform very little science-based R&D. Modeling all industries using equation (39) may therefore prove problematic. A related issue is that productivity growth for certain industries is poorly measured and including these observations in the regression may distort its coefficient estimates.

Finally, we need practical values for $\tau$ and $\mu$ to implement the regression. We are willing to use the “maximal consumption” (i.e., $\tau = 1$) steady state assumption because the UK and many other advanced industrialized economies generally have stable industry-level R&D intensities. But using the Romer zero intertemporal innovator profits (i.e., $\mu = 1$) assumption is problematic because productivity episodes do not necessarily correspond to periods of zero innovator profits for industries or sectors.
It is therefore important to consider a very practical reason for setting $\mu$ greater than one, namely, that the parameter places in-house R&D on the same footing with marketed R&D services. The costs of R&D exchanged between R&D establishments classified in a different industry than the parent/owner firm were in fact “marked up” in the US R&D satellite account for this reason (Moylan and Robbins 2007, p.52). A related strategy is to use $\mu$ as a R&D co-investment multiple (see earlier discussion and footnote 13).

Following Moylan/Robbins a markup margin can be obtained using the ratio of net operating surplus to gross output for the miscellaneous professional, scientific, and technical services industry; we estimate this ratio averages about .15 in the United States (implying an average innovator markup of 1.15). Hulten and Hao (2008) studied six multinational pharmaceutical firms and estimated that the “shadow” value of own-produced pharmaceutical R&D was 50 percent greater than its cost (i.e., the innovator markup was 1.5) in the year they studied (2006). They also estimated that the increment to organizational capital was 30 percent of the value of own-produced R&D (i.e., the R&D co-investment multiple is 1.3).

Although the Hulten/Hao results suggest that in some years some industries have large markups, we proceed by applying the same markup to all industries in all years. We therefore use 1.15 as our central estimate for $\mu$—the value needed to put in-house R&D on the same footing with marketed R&D services—but examine results for higher values in light of Hulten/Hao.

### 3.3 A productivity decomposition for the UK

We constructed an industry dataset that integrates gross output-based TFP estimates with R&D performance statistics for 29 UK market sector industries from 1985 to 2005. The major data sources used were EUKLEMS (March 2008) and the ONS R&D survey (BERD). A few of the 29 industries are nonperformers according to BERD and certain others have very low R&D intensities (for further information see the appendix). Accordingly, summary statistics for entire market sector are shown on the first three lines of table 1, followed by statistics excluding the nonperformers, industries in the lowest R&D intensity quartile, and industries with problematic TFP estimates. (The lowest quartile R&D performers are industries with $s_{G,t}^N < .003$).
Line 1 of the table shows the aggregate productivity of the UK market sector, and line 2 reports a simple average of its constituent industry productivities. For all items, statistics for the entire period and for two sub-periods with 1995 as the break year are shown. As may be seen, both aggregate TFP growth and average industry TFP growth decelerates 0.2 percentage points between the two periods. When problematic industry TFP estimates and the lowest quartile of R&D performers are excluded, average industry productivity growth still decelerates (line 4).

Line 3 summarizes the $\mu=1.15$ R&D intensity of market sector industries. This statistic trails downward, as does the more familiar statistic, R&D relative to GDP (not shown) or R&D relative to market sector GVA, shown as a memo item on line 8. When the lowest quartile of

<table>
<thead>
<tr>
<th>Table 1. UK market sector productivity and R&amp;D summary statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All market sector industries:</strong></td>
</tr>
<tr>
<td>1. $\sum_{i=1,J} Domar_i \times \Delta \ln TFP_{G,i}^{measured} \times 100$</td>
</tr>
<tr>
<td>2. $(1/J) \sum_{i=1,J} \Delta \ln TFP_{G,i}^{measured} \times 100$</td>
</tr>
<tr>
<td>3. $(1/J) \sum_{i=1,J} s_{G,i}^N \times 100$</td>
</tr>
<tr>
<td><strong>Excl. lowest R&amp;D quartile and industries with problematic TFP estimates:</strong></td>
</tr>
<tr>
<td>4. $(1/J) \sum_{i=1,J} \Delta \ln TFP_{G,i}^{measured} \times 100$</td>
</tr>
<tr>
<td>5. $(1/J) \sum_{i=1,J} s_{G,i}^N \times 100$</td>
</tr>
<tr>
<td><strong>Memos:</strong></td>
</tr>
<tr>
<td>6. Nominal R&amp;D spending $^4$</td>
</tr>
<tr>
<td>7. Real R&amp;D spending (conventional) $^4,5$</td>
</tr>
<tr>
<td>8. R&amp;D spending/GVA ($s_{Y}^{N,measured}$) $^5$</td>
</tr>
</tbody>
</table>

Notes — TFP growth rates are calculated using the dual approach. R&D performed in the R&D services industry is allocated to purchasing industries, and aggregation is over 29 market sector industries excluding the R&D services industry. See the appendix for further details and list of market sector industries used.

1. The Domar weight is calculated as industry gross output relative to value added.
2. Average R&D intensity of industries with $\mu=1.15$.
3. Problematic TFP exclusions are computer and software services in the first period and post and telecommunications in both periods.
4. Growth rate calculated using log differences.
5. Deflated using the GDP deflator.
6. GVA for the market sector is used.

R&D performers and nonperformers are excluded, however, the average R&D intensity of industries trends up (line 5). Underlying this divergence is the fact that value added in major R&D-performing industries is falling as a share of total GDP. While this suggests conventional GDP-based science policy benchmarks for R&D are somewhat ill focused, more relevant to this study is the fact that the conventional real R&D spending measure—shown on line 7—grows rather slowly (under 2 percent per year).

To estimate equation (39) we use the data in two cross-sections corresponding to the sub-periods in table 1. The upper panel of figure 1 shows a scatter plot of the 52 $\mu=1.15$ data points that we have available for estimating the regression coefficients. As may be seen, there are notable outliers, and a regression using all of these data points lacks robustness. Nonetheless, the figure confirms that the conduct of UK R&D is concentrated in a handful of industry sectors. It also suggests an underlying linear relationship between total factor productivity and R&D intensity.

The bottom panel of figure 1 shows a plot of the 34 data points that we have after excluding outliers and the bottom quartile of R&D performers. As may be seen the exclusion of the latter mainly reduces the mass (rather than the dispersion) of the data points at low R&D intensities while exclusion of the former appears to sharpen the underlying relationship. The bottom panel also distinguishes pre- and post-1995 data points and shows that the lower average industry productivity growth in the post-1995 period appears in industries with very high R&D shares.

Using the dataset plotted in the lower panel, we experimented with estimation technique (fixed versus random effects, OLS versus robust methods) and all methods yielded identical estimates of $a$ and $b$. We also explored weighted LS (with Domar weights reflecting each industry’s contribution to overall productivity) and found it lacked robustness. We then examined the sensitivity of the regression’s estimates of $\theta$ on the value assumed for the innovator markup and tested whether the estimates were stable across sub-periods.

