Winners and Losers in the Knowledge Economy: The Role of Intangible Capital

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Abstract

Intangibles are increasingly seen as key to growth in the knowledge economy. Much existing study of intangibles focuses on measurement at the macroeconomic and industry level. Most micro-level studies focus on specific intangibles. In this paper we develop a comprehensive dataset of UK firms 2002-2015, including measures of a broad set of capitalised intangible investments, in order to investigate how firm-specific knowledge assets contribute to the differential productivity performance of businesses. With these data we find that on average large firms in the top decile of the firm productivity distribution 2002-2004 in the UK were more than six times as productive as firms in the lower half of the distribution. They were also much more likely to invest in both tangible and intangible assets and were more likely to be foreign owned. Ten years on, the firm productivity distribution has widened significantly and investment has become more skewed towards firms at the top end of the distribution. The rewards to investing in intangibles are non-negligible for those that make these investments. The widening of the productivity distribution over time has not been mirrored by changes in the wages paid by firms. Rather, a set of firms have emerged with supra-normal returns.

Key words: intangibles, productivity, labour share, frontier firms, business micro-data

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1. Introduction

Intangibles are increasingly seen as the “missing input” in the knowledge economy. With the information technology revolution, advanced telecommunications were introduced and new digital technology products were launched. Many of these are complementary to other investments. However, investments in intangible assets, in contrast to tangible ones, have traditionally been considered as intermediate inputs in firm-level and national accounts, effectively deducting them from rather than adding their contribution to economic growth (Van Ark et al., 2009). It is now widely accepted that traditional productivity measurement, which focus on labour and tangible capital inputs only, does not account adequately for other important factors explaining differences in productivity across firms, industries and countries.[1] It is also recognised that intangible assets may differ to tangible assets in more ways than just their lack of tangibility. Westlake and Haskel (2017) describe the characteristics of intangibles with three words: sunk, scalable and synergies. As they point out, all of these features may help to explain the emergence of superstar firms and the increasing disparity in productivity between firms that are global leaders and other firms, a trend documented in a series of studies by the OECD[2]. These characteristics may also help explain other phenomena, such as an apparent slowdown in investment and declining labour share.[3]

Much progress has been made in measuring intangibles, in particular at the macro-level, following the work by Corrado et al (2005) to develop a framework which identifies and classifies various types of intangible investments and integrates these within a national accounting framework. These methods are increasingly seen as the standard for measuring intangibles.[4] These efforts are very important. But, to study some of the important questions about intangibles and productivity performance alluded to above we also require representative micro-data on firms’ use of intangibles and other firm characteristics. Much of the micro-analysis of intangibles has been ad hoc, typically relying on indicator variables

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[1] A number of studies document that IT-related productivity gains played an important role in explaining aggregate US productivity growth in the past decades (see for example Jorgenson et al., 2005, 2008 and Oliner et al, 2007). Also van Ark et al (2008) show that the later appearance and the smaller investment in IT technologies can partly explain the slow productivity growth in Europe compared to the US in the same period. Researchers have long proposed that management and organization can affect productivity (Bloom and Van Reenen 2007, 2010, Bloom et al, 2011) and in particular when combined with IT (Bloom et al, 2005, 2012, 2014; Basu et al, 2003; Black and Lynch, 2001; Bresnahan et al 2002). There is a long literature linking R&D and productivity, finding a positive association between the two in the US (see for example Griliches, 1979, Shankerman, 1981, Griliches and Mairesse, 1983 and Cueno and Mairesse, 1983) and a still positive but smaller elasticity in the UK (see for example Griffith et al 2006, an Bloom et al, 2002 and Jona-Lasino, 2011).

[2] See, for example, Andrews, Criscuolo and Gal (2016).

[3] Autor et al. (2017) suggest a rise in industry concentration resulting from the emergence of superstar firms is associated with recent declines in labour share.

[4] Recently, the UK Office for National Statistics has begun publishing estimates of intangibles using these methods.

and capturing only one or two aspects of intangible capital that, in general, is not capitalized.[5]

In this paper we detail the construction of a comprehensive and representative dataset of UK firms 2002-2015 that includes measures of a broad set of capitalised intangible investments. We then investigate how these firm-specific knowledge assets contribute to the differential productivity performance of UK firms. We find within detailed industries significant differences in the productivity performance of firms in the upper and lower parts of the productivity distribution and this disparity has increased over time.[6] This is partly related to increased disparity in the use of both tangible and intangible assets in the different parts of the productivity distribution, as well as foreign ownership. We also find that the likelihood of remaining in the top group from one year to the next has increased over the last decade. The distribution of intangible investment is more skewed than the distribution of tangible investment. For those firms that do invest in intangibles the returns are significant. Production function estimates suggest the returns to intangible investment vary across different industry groups. They are particularly significant in knowledge intensive services, but are also important in other sectors. We find evidence of complementary investments. Firms that invest most in software and databases also tend to invest more in marketing and branding and tangibles. We find that what happens to firms at the top is disproportionately relevant for the aggregate productivity statistics. This is not because these firms are particularly large. Rather it is because their productivity is so much higher than for the rest of firms. We find that between the early 2000s and the early 2010s, the large increases in productivity amongst the top performers compared to other firms have not trickled through to wages.