The central findings are set out in table 2. Estimation is by random effects with robust standard errors. Results are unweighted and most coefficients are estimated precisely. Column 1 and
column 2 differ only according to the value for $\mu$ used to calculate the innovation intensity. As may be seen, the value for $\mu$ affects the estimated coefficient on the innovation intensity (the estimate of upstream productivity) while the estimated constant term is unaffected. In fact, the column 2 coefficient on $s_{G,j}^N$ is 15 percent smaller than the column 1 coefficient because the observations are precisely 15 percent larger by construction. This suggests that estimates of $\theta$
Table 2. Decomposition of UK productivity change, 1985 to 2005

<table>
<thead>
<tr>
<th>Dependent variable: ( \Delta \ln TFP_{Gi}^{measured} )</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent variables</strong></td>
<td>( \mu=1.00 )</td>
<td>( \mu=1.15 )</td>
<td>( \mu=1.15 )</td>
<td>( \mu=1.15 )</td>
<td>( \mu=1.15 )</td>
</tr>
<tr>
<td>Constant</td>
<td>.0091***</td>
<td>.0091***</td>
<td>.0107***</td>
<td>.0089***</td>
<td>.0080***</td>
</tr>
<tr>
<td></td>
<td>(.0017)</td>
<td>(.0017)</td>
<td>(.0019)</td>
<td>(.0015)</td>
<td>(.0019)</td>
</tr>
<tr>
<td>( s_{G,i} )</td>
<td>.1431***</td>
<td>.1244***</td>
<td>.1318***</td>
<td>.2258***</td>
<td>.2423***</td>
</tr>
<tr>
<td></td>
<td>(.0505)</td>
<td>(.0439)</td>
<td>(.0482)</td>
<td>(.0482)</td>
<td>(.0544)</td>
</tr>
<tr>
<td>1995-2005 dummy</td>
<td>--</td>
<td>--</td>
<td>-.0040*</td>
<td>--</td>
<td>.0002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(.0023)</td>
<td></td>
<td>(.0030)</td>
</tr>
<tr>
<td>( s_{G,i} ) * 1995 – 2005 dummy</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>-.1852***</td>
<td>-.2222***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(.0541)</td>
<td>(.0771)</td>
</tr>
</tbody>
</table>

**Memos:**

\( \theta \) | .73 | .73 | .70 | .71 | .76 |
| \( \theta_1 \) (1985 - 1995) | .77 | .63 | .57 |
| \( \theta_2 \) (1995 - 2005) | .63 | .83 | .94 |

Note--Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
3.4 Calculating price indexes for R&D

With key parameters specified, we are very close to taking equation (8) to the data. We still need the weights \( \omega_i \) to be applied to each industry’s estimated price change in the overall price index for R&D—recall that they were left unspecified in section 2—and we need to develop an approach to computation. Dividing by very small industry-level \( s_{G,i,j}^R \) terms as per equation (8) is not viable, and most integrated R&D/productivity datasets will have many such terms.

We proceed as follows:

We first calculate the numerator of equation (8) for each industry as

\[
\Delta \ln P_{G,i}^{GO} - (1 - s_{G,i,j}^R) \Delta \ln C_{G,i,t}^{measured} + \theta \Delta \ln TFP_{G,i,t}^{measured}
\]

(40)

where \( \Delta \ln P_{G,i}^{GO} \) is the change in the downstream industry’s final output price (its gross output price) and \( \Delta \ln C_{G,i,t}^{measured} \) is the change in its share-weighted input costs (labor, capital, and materials).\(^{138}\) Ignoring time subscripts, for each industry, equation (40) gives \( s_{G,i,t}^R \Delta \ln P_i^R \), i.e., the contribution of the change in R&D asset rental prices to the change in industry \( i \)'s final output price. The overall contribution of the change knowledge asset prices to final output prices is obtained by aggregating these industry-level contributions using Domar weights.

We approximate Domar weights by the ratio of industry gross output \( (GO_i) \) to sector value added \( (GVA_s) \). The sum of the industry-level contributions is then given by:

\[
s_i^R \Delta \ln P^R = \sum_{i=1}^{J} \frac{GO_i}{GVA_s} \cdot s_{G,i}^R \Delta \ln P_i^R
\]

(41)

where \( s_i^R \) is the aggregate knowledge capital income share. From (38) \( s_i^R \) is given by—and calculated as:

\[
s_i^R = \tau P^N \cdot GVA_s.
\]

(42)

The division of equation (41) by equation (42) yields an expression for aggregate R&D price change. The result also reveals three features of the downstream approach. The first concerns its computation. Namely, the change in the R&D asset price can be computed as follows:

\[
\Delta \ln P^R = \sum_{i=1}^{J} \frac{GO_i}{\tau P^N} \cdot s_{G,i}^R \Delta \ln P_i^R
\]

(43)

i.e., by weighting each industry’s contribution by industry gross output relative to aggregate R&D capital income. This does not involve division by very small industry R&D intensities.

\(^{138}\) The source for these items of data is the March 2008 version of the UK EUKLEMS dataset.
The second is that the final price index calculated on the basis of (43) does not depend on assumptions for \( \tau \). Substitution from (38) yields the equivalent expression,

\[
\Delta \ln P^R = \sum_{i=1,j} \frac{GO_i}{PN_i} s^N_{i,j} \Delta \ln P^R_i
\]

which does not involve the parameter \( \tau \). Although this \( \tau \)-independence result will not hold when industry-specific values for \( \tau \) apply, it nonetheless suggests that pinning down \( \tau \) is not a first order concern when using the downstream approach to construct a price index for R&D.

Finally, a third feature is that further simplification (substitution of \( P^N N_i/GO_i \) for \( s^N_{i,G} \)) reveals that the implicit weight applied to each industry’s R&D asset price is the industry’s share of total R&D investment, or \( P^N N_i/P^N N \). Therefore, when equation (44) is used to calculate a price index for R&D, the result is formulaically equivalent to equation (8) where the \( \omega_i \) weights are each industry’s share of total private R&D. (This result thus substantiates BEA’s choice of weights for its “output-based” R&D price index.)

The results of proceeding with the above computations are shown in table 3. The first two columns are benchmarks that correspond to two common national accounting practices. The first is to assume R&D productivity shows no change. This produces the national accountants’ “input-cost” price index, and as may be seen in column 1, it increases 4.0 percent per year. This is a faster rate of increase than the 3.5 percent per year change in the UK GDP price index.

The second column shows the result of assuming R&D productivity is identical to operational productivity, akin to national accountants substituting average measured productivity in market services for “hard-to-measure” or nonmarket services, such as R&D. This implies there are neither spillovers from public R&D nor private appropriated returns to investments in product
Table 3. R&D price change under alternative assumptions for R&D productivity change (ΔlnTFP^v).

<table>
<thead>
<tr>
<th>Period</th>
<th>0 [θ = 1]</th>
<th>ΔlnTFP^v [1/(1 + s_{i,G}^B)]</th>
<th>Estimated [θ = θ]</th>
<th>Estimated [θ = θ_1, θ_2]</th>
<th>Memos:</th>
<th>Column (3) with μ = 1.3</th>
<th>R&amp;D weighted output price change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 1985-1995</td>
<td>6.0</td>
<td>4.2</td>
<td>-9.2</td>
<td>-14.7</td>
<td></td>
<td>-8.4</td>
<td>3.6</td>
</tr>
<tr>
<td>2. 1995-2005</td>
<td>2.0</td>
<td>.8</td>
<td>-5.8</td>
<td>-3.0</td>
<td></td>
<td>-5.5</td>
<td>.7</td>
</tr>
<tr>
<td>3. 1985-2005</td>
<td>4.0</td>
<td>2.5</td>
<td>-7.5</td>
<td>-8.8</td>
<td></td>
<td>-7.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Notes—Recall θ = ΔlnTFP^v / ΔlnTFP^measured and ΔlnTFP^v is downstream productivity change. Columns (1) through (4) use μ = 1.15.

1. Industries with problematic TFP estimates as well as those in the lower R&D quartile use ΔlnTFP^v = ΔlnTFP^v.
2. The estimated θ̂ is from column 2 of table 2.
3. The estimated θ_1, θ_2 are from column 4 of table 2.
and process innovation. In this scenario, the R&D price index increases 2-1/2 percent per year, less than the input-cost index and similar to the BEA-style R&D weighted output price index shown in column 6.

Columns 3 and 4 show the results of using our estimated values for R&D productivity (from regressions shown in columns 2 and 4 of table 2, respectively). As may be seen, the impact of attributing returns to the conduct of R&D is substantial. The price indexes in columns 3 and 4 fall 7.5 percent and 8.8 percent per year, respectively. The results for sub-periods are very sensitive to the shift in the assumed value for theta, however, suggesting that the assumed value for theta is of first order importance to determining the magnitude of R&D price change. By contrast, the results in column 5—where the innovator margin is doubled—suggest rather less sensitivity to this parameter.

In interpreting the estimates shown in columns 3 and 4, note that the overall assumed fraction of measured productivity growth attributed to the conduct of R&D reflects more than the assumption for \( \theta \) that is applied to the upper three quartiles of R&D performing industries. The overall fraction also reflects the \( \ln \ln (\text{TFP}) = \ln \ln (\text{TFP})^r \) assumption used for the lower quartile (and nonperformers and industries with problematic TFP measures). For example, when .73 is used to decompose productivity change for the major performers, the value for theta averaged over all industries, \( \bar{\theta} \) (unweighted), is .84—implying that the conduct of R&D accounted for 16 percent (not 27 percent) of average industry TFP growth in the UK during the 1985 to 2005 period.

In keeping with our earlier caution against using the literal results of the break-adjusted productivity estimates, our preferred results from table 3 are those in column 3. The annual changes in this index are plotted in the upper panel of figure 2, along with components of its price dual (price change = cost change - productivity change), where the cost change are the input-cost data and productivity is a residual and includes the markup. The resulting real growth rate of R&D spending is shown in the bottom panel of figure 2; it grows 15.6 percent per year in the first period, 9.9 percent in the second, and 12.7 percent per year overall.
The results shown in figure 2 are the central results of this paper. Their sensitivity to the decomposition parameter \( \theta \) is illustrated in table 4. The table shows changes in the R&D price index \((P^N)\), the real growth of R&D \((\Delta \ln N \text{ or } g)\), and the associated \( \bar{\theta} \) for all industries according to a range of values for \( \theta \) for industries with \( s_{G,i}^N > .003 \). All estimates in table 4 imply faster growth of real R&D (line 3) than conventional estimates based on the GDP deflator (table 1, line 7).

<table>
<thead>
<tr>
<th>Table 4. UK R&amp;D price change for a range of values of ( \theta ), 1985-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ( \theta ) if ( s_{G,i}^N &gt; .003 )</td>
</tr>
<tr>
<td>2. ( \Delta \ln P^N )</td>
</tr>
<tr>
<td>3. ( \Delta \ln N \text{ (or } g) )</td>
</tr>
<tr>
<td>4. ( \bar{\theta} ), all industries</td>
</tr>
</tbody>
</table>

Note—Figures are calculated assuming \( \mu = 1.15 \), \( \tau = 1 \). The variation in \( \theta \) applies to productivity of major R&D performers only.

Applying the approximation, \( g \approx \rho^N \), the table’s values for real investment growth also are seen as suggestive of the range for the rates of return to R&D that inhere in our price estimates. It is difficult to say how our real investment growth rates line up with the results in the literature that estimates a rate of return to R&D because that literature is not at all definitive—indeed, it has produced results for the UK that range from 10 to 70 percent (Hall, Marisse, and Mohen 2009). From this perspective, the range of the estimates shown in table 4 is relatively narrow and our central estimate appears rather reasonable.

\[ 139 \] Indeed one might ask how the estimates in tables 3 and 4 relate to the literature on returns to R&D as most recently surveyed in Hall, Mairesse, and Mohen (2009), hereafter HMM. This literature runs a regression similar to ours. HMM point out that a regression for estimating the rate of return to R&D must use an “adjusted TFP” that has been calculated after subtracting R&D factor inputs. Productivity growth so calculated equals \( s_{Y}^P \Delta \ln K^P \) in our notation, and regressing it on \( s_{Y}^P \) yields a coefficient that is related to the rate of return to R&D, namely, \( g[(\rho^N + \delta^P)(1+g)]/(g+\delta^P) \). (Due to the presence of a discrete time term in \( 1+g \), this is not quite what HMM obtain in equation (5) of their paper but our derivation is similar.) Substituting our expression for \( \tau \), the rate-of-return-approach regression is seen to yield a coefficient on \( s_{Y}^P \) that equals \( gt \), which approaches \( \rho^N \) as \( t \) approaches one.
3.7 Implications

We now turn to gauging the importance of our new index for productivity and the contribution of R&D capital deepening to the growth in output per hour.

As depicted so far, the measured economy does not capitalize investments in innovation and track knowledge capital as a macroeconomic statistic. When national accountants move to recognize R&D spending as investment, in our simple model (a closed economy, now with no intermediates) both aggregate final demand and aggregate industry value added \( Q \) will include the innovation sector and GDP becomes the sum of each sector’s output \( Q = Y + N \). In this situation, aggregate productivity is given by

\[
\Delta \ln TFP^Q = (1 - s^N_Q) \Delta \ln TFP^Y + s^N_Q \Delta \ln TFP^N
\]

(44)

where \( s^N_Q = P^Y N / (P^Y Y + P^N N) \). As may be seen, this differs only slightly from the expression derived for productivity growth without capitalization, equation (37).\(^{140}\)

The conceptual basis for the similarity in TFP growth before and after capitalization of R&D is, in fact, the premise of this paper—that the impact of the conduct of R&D on productivity is already in measured productivity. By contrast, the capitalization of R&D should produce visible changes in the growth of real output and real output per hour because real GDP will now include a component that is growing 12.5 percent per year.

These propositions are illustrated in table 5, which shows the growth in UK output per hour and TFP before and after capitalization of R&D. As may be seen little or no effect is discerned on TFP growth (line 2b) whereas the growth of output per hour is noticeably affected (line 1b). Moreover, the bulk of the impact on output per hour stems from the R&D deflator (line 1c), not from the addition of new nominal investment to GDP. Finally, as shown on line 3, with our downstream deflator, estimated real stocks of R&D assets grow rapidly, especially from 1985 to

\(^{140}\) The new trend in measured TFP change should be slightly lower than the rate prior to R&D capitalization because, arithmetically, the first component in equation (44) vs. equation (37) is smaller by \( s^N_Q \Delta \ln TFP^Y \) (two small numbers multiplied by each other) and the second component has a slightly smaller weight (i.e., \( s^N_Q < s^N_Y \)).
Table 5. Growth in output per hour, TFP, and R&D stocks, UK market sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Output per hour, R&amp;D capitalized</td>
<td>2.9</td>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>1a Without R&amp;D capitalization</td>
<td>2.7</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>1b Difference due to capitalization</td>
<td>.22</td>
<td>.30</td>
<td>.14</td>
</tr>
<tr>
<td>1c Contrib. of R&amp;D deflator</td>
<td>.16</td>
<td>.21</td>
<td>.12</td>
</tr>
<tr>
<td>2. TFP, R&amp;D capitalized</td>
<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
</tr>
<tr>
<td>2a Without R&amp;D capitalization</td>
<td>2.2</td>
<td>2.3</td>
<td>2.1</td>
</tr>
<tr>
<td>2b Difference due to capitalization</td>
<td>-.05</td>
<td>-.06</td>
<td>-.05</td>
</tr>
<tr>
<td>3. Real stocks of R&amp;D assets</td>
<td>12.7</td>
<td>14.2</td>
<td>11.1</td>
</tr>
<tr>
<td>3a Contrib. of R&amp;D capital deepening</td>
<td>.25</td>
<td>.33</td>
<td>.17</td>
</tr>
</tbody>
</table>

Note—Growth rates are calculated using log differences. Italicized entries are percentage points.
1. Line 1 less line 1a.
2. Line 2 less line 2a.
3. Contribution to the growth in output per hour, line 1.

1995. That said, stocks continue to grow at a rapid clip in the post 1995 period and R&D capital deepening contributes more than ¼ percentage points to the growth in output per hour from 1995 to 2005.

4. Conclusion

Aggregate business output may be modeled as emanating from two sectors: one, the aggregate behavior of business functions devoted to innovation and R&D, and the other, an operations and/or producing sector consisting of all other business functions. The model is very simple, assuming only the following: the innovation sector is entirely upstream of the operations sector; the operations (or “downstream”) sector produces all final output and is a price-taker for inputs; and the aggregate value of final output equals the sum of all factor payments by business.