The paper is organized as follows. Section 2 defines intangible capital and how we measure it in this paper. Section 3 provides some details about our source data. In section 4 we discuss the productivity distribution of UK firms and in section 5 we look at intangibles use across the productivity distribution and analyse the relationship between intangibles and productivity in a production function framework. Section 6 provides some concluding remarks.

2. Intangibles: definition and measurement

Intangibles are not easily verifiable, are not always visible, and non-rival in consumption (and thus display elements of public good) and (as with R&D) it is not always easy to fully appropriate the returns. Despite these problems, fundamentally, any input that reduces

[5] There have been a number of firm level estimates of intangibles however these stem from the accounting literature rather than economics (see for example Lev et al (2009) and Hulten et al (2010)). Statistics agencies and other bodies also collect regular information on an increasing set of intangibles at the level of the firm (for example the management surveys led by Bloom and Van Reenen).

[6] This is in line with the trends highlighted by OECD, although our results should not be directly compared to theirs due to differences in methodology.

current consumption so that future consumption increases, qualifies as an investment and should be treated as such (Corrado et al, 2009). Corrado et al are largely credited with developing the current 'best practice' methodology for incorporating a wider definition of intangibles into the national accounts methodology, and we use their breakdown of intangibles into three main categories: digitized information (DI), innovative property (IP) and economic competences or organizational capital (OC).[7]

We collect information on firms' intangible investments using linked business datasets, which are detailed in the next section. Investment in software and databases is collected by asking firms directly about their investments, both purchased and developed by the firm (own-account) and is available in the main business survey that we rely on (the ARDx). Information on R&D investments, both intramural and extramural, is linked to the ARDx from the BERD. The ARDx also asks firms about their advertising and marketing purchases. We use this to derive an investment flow. These are the main intangible investments that we consider in this paper.

For very large firms we are also able to link to firms information on the type of employees that they employ and what they are paid. Here we derive an own account intangible investment flow based on a similar methodology to that used in Riley and Robinson (2011) and Piekkola (2010). We identify three groups of workers that are likely to be engaged in the production of own account intangibles. Organisation capital (OC) incorporates human resources managers and directors, vocational and industrial trainers (HRM); sales, marketing, advertising & public relations managers (BRAND); chief executive and senior officials, production and operations department managers (MANAGEMENT). Intellectual property (IP) is our second category of workers which would incorporate natural and social science professionals and managers, architects, engineering professionals, business research professionals, highly skilled artistic workers, designers. Our final occupational category of worker is ICT professionals or managers (DI).[8] For further details see Appendix A.[9]

A firm's investment in intangible assets is then assumed to be proportional to the firm's labour costs associated with workers in these intangible occupations (i.e. involved in the creation of intangible capital goods). We choose the proportionality factor (or investment share) i^{IC} using common assumptions in the literature which are detailed in Table 1. Thus, a firm's own-account investment in intangible assets is derived as:

[7] See Giorgio-Marrano et al (2009) and Haskel et al (2013) for application of these to the UK using the Corrado et al (2006) methodology.

[8] For a related, but broader, occupational classifications of occupations involved in the production of intangibles see FP7 INNODRIVE and Riley and Robinson (2011) *Skills and Economic Performance: The Impact of Intangible Assets on UK Productivity Growth*, UK Commission for Employment and Skills.

[9] In the next version of this paper we use these occupations not to understand own account investment in intangibles in individual firms, which is only possible for the very few very large firms for whom we have sufficient numbers of linked workers, but rather to understand the employment structure of different segments of the productivity distribution across firms.

(1) $$I_{it}^{IC} = {}^{i^{IC}}w_{it}^{IC}L_{it}^{IC}$$

where w_{it}^{IC} and L_{it}^{IC} are the wage and labour input of intangible workers type *IC* (where *IC=DI, IP, HRM, BRAND, MANAGEMENT)* in firm *i* at time *t*.