The recursive nature of the model’s price-dual relationships shows how the price of commercially-produced knowledge (i.e., R&D assets) is related to innovator market power and measured final (i.e., downstream) output prices, factor costs, and productivity. To exploit these relationships to construct a price index for R&D, a decomposition of measured productivity

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141 The stocks are calculated using a depreciation rate of 15 percent (the rate used by the US BEA) and an initial value as in Griliches (1980). See also equation (3) in Sliker (2007, p. 3).
change into upstream and downstream components is needed. We related the model’s expression for R&D price change to methods under consideration for calculating an investment price index for R&D in national accounts and found that these methods tend to embody unrealistic assumptions for R&D productivity (or innovator market power).

The model, its parameterization via productivity decomposition, and use of price-dual solutions have ample precedence in the literature: The model is related both to Romer (1990) and the intangible capital literature (e.g., Corrado, Hulten, and Sichel 2010); the productivity decomposition is related to the literature on estimating returns to R&D (e.g., Griliches 1980, Mansfield 1980, and Schankerman 1981); and exploiting price-dual growth accounting relationships for productivity analysis was done by Oliner and Sichel (2000), among others.

When our downstream approach is applied to the UK data, we found that UK R&D investment prices fell 7.5 percent per year from 1985 to 2005, and that R&D capital deepening contributed notably to the growth in output per hour. The precise fall in a R&D price index obtained using the downstream approach depends on the decomposition of measured productivity between a contribution from R&D and from other factors, but our central finding of falling R&D prices is robust relative to all that we know from the empirical R&D literature (spillovers, above average rates of return, etc.)—and stands in stark contrast to the assumption of rising R&D prices in all other work on the topic.
References


Figure 1
UK Industry Productivity and R&D Intensity

All market sector industries

Excl. outliers, nonperformers, and lowest R&D quartile

R&D relative to industry gross output

1985 to 1995
1995 to 2005
Figure 2
R&D Price Index and Real R&D Spending (percent change)

R&D cost change
less: R&D Productivity change
equals: R&D Price change

Nominal R&D spending change
Real R&D spending change
APPENDIX

R&D and TFP industry-level data

We have four distinct industry-level data sources. First, we have the UK R&D spending data from BERD, which surveys own-account R&D spending by firms and reports R&D for 32 product groups that generally correspond to industry groups.\footnote{Because individual companies can perform R&D for a range of products, the correspondence must be regarded as an approximation, however.} Second, we have the UK EUKLEMS March 2008 dataset covering the period through 2005, the latest data as of this writing. This dataset reports capital input and gross output-based TFP estimates for 26 market sector industries along with prices and quantities of output and labor and material input for 72 (more detailed) industries.\footnote{The market sector in EUKLEMS is NACE sectors A-Kpt plus O and P. We exclude P (private households) and work with NACE sectors A-Kpt plus O. Kpt is sector K excluding industry 70 (real estate).} Third, we have capital services data from the UK ONS at a more disaggregate level than available from EUKLEMS (e.g., motor vehicles and other transport, rather than total transport equipment). We use these capital services estimates along with other information from EUKLEMS and ONS to calculate TFPs for 5 additional industries. Fourth, we have the UK supply-use (IO) tables, for more than 100 industries from 1992 to 2006.

After merging the BERD data with the EUKLEMS, ONS and IO data and aggregating certain industries, we have a data set for 29 industries from 1985 to 2005. The industries are listed in table A1. Note that, due to disclosure issues, we do not have separate capital stocks for pharmaceuticals—the largest R&D performer in the UK—and other chemicals and are therefore forced to work with the aggregate chemicals sector. The list shown in table A1 also excludes the R&D services industry because its R&D is allocated to using industries based on input-output relationships.

The lower quartile bound

The allocation of the R&D services industry causes three industries that do not conduct scientific R&D according to BERD to show non-zero R&D intensities, albeit very small ones. These industries are financial services, hotels and restaurants, and other social, community and personal services. Accordingly, when we calculate the cutoff point used to determine the lower quartile of R&D performers, intensities for these nonperformers are excluded from the calculation.
The cutoff point we use is .003 (of gross output), and it is calculated as the lower quartile bound using the 1985-2005 average ($\mu=1.15$, $\tau=1$) value for $s_{G,i}^R$ for the 26 R&D performing industries shown in table A1, i.e., all industries except financial services, hotels and restaurants, and other social, community and personal services. Another way of thinking about this cutoff is that the lower 1/3 percentile of the industries shown in table A1 is dropped; the two approaches yield the same results.

**Observations in the productivity regression**

To determine the observations used in the productivity decomposition regression, we first exclude the nonperformers and the lower quartile of R&D performers. Then we test for outliers.

We apply the cutoff to each sub-period separately; this procedure leaves us with 38 observations. We note that two industries that make the cutoff on the basis of averages for the whole period do not make the cutoff in the second sub-period (utilities and miscellaneous business services). Also, two industries that fail to make the cutoff on the basis of averages for the whole period do make the cutoff in the first period (mining and other manufacturing). Thus our observations consist of 21 observations on the first period and 17 on the second.

Of these 38 observations, the negative observations for computer and software services in the pre-1995 period and petroleum refining in the post-1995 period are detected as outliers and excluded from our regression analysis. The observations for the post and telecommunications industry also are excluded. Research has shown that quality change in the capital equipment used in this industry is substantially understated (Doms and Forman 2005, Doms 2005, Byrne and Corrado 2011), and we believe the industry’s TFP estimates are overstated. For the U.S. broadcasting and telecommunications industry (NAICS 513), the overstatement of TFP growth due to mis-measured capital is estimated to be about 50 percent of the change based on published data (Corrado 2011). This type of measurement problem is not covered by the analysis in section 2.4 and, accordingly, the observations are dropped for our regression analysis. All told, the regressions use 34 observations.
Appendix C

CAN INTANGIBLE INVESTMENT EXPLAIN THE UK PRODUCTIVITY PUZZLE?

Peter Goodridge*, Jonathan Haskel** and Gavin Wallis***

Abstract
This paper investigates whether intangibles might explain the UK productivity puzzle. We note that since the recession: (a) firms have upskilled faster than before; (b) intangible investment in R&D and software has risen whereas tangible investment has fallen; and (c) intangible and telecoms equipment investment slowed in advance of the recession. We have therefore tested to see if: (a) what looks like labour hoarding is actually firms keeping workers who are employed in creating intangible assets; (b) the current slowdown in TFP growth is due to the spillover effects of the past slowdown in R&D and telecoms equipment investment. Our main findings are: (a) measured market sector real value added growth since the start of 2008 is understated by 1.6% due to the omission of intangibles; (b) 0.75pppa of the TFP growth slowdown can be accounted for by the slowdown in intangible and telecoms investment in the early 2000s. Taken together intangible investment can therefore account for around 5 percentage points of the 16% productivity puzzle.

Keywords: Intangible investment, productivity

JEL Classifications: O47, E22

March 2013

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We are very grateful for financial support for this research from NESTA, ESRC (Grant ES/I035781/1) and UK-IRC. We also thank three anonymous referees and an editor for useful comments and suggestions. This work contains statistical data from ONS which is Crown copyright and reproduced with the permission of the controller of HMSO and Queen's Printer for Scotland. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets which may not exactly reproduce National Statistics aggregates. The views expressed in this paper are those of the authors and do not necessarily reflect those of affiliated institutions. All errors are of course our own.
Introduction

Between 2007 and 2009 real UK market sector value added fell by 7.4%. Market sector hours worked fell by 3.5% and hence market sector productivity fell by 4%.\textsuperscript{144} In 2010, hours started to grow again, but output has grown very slowly. Between 2011 and 2012Q3, the latest period for which market sector data are available, hours have grown by 3.4% but market sector value added by 0%. Hence productivity has fallen by 3.4%. Market sector output per hour is now around 16% below its pre-crisis trend. Why?

The standard explanation for the initial fall in productivity is labour hoarding. In most previous recessions, firms cut output but kept labour in reserve for the recovery. Productivity, output per worker, falls at first, but then recovers as the firm uses the reserve inputs. Strictly speaking the fall in productivity is mismeasurement since the output per utilised input is the same, but with utilisation typically poorly measured this shows up as a fall, then rise, in productivity.