Having determined an investment flow, either as per equation (1) or as determined by firms' responses to survey questions about their investment expenditures and intermediate purchases we then capitalize these investments for the firm according to the perpetual inventory method:

(2) $$K_{it}^{IC} = I_{it}^{IC} + (1-\delta^{IC})K_{it-1}^{IC}$$

where K_{it}^{IC} denotes the end of year stock of intangible capital type *IC* and δ^{IC} denotes the depreciation rate. As described in Görzig et al (2011), we assume starting stocks (for the year before we first observe a firm in the data) are proportional to the sample average of intangible investment (discounted appropriately), $\bar{I}_i^{IC}$, for the firm:

(3) $$K_{i\,start}^{IC} = \bar{I}_i^{IC}\frac{1-(1-\delta^{IC}-g)^T}{1-(1-\delta^{IC}-g)}$$

where *T* is set to 100 and *g* is set to 0.02. Inevitably, with a relatively short span of firm-level data, our intangible capital stocks are sensitive to these initial assumptions. Table 1 details our data sources, and key assumptions made about investment shares and depreciation rates. We highlight in red the data components that we focus on in this paper.

Table 1. Assumptions and data sources

Intangibles	***Data description***	***Source***	***Investment share***	***Depreciation rate***
Digitised information				
Own account	Labour costs of IT occupations	ASHE/ARD	0.50	0.33
	Investment in Software/Dbase	**ARD**	**1.00**	**0.33**
Purchased	**Investment in Software/Dbase**	**ARD**	**1.00**	**0.33**
Intellectual Property				
Own account	Labour costs of R&D occupations	ASHE/ARD	1.00	0.20
	Intramural R&D expenditure	**BERD**	**1.00**	**0.20**
Purchased	**Extramural R&D expenditure (adjust tangibles investment)**	**BERD**	**1.00**	**0.20**
Organisational				
Brand				
Own account	Labour costs of sales occupations	ASHE/ARD	0.40	0.55
Purchased	**Purchases of Advertising Services**	**ARD**	**0.60**	**0.55**
Management (OA)	Labour costs of manager occupations	ASHE/ARD	0.20	0.40
HRM (OA)	Labour costs of HR occupations	ASHE/ARD	0.20	0.40

Depreciation rates and investment shares based on assumptions in Corrado, Hulten & Sichel (2005, 2006), Giorgio Marrano, Haskel & Wallis (2009), Görzig, Piekkola & Riley (2011), Corrado, Haskel, Jona-Lasinio & Iommi (2012).

3. Data

Our main data sources are the ARDX and BERD (the two datasets are linked together by an establishment indicator). We derive the firm level productivity distribution using the ARDX focusing on all firms with 10 or more employees[10], but for our analysis of intangibles we consider only large firms (with 250 employees or more). This is because we have better longitudinal information for these firms, necessary for constructing capital stocks, because the link between ARDX and BERD is best for large firms, and because large firms are more likely to have provided detailed information in the ARDX (i.e. responded to the detailed questionnaire which queries investment and intermediate purchases). We consider the non-farm non-financial market sector.[11]

The ARD(x) dataset

The Annual Respondents Database (ARDX)[12] is an establishment level business survey (or set of surveys) conducted by the UK Office for National Statistics (ONS) that is widely used in the study of firm behaviour and productivity analysis in the UK. The ARDX holds information on the nature of production in British businesses and is essentially a census of larger establishments and a stratified (by industry, region and employment size) random sample of establishments with less than 250 employees (SMEs). It covers businesses in the non-financial non-agriculture market sectors back to 1997, but the key questions we need to measure intangibles are not available before 2002.

The sampling frame for the ARDX is the Inter-Departmental Business Register (IDBR), a list of all UK incorporated businesses and other businesses registered for tax purposes (employee or sales taxes). Sampling probabilities in the ARDX vary by size of firm. The population data allows us to calculate grossing weights so that our analysis is representative[13]. We also use information in the ARDX on firms' investment expenditures to construct tangible capital stock. We construct firm level measures of machinery & equipment capital stocks using information on investment net of disposals. Investments are deflated by investment deflators by asset and industry obtained from ONS. Firm-level capital stocks are then calculated using the perpetual inventory method and EUKLEMS depreciation rates. Starting stocks are informed by industry capital stocks that can be derived by a similar method using EUKLEMS/ONS investment data.

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[10] We exclude firms with 0-9 employees as the survey does not provide very accurate estimates of productivity for these firms. Also, due to sampling rules there are very few of these micro businesses in the longitudinal data, despite their significant presence in the economy. For a discussion of these issues see Riley and Rosazza Bondibene (2016).

[11] The ARDX does not survey firms in the financial sector. We also exclude mining and real estate.

[12] ONS. VML. University of West England, Bristol (2017)

[13] We follow the advice in ONS (2002) and use the ratio of population to survey aggregates (e.g. number of firms or employment) within sampling strata as grossing weights. Sampling strata are defined in terms of industry, employment size groups and region. We ignore regions due to small cell sizes. Extreme grossing weights due to small cell sizes are eliminated by further aggregating industry groups and then recalculating.