This explanation seems to carry less and less weight for the post 2008 years, for it seems very unlikely that firms are still carrying underutilised workers four years on. Further, as we document below, during the recession and since, firms have upskilled at a much faster pace (skill-adjusted labour composition rose at 0.5\%pa 2005-08, but at 1.1\% after 2008\textsuperscript{145}). Thus if firms are holding onto workers, it is the high skilled, not the low skilled.

Therefore a number of different explanations of the UK productivity puzzle have been put forward. First, there are the arguments on labour hoarding and labour utilisation noted above. Second, that this recession has come at a time of greater labour market flexibility so that declines in real wages have allowed firms to keep on less productive workers. At the same time the financial crisis may have increased the cost of capital so that at the margin firms are substituting away from capital and towards labour, thus reducing labour productivity. Third, that the financial crisis has impaired the re-allocation of capital and that there is less migration of capital away from low return activity to higher returns (Broadbent, 2012). Fourth, that a greater degree of forbearance and also increased risk aversion on the part of banks has resulted in less entry and exit since the recession, with ‘zombie firms’ maintained and few high productivity entrants.

Fifth, that a decline in business investment has reduced the capital-labour ratio and therefore labour productivity. We consider here a potential sixth explanation to do with the role of intangible investment in terms of both measurement and its impact on growth.

\textsuperscript{144} Productivity as measured by GDP per hour looks very similar. For example, GDP in 2012, for which complete data are now available, rose by 0.0\% (data downloaded in January 2013). We prefer to work with market sector output where possible in this paper, given the problems of accurately measuring government output.

\textsuperscript{145} Average growth for 2005 to 2008 and 2009 to 2010 for the market sector (Acheson and Franklin, 2012)
In this paper we thus examine the role of intangibles. A broad range of intangible assets are included, under three main intangible asset classes, based on the definitions first developed in Corrado, Hulten and Sichel (2005). Firstly, computerised information (mainly software), secondly, innovative property (covering scientific and non-scientific R&D) and finally firm-specific resources (company spending on reputation, human and organisational capital.

To examine the role of intangibles, our starting point is the observation that whilst investment in tangibles, plant/vehicles/buildings has fallen and stayed low, a point perhaps not noticed is that investment in intangibles, specifically Research and Development (R&D) and software has risen since the recession (software fell and has since been rising, R&D was flat and then rose). Consider then a firm who has reduced production but maintained investment in intangibles. Its skill level rises, since intangible investment typically requires high qualified workers. Its measured output falls, since the output of e.g. R&D projects might not manifest itself for a few years. Thus labour productivity falls, in a pattern that looks just like labour hoarding.

There is a second effect. Although intangible investment has been relatively robust over the recession, it fell before 2008. This was because there was a huge surge in intangible investment in the late 1990s around the introduction of the internet, with new software, machinery etc. In addition, as is well known, R&D investment as a share of GDP has been falling for quite some time in the UK. If such investment has spillovers, and they take some time, then it might be that productivity/total factor productivity (TFP) would have fallen in the late 2000s anyway, due to the slowdown in intangible investment in the early 2000s.

This paper then reviews these hypotheses. It therefore attempts to add an additional hypothesis to that literature on the UK productivity puzzle. There is a wide range of commentary and articles written on the productivity puzzle and offering a number of different explanations. For example, the productivity puzzle has been discussed in various speeches by MPC members including Dale (2011), Broadbent (2012) and Weale (2012) and by other commentators such as Martin and Rowthorn (2012). See also Hughes and Saleheen (2012) for the UK productivity puzzle in an historical and international perspective. See ONS (2012a, 2012b) for a measurement perspective on the productivity puzzle and ONS (2013) for a microdata perspective. See Disney et al (2013) for a review of most of the explanations put forward to explain the productivity puzzle.

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146Explanations for the recent weakness in productivity are summarised in a box on page 33 of the November 2012 Inflation Report.
Our main conclusions are as follows. First, measured market sector real value added growth since the start of 2008 is understated by 1.6% due to the omission of intangibles. Second, TFP growth would have slowed down anyway by around 0.75 pppa. The actual slowdown has been much larger than this, since TFP has gone from a pre-recession average of 1.39%pa (2002-7) to -2.29%pa (2007-10)\textsuperscript{147}. Taken together this accounts for around 5 percentage points of the 16% productivity puzzle.

**Productivity, TFP growth and investment**

*Ia. Some facts*

Figure 1 shows the UK productivity puzzle for the market sector. As the figure shows, market sector output per hour\textsuperscript{148} fell very sharply in 2008, but then recovered somewhat afterward before falling again. Output per hour is around 16 per cent below its pre-crisis trend. Mechanically, there has been weak output growth combined with a much more robust labour market than most people expected. Hours have not fallen by as much as previous falls in output would predict.

**Figure 1: UK Labour Productivity Index (2008=100)**

![Graph showing UK Labour Productivity Index](image)

Notes: Solid line is an index of output per hour worked. Dashed line is a trend of output per hour worked prior to the recession. Data from Goodridge, Haskel and Wallis (2012a), for the UK market sector, based on a National Accounts definition of GDP where software, artistic originals and mineral exploration are the only capitalised intangibles.

Figure 2 sets out the TFP growth picture (TFP calculated as output per hour less share weighted capital and labour services per hour). It shows the weakness of the recovery in TFP, with the current situation remarkably similar to the UK experience in the 1970s.

\textsuperscript{147} Estimates based on Goodridge, Haskel and Wallis (2012a), where R&D, software, artistic originals and mineral exploration are the only intangibles capitalised. Data extended to 2010 using ONS TFP estimates.

\textsuperscript{148} Note the market sector data underlying this chart (and Figure 6) differ slightly from that quoted from ONS. The ONS data include private delivery of education and health and exclude public services in section ‘O’. These data are based on GHW (2012) and do not include private health/education and do not exclude public services in ‘O’.
Figure 2: Index of TFP following UK recessions

Notes: TFP estimates taken from the UK EUKLEMS dataset and extended using ONS estimates. X-axis marks the number of years from each recession. TFP has been estimated accounting for changes in labour composition.

The difference between productivity and TFP is that the latter accounts for changes in capital deepening and labour composition. To shed light on capital deepening, Figure 3 shows business investment over the same period, with investment broken out into (non-residential) buildings, total plant & machinery (including computers), software and R&D. The data show the well-known collapse in buildings and plant investment after 2007 and the remaining low investment levels. Less well-known, however are the levels of R&D and software investment. Both hardly fell over the period and indeed have risen in contrast to other categories.

Figure 3: Index of UK nominal private sector investment in selected assets (2008=100)
Notes: Data for buildings, plant and machinery (P&M) and software are private sector business investment in current prices. Since this is business investment, buildings exclude dwellings. The data for software only refer to purchased and do not include own-account. Data for Plant & Machinery include ICT hardware. The data for R&D are the BERD data for Total Civil intramural R&D. Source: Buildings, P&M (Blue Book tables); Software (GFCF First Release); R&D (BERD)

Table 1 shows recent labour productivity and TFP growth for the UK before and during the recession from a number of sources.

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<tbody>
<tr>
<td>Δln(V/H)</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
</tr>
<tr>
<td>(without intangibles, market sector)</td>
<td>2.7%</td>
<td>-1.6%</td>
<td>-2.3%</td>
<td>1.5%</td>
<td>0.1%</td>
<td>-2.8%</td>
</tr>
<tr>
<td>sLΔln(L/H)</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
</tr>
<tr>
<td>(contribution of labour composition, whole economy)</td>
<td>0.4%</td>
<td>0.3%</td>
<td>1.0%</td>
<td>1.0%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>sKΔln(K/H)</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
</tr>
<tr>
<td>(contribution of capital deepening, whole economy)</td>
<td>1.0%</td>
<td>1.0%</td>
<td>1.6%</td>
<td>1.0%</td>
<td>0.9%</td>
<td>0.9%</td>
</tr>
<tr>
<td>ΔlnTFP</td>
<td>GHW(2012)</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
<td>ONS</td>
</tr>
<tr>
<td>(without intangibles, market sector)</td>
<td>1.3%</td>
<td>-1.9%</td>
<td>-5.0%</td>
<td>-5.0%</td>
<td>-0.4%</td>
<td>-</td>
</tr>
<tr>
<td>ΔlnTFP (with intangibles, market sector)</td>
<td>0.8%</td>
<td>-2.3%</td>
<td>-3.6%</td>
<td>-4.4%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Utilisation</td>
<td>Conference Board: Total Economy Database</td>
<td>GHW(2012)</td>
<td>ONS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(hours per worker, market sector (000’s))</td>
<td>1.1%</td>
<td>-2.0%</td>
<td>-5.1%</td>
<td>-</td>
<td>-1.6%</td>
<td>-</td>
</tr>
<tr>
<td>ONS</td>
<td>1.71</td>
<td>1.70</td>
<td>1.67</td>
<td>1.68</td>
<td>1.68</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Data for 2012 in column 1 are extrapolated from three quarters of data. Data in column 1 do not quite match figures in introduction since those are to 2012Q3. Columns 2 and 3 are the contributions of labour composition and capital deepening as reported in ONS TFP estimates. TFP estimates in columns 4 to 6 are estimated accounting for labour composition. Note that ONS estimates of TFP and factor contributions do not sum to labour productivity as the data are from different sources and apply to different aggregations (factor contributions refer to the whole economy and ONS TFP to the market sector). Abbreviations: V=GDP; H=actual person-hours; L=labour services; K=capital services. Sources: Column 1 (ONS Labour Productivity First Release); Columns 2, 3 and 5 (ONS TFP estimates); Columns 4 and 7 (Goodridge, Haskel and Wallis, 2012a); Column 6 (The Conference Board, Total Economy Database); Column 8 (ONS Labour Productivity data).

Data for growth in labour productivity, measured as growth in value-added per hour worked, are presented in column 1. The story they tell is by now familiar. Labour productivity fell sharply in the recession of 2008 and 2009, but has remained weak in the recovery and the decline in productivity in the second recession of 2012 is even greater than that in either year of the initial recession itself.

### IIb. Capital/labour substitution and labour hoarding

Columns 2 and 3 show the contributions to labour productivity growth of growth in capital services per hour and labour services per hour. Both columns shed light on two hypotheses concerning the labour market. One is that the decline in real wages has lowered the relative price
of labour to capital thus incentivising substitution away from capital towards labour. At the same
time, tightening of credit conditions since the financial crisis might have further increased the
relative price of capital.

The data here give some slight support for this view. As column 3 shows, the contribution of
capital services per hour up to the recession was 1% pa. In 2009, that contribution rose strongly,
that is, labour was reduced more than capital. In 2010 by contrast, the contribution fell quite
markedly, suggesting that firms are, relative to before, substituting towards labour. This pattern is
reflected in columns 4, 5, and 6 which show TFP growth. As we set out below, TFP growth
measures labour productivity growth controlling for capital/labour inputs. TFP growth declined
very sharply in the recession, suggesting that labour productivity did not just fall due to
capital/labour substitution.

A second view is labour hoarding. Rowthorn and Martin (2012) advance the view that the fall in
labour productivity is due to labour hiring behaviour. Consider a firm with “overhead” and
“variable” labour. An initial fall in demand causes overhead labour to be hoarded and variable to
be fired, though these effects are moderated with a fall in real wages. Productivity falls as
overhead labour is under-utilised. A recovery in demand, at low wages, causes variable labour to
be hired. Productivity rises as overhead labour utilisation recovers, but might fall as more labour
is hired. To get an overall fall in productivity and then no rise in the employment recovery, they
posit high and low productivity sectors. In the initial recession the high productivity sector fired
variable labour and kept on overhead labour at low utilisation. In the recovery, that sector hired
few new workers and raised utilisation: a jobless recovery with rising productivity in that sector.
The low productivity sector by contrast fired both types, so that in the recovery they hired both
types, lowering overall productivity via a mix effect. They present evidence that the recovery in
employment since 2008 has been entirely in the low productivity sector (see their Chart 14 and
Table 12, www.cbr.cam.ac.uk/pdf/BM_Report3.pdf). (their high productivity sectors are
manufacturing, financial and business services, low productivity are agriculture, construction,
distribution, hotels and restaurants).

One way to look at the Martin/Rowthorn hypothesis is via labour composition indices. These are
indices of labour hours adjusted for various dimensions of labour composition (e.g. skill, age,
gender). In practice they are driven by skill levels so that if the index of labour composition rises
(labour services per hour worked), then firms are increasingly hiring more skilled workers per
hour worked. ONS data for the contribution of quality-adjusted labour services per hour worked
is presented in Column 2 of Table 1. If low-skilled labour had been hoarded, we would expect the
contribution of labour composition to either grow less fast or even decline. But growth in the
contribution of labour composition in 2009 and 2010 has been extremely strong, suggesting the opposite has occurred. That is that firms have hoarded high-skilled labour at the expense of low-skilled. This is borne out in the analysis contained in Acheson (2011) and Acheson and Franklin (2012). Note that this is also consistent with the data for R&D investment in Figure 1, and other categories of intangible investment, all consistent with the idea that it is the higher skilled “knowledge workers” that have been kept on by firms.

However, the Rowthorn/Martin view is across different sectors. In the recession, they argue, the high productivity sectors have hoarded relatively more skilled labour and let go relatively more unskilled. Thus they should have a relatively large rise in labour composition. In the recovery, the high productivity sector employs more fully their hoarded skilled workers and takes on relatively few unskilled. The low productivity sectors, take on relatively more low skilled labour. So again, the high productivity sector should have a relatively high rise in composition. The data from Acheson and Franklin (2012) do not support this version of the Rowthorn/Martin view. In the initial recession growth in labour composition was 1.6%pa and 2.5%pa in the high and low productivity sectors and in the recovery 1.9% and 2.0%. Thus, in the recession, the low productivity sectors retained relatively more skilled than the high productivity and in the recovery have hired relatively more skilled than the high productivity sectors\(^{149}\). The data used to make this comparison are presented in Table 2.

\(^{149}\) This takes Table 2 and 3 in Acheson and Franklin (2012) and allocates as low productivity sectors (following Rowthorn/Martin) Agriculture, Wholesale/Retail, Administration, Public services and Arts (ABDE, GI, LMN, OPQ and RSTU), the rest being high productivity and calculates the averages of “labour quality index per hour” for high and low, for 2008-9 and 2009-10.
Table 2: Changes in labour composition during and after the 2008-09 recession

<table>
<thead>
<tr>
<th>Rowthorn &amp; Martin: Low (L) / High (H) productivity sectors</th>
<th>2008Q1 - 09Q2: Change in labour composition (Δln(L/H))</th>
<th>2009Q3 - 10Q4: Change in labour composition (Δln(L/H))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole economy</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Market sector</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Agriculture &amp; Mining</td>
<td>L</td>
<td>2.7</td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td>1.1</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td>Distribution</td>
<td>L</td>
<td>2.3</td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td>-0.1</td>
</tr>
<tr>
<td>Information &amp; Communication</td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>Financial Services</td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>Professional &amp; Administrative Services</td>
<td>L</td>
<td>1.4</td>
</tr>
<tr>
<td>Public Services</td>
<td>L</td>
<td>1.3</td>
</tr>
<tr>
<td>Arts &amp; Recreation</td>
<td>L</td>
<td>4.6</td>
</tr>
<tr>
<td>Average High</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Average Low</td>
<td></td>
<td>2.5</td>
</tr>
</tbody>
</table>

Notes: The table sets out the data from Acheson and Franklin (2012) showing changes in labour composition between the dates indicated, with the second column marking the low productivity sectors (the others being high) as best we can match to the Martin/Rowthorn classification. The final row shows average changes for the high productivity and low productivity sectors.

Iib. Direct evidence on utilisation.

Direct evidence is very hard to come by on utilisation since it is so hard to observe. Basu et al (2006) suggest a theory to measure it essentially by actual hours per worker per year (H/N)$^{150}$. To do this, they suggest estimating the regression

\[
\Delta \ln TFP^{\text{MEAS}} = \hat{\alpha} + \hat{\beta} \Delta \ln(H / N)
\]

providing an estimate of $\hat{\beta}$ which allows us to form a measure of TFP adjusted for the impact of utilisation as

\[
\Delta \ln TFP^{\text{ADJ}} = \Delta \ln TFP^{\text{MEAS}} - \hat{\beta} \Delta \ln(H / N)
\]

In contrast to results in the US, as in Basu et al (2006), it turns out that in the UK data $\hat{\beta}$ is relatively small at 0.39 (compared to $\hat{\beta} > 1$ in the US data). The adjustment to TFP is shown in the following chart.$^{151}$

$^{150}$ Consider a firm employing N workers for H hours per worker, working with unobserved effort E per hour. Labour input is then N×G(E,H), where G transforms the bundle of E and H into per worker effort-hours. A firm wishing to raise E or H will face some costs of doing so. Assume they are a function of EH and that firms are optimising on all margins. Then the first order condition holds: $dG/dH(H/G)=dG/dE(E/G)$. Log linearising, one can write the unobservable E/N in terms of the observable H/N as $\ln E/N = \beta \ln(H/N)$ as is done above.

$^{151}$ Note that utilisation is partly controlled for in the factor shares following the Berndt-Fuss-Hulten theorem. A new building for example raises $\Delta \ln K$. But if it is unoccupied, then its rent income is zero, hence $s^{K}_{0}=0$ and so it has no
Figure 4: Measured TFP vs. TFP adjusted for utilisation

![Utilisation adjusted ΔlnTFP](image)

Notes: Red line is UK market sector TFP (ONS). Estimates for hours per worker are from ONS data for market sector hours and workers as used in the Labour Productivity First Release. Blue line is UK market sector TFP adjusted for utilisation. Recession marked with blue columns.

Looking at the years prior to the recession utilisation adjusted TFP was higher than measured TFP in the early 2000s. The adjustment in the years immediately before the recession was very small. The major interest is in 2008 to 2009. As the graph shows, adjusting for utilisation removes some of its impact from TFP, suggesting TFP did not fall as fast as in the measured data. The adjustments are not that large however. The reason is that in 2009 TFP (ONS) was -3.6%. In that year Δln(H/N)(ONS) was -1.6%. Our UK estimate for $\hat{\beta}$ is 0.39. The contribution of utilisation in 2009 is therefore (0.39*-0.016=-)0.6%, thus adding 0.6% to TFP. Note that if the UK estimate of $\hat{\beta}$ were more similar to that found in the US, say $\hat{\beta}$=1.008 the contribution of utilisation would be (1.008*-0.016=)1.59% and would explain around 44% of the fall in TFP.153

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152 Basu et al (2006) report estimates of $\hat{\beta}$ for durables manufacturing (1.34), nondurables manufacturing (2.13) and nonmanufacturing (0.64). Applying some approximate weights for each within the UK market sector of 0.1, 0.2 and 0.7 respectively, yields a comparable estimate of $\hat{\beta}$ =1.008.

153 To see how much this matters in the US, the Fernald quarterly TFP growth series, www.frbsf.org/csip/tpf.php, and Fernald (2010) show that measured TFP growth was -1.66 and -1.39 in 2008 and 2009, but when utilisation adjusted was 0.47 and 2.51.
The relation between productivity, TFP growth and investment

To explain these data let us set out a slightly more formal model. Consider the following framework. Let output $Q$ be a function of the services of labour, $L$, tangible capital, $K$, and intangible capital, $R$, with a shift term $A$. Then we can write GDP in terms of a production function and in terms of nominal expenditure as

$$Q_t = A F (L_t, K_t, R_t)$$

(3) $$V = C + I$$

$$Q = C + I + N$$

Where $I$ and $N$ are the real values of tangible and intangible investment. $V$ is the sum of consumption and tangible investment and will appear below. This means we can write the relation between measured output growth, $\Delta \ln V$, and true output growth, $\Delta \ln Q$, which is

(4) $$\Delta \ln Q_t = \Delta \ln V_t + s^{Q,N}_t (\Delta \ln N_t - \Delta \ln V_t)$$

We are now in a position to review the possible biases due to omitted intangibles. First, if in the recovery $\Delta \ln N > \Delta \ln V$, for which we have seen some evidence in Figure 3, measured $\Delta \ln V$ understates true, $\Delta \ln Q$.

The term $s^{Q,N}_t (\Delta \ln N_t - \Delta \ln V_t)$ is an estimate of the bias to measured output if intangibles are not treated as capital goods. We consider the full range of intangible assets proposed in Corrado, Hulten and Sichel (2005)\textsuperscript{154}. Since our intangibles dataset only extends to 2009, some assumptions to extend the series have been made. First we assume that the intangible investment share (excluding software, mineral exploration and artistic originals), $s^{Q,N}_t$, is the same in 2010, 2011 and 2012 as it was in 2009 (at 0.09). Second we assume that real intangible investment is growing at the same rate as real R&D investment in 2010 and 2011, and that the rate for real R&D investment is the same in 2012 as in 2011. Estimates of real measured growth and changes in the output deflator have also been extended with the latest ONS data. The following chart presents an estimate of this bias term.

\textsuperscript{154} Therefore including: software; scientific R&D; non-scientific R&D; design; artistic originals; mineral exploration; financial product innovation; training; advertising; market research; organisational capital.
The chart shows that in the late 1990s, when there was an intangible investment boom, the term is positive, that is value-added including intangibles was growing faster than measured value-added. In general for much of the 2000s the term is negative, with growth in intangible output weaker than measured final output, suggesting growth was being overstated during that time. However in 2009 the term is positive and suggests an understatement to output growth of 0.1%. The terms for 2010 and 2011 suggest an understatement of 0.12% and 0.5% respectively. In 2011 and 2012 market sector GVA growth was 1.17% and -0.26% pa respectively. Thus the bias of 0.57% for 2012 means output growth would instead would be 0.31% pa rather than negative.

The impact of this in terms of labour productivity can be seen in Figure 6. There the red line is an index of market sector labour productivity (GDP per hour) as conventionally measured, and the green line an index of labour productivity with the underlying output measure adjusted to treat intangible spending as capital investment. As can be seen, by 2012, not accounting for intangibles results in the index of labour productivity being underestimated by around 1.6 index

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Note: Chart presents the correction to real output growth if intangible investment is not included in final output. So, for example, in 2011, real output growth should be 0.50% higher than it is measured. For 2012 that figure is 0.57%. Recession highlighted.

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155 This estimate for 2012 is extrapolated from three quarters of data
The reason is that market sector growth since the start of 2008 is -4.4%, but adjusted market sector growth is approximately -2.8%.

Figure 6: UK Labour Productivity Index adjusted for intangibles (2008=100)

Notes: Red line is measured labour productivity and dark red line is trend labour productivity based on the pre-crisis data as in Figure 1, with software, mineral exploration and artistic originals the only intangibles that are capitalised. Green line uses an output measure adjusted for the capitalisation of all other intangibles in the Corrado, Hulten and Sichel (2005) framework. Data are based on Goodridge, Haskel and Wallis (2012a). Data for intangible investment in 2010 to 2012 have been projected forward using data for R&D investment as reported in BERD.

**Spillovers**

Intangible investment affects the productivity growth of the firm undertaking the investment. But it has an additional effect if there are spillovers. There is a large body of work suggesting that R&D has spillover effects to other firms see e.g. Griliches (1973) for a survey, concentrating mostly on US work, and Goodridge, Haskel and Wallis (2012b) for recent work for the UK.

A number of US authors (e.g. Fernald (2012)) have noted a slowdown in US TFP growth before the 2008 recession, which they ascribe in turn to a slowdown in intangible investment in the early 2000s following the heavy burst of intangible investment in the late 1990s internet/computer boom. In the UK, there has also been a sustained slowdown in UK R&D/GDP spend noted by a number of authors and policy-makers. We thus examine the data for the UK: was there an intangible investment slowdown and might that have slowed down underlying TFP growth before the recession?

Figure 7 sets out intangible and tangible investment as a proportion of GDP. Intangible investment rose since the 1980s, but slowed down in the early 2000s. Tangible investment has

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363 Taking the self-employed out of the headline measure of productivity also accounts for about 1 per cent of the productivity puzzle.
generally been in decline throughout the 2000s. So if there are spillovers from intangible investment to TFP and if they take, say two years to show up, then TFP growth in the late 2000s would slow. Of course, it might well slow down before the shock of 2008 and the shock might have an additional effect, but even so, there remains the possibility that at least some of the slowdown might be due to a feed through from the earlier slowdown in intangible investment.

**Figure 7: Nominal tangible and intangible investment as a proportion of nominal GDP**

Note s: Tangible and intangible investment as a share of GDP. In each GDP has been adjusted for the capitalisation of intangibles. Data from Goodridge, Haskel and Wallis (2012a).

Figure 8 shows the changes in capital stocks as a result of this investment, along with changes in R&D capital and telecoms equipment. The latter bears some comment. One way of thinking about the internet is that it is a (very large) piece of communications capital equipment, building on older telecoms capital and being augmented by broadband and mobile technologies. If one thinks of such equipment as building networks it is very natural to ask if there is any evidence of spillovers from telecoms equipment. As Corrado (2010) points out, there are many channels through which communications capital deepening may have contributed to improved growth in TFP e.g. improved opportunity and ability for collaboration; more effective communication and increased quality of information communicated both within and between organisations; improved access to freely available knowledge via the internet; and improved organisational and business processes, including within supply chains, derived from each of the previous effects described. Such spillovers could be even more substantial in more knowledge-oriented economies. In fact, recent studies (Adams, Black, Clemmons and Stephan 2005; Ding, Levin, Stephan and Winkler 2010) have shown a positive impact from the internet on academic collaboration and productivity.
Figure 8: Growth in capital services, selected assets

Notes: Data are changes in the log of the capital stock for selected assets. \( \text{dlnK(telecom)} \) refers to telecoms equipment defined as I-O groups 71 (Insulated wire and cable), 74 (Television and radio transmitters and apparatus for line telephony and line telegraphy) and 75 (Television and radio receivers, sound or video recording or reproducing apparatus and associated goods). Recessions marked by blue columns. Data are from Goodridge, Haskel and Wallis (2012a).

The figure shows growth in capital services for each of these intangible groups. Growth in R&D capital was very high in the 1980s before slowing, speeding up again around 2000 and then slowing. Growth in telecoms capital was low, even negative, in the early 1990s before growing very fast in the late 1990s and then slowing. In general growth in capital for these assets slows down in the early 2000s relative to the late 1990s. If there is a lagged effect on TFP, this would slowdown TFP in the late 2000s.

How big might these effects be? Table 3 sets this out. In this table, TFP growth is measured including R&D as an intangible (excluding all other intangibles) to study the possible effects from R&D spillovers. We confine ourselves to R&D since R&D spillovers seem quite well established in the literature. The table reads as follows. Column 3 sets out TFP growth, estimated including R&D, for four year-spans, starting in the trough of 1991, being a trough to peak, peak to trough and another cycle. As the table shows, TFP sped up between late 90s and mid 00s, (1998/02 and 2002-07), (0.12%pa), but then slowed down severely in the latest period (-3.68%).
Interestingly, as columns 4 and 5 show, lagged growth in the capital stock for R&D and telecoms equipment show a suggestive pattern. Both sped up in the late 90s relative to the early 90s and late 90s and then slowed down again. Both of these speedups were followed by a speedup in TFP growth. And both slowdowns were followed, this time in the current cycle, by a slowdown in TFP growth. The final two columns show the contribution to the DlnTFP speedup and slowdown, being a coefficient times the lagged growth in the capital stock. The coefficients are drawn from Goodridge, Haskel and Wallis (2012b) and Goodridge, Haskel and Wallis (2013) and are the elasticities of DlnTFP to changes in the stock. As the final columns show, the 2002-07 slowdown is over predicted, but the current slowdown is under predicted. In fact, the effect from the changes in the stock of R&D and telecoms equipment account for 20% ((0.47+0.26)/3.68) of the current slowdown. So a slowdown in current DlnTFP of around 0.75%pa is predicted but these data are insufficient to predict the whole very large slowdown. Of course, much of that slowdown is dominated by the massive fall of around 5% of measured TFP in 2008.

Table 3: Spillovers and the slowdown in ΔlnTFP

<table>
<thead>
<tr>
<th>Year</th>
<th>Peak/Trough</th>
<th>DlnTFP</th>
<th>DlnK(rd)</th>
<th>DlnK(com equip)</th>
<th>dlnTFP slowdown</th>
<th>0.25*lagged dlnK(rd) slowdown</th>
<th>0.04*lagged dlnK(com equip) slowdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-98</td>
<td>T-P</td>
<td>1.83%</td>
<td>1.60%</td>
<td>1.86%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1998-02</td>
<td>P-T</td>
<td>1.26%</td>
<td>3.75%</td>
<td>8.77%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002-07</td>
<td>T-P</td>
<td>1.39%</td>
<td>1.87%</td>
<td>2.28%</td>
<td>0.12%</td>
<td>0.54%</td>
<td>0.28%</td>
</tr>
<tr>
<td>2007-10</td>
<td>P-T</td>
<td>-2.29%</td>
<td>1.20%</td>
<td>-1.94%</td>
<td>-3.68%</td>
<td>-0.47%</td>
<td>-0.26%</td>
</tr>
</tbody>
</table>

Notes: Columns 1 and 2 indicate years and peak to trough or trough to peak. Columns 3, 4, and 5 are ΔlnTFP, ΔlnK(R&D) and ΔlnK(telecoms equipment). Column 6 is ΔlnTFP slowdown, that is the respective row less the row above it. Columns 7 and 8 are the indicated coefficient times the slowdown in ΔlnK in the previous periods. So for example, -0.47 in column 7, final row equals 0.25*(DlnK(R&D)(2002-07) - DlnK(R&D)(1998-02)). Data are from Goodridge, Haskel and Wallis (2012a).

**Conclusion**

We have investigated whether intangibles might explain the UK productivity slowdown. We have noted that since the recession

a. firms have held onto their more skilled workers and decreased their unskilled workers at an increasing rate

b. intangible investment in R&D and software has risen whereas tangible investment has fallen.

c. intangible investment and telecoms equipment slowed in advance of the recession

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We have therefore tested to see if

a. What looks like labour hoarding is actually firms retaining workers who are employed in creating intangible assets (e.g. R&D teams); whose current output is therefore zero and whose contribution to total investment is unmeasured since intangibles are treated as expenses not investment

b. How much the slowdown in current TFP growth is due to the spillover effects of the slowdown in R&D and telecoms equipment investment in the past.

Our main findings are

a. First, measured market sector real value added growth since the start of 2008 is understated by 1.6% due to the omission of intangibles.

b. 0.75pppa of the TFP growth slowdown can be accounted for by the slowdown in intangible and telecoms investment in the early 2000s.

c. Taken together intangible investment can therefore account for around 5 percentage points of the 16% productivity puzzle.

Does that mean the UK still has an output gap? If potential output growth is determined by TFP growth, as it is in many models, our spillover results suggest that potential output growth has fallen. But potential output growth is not a given, since intangible investment may be amenable to policy levers. One of those levers might be Keynesian demand expansion. Others might be more on the supply side, e.g. expanding the R&D tax credit to other intangible assets. Whichever it is, we believe that unmeasured intangibles are part of the explanation of the productivity puzzle, but not all of it.
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