The ARDX financial information is published in current values. GVA deflators published by the ONS are used to construct real values; these are available at the 2- and sometimes the 3-digit sector level.

The ASHE dataset

The Annual Survey of Hours and Earnings (ASHE)[14] is a 1% random sample of employee jobs on the PAYE register held by the UK tax authorities, and contains detailed information on approximately 160,000 employees every year. Sample selection occurs on the basis of National Insurance numbers and is maintained over time. The survey covers all sectors of the UK economy. Detailed information on pay and hours worked are collected from employers, as well as detailed occupation and industry category. It contains no information on employees' qualifications.

The BERD dataset

The Business Expenditure on Research and Development (BERD)[15] is an annual survey designed to measure R&D expenditure and employment in the UK. The survey ask for quantitative data on in house expenditure in R&D (own account R&D) and how much is commissioned outside the company (purchased R&D), along with average employment and headcount on R&D. We adjust tangible investment from the ARDX with intramural R&D expenditure on machinery and equipment so as not to double count machinery and equipment investment. Since 1995, the BERD survey has used a stratified random sample, stratified by product group and employment size bands, where only larger firms with 400 or more employees are fully sampled[16]. The BERD also contains imputed information on R&D for all the other firms in the UK economy doing R&D (i.e. not in the selected sample). For the non-selected establishments, data is imputed on the basis that these enterprises have the same R&D to employment ratio as selected establishments in their class.

Linked and matched samples

In order to generate the wage and the labour input of intangible workers as expressed in equation (1) we need to link the ARDX and the ASHE. Since the ARDX contains information only on employment and labour cost totals of a firm, we need to measure the occupational distribution of the firms' workforce from ASHE. We therefore link information on the occupational distribution of labour costs and employment from the ASHE to the financial information of firms in the ARDX via the enterprise reference available in both datasets. This way we are able to generate wage and labour inputs of intangible workers. However, this procedure is only meaningful for firms where we have a sufficient number of ASHE employees. Because of the restrictive ASHE sample of firms' employees, our firm-sample becomes very limited in coverage and highly skewed towards very large firms. For

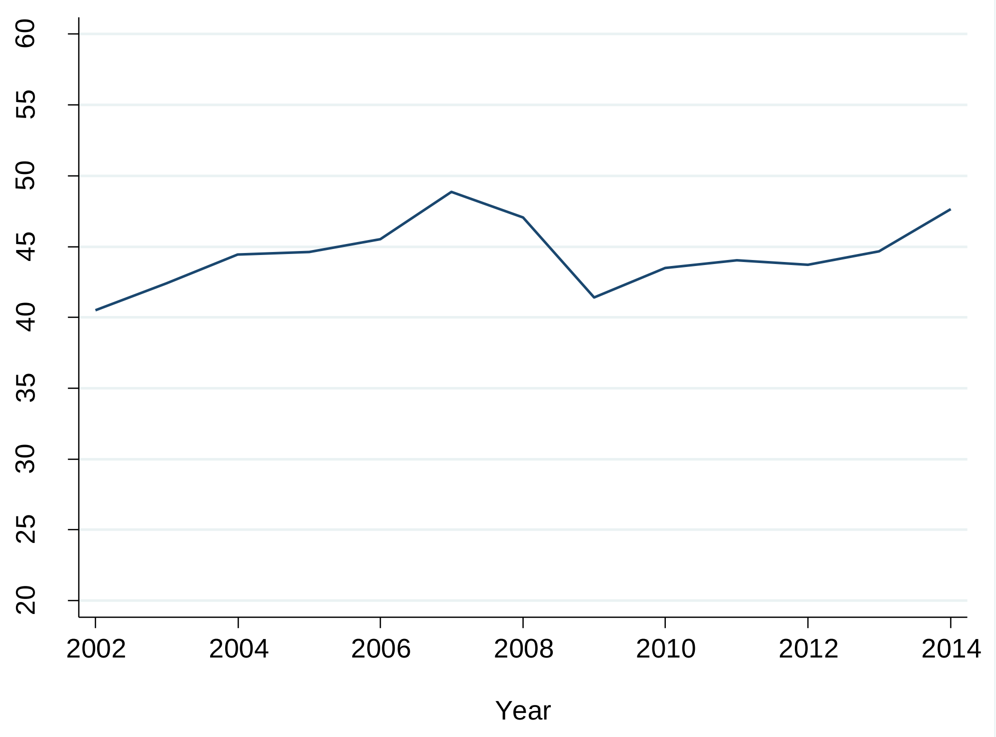
[14] ONS (2018)
[15] ONS (2017).

instance, focusing on linked firms where we have at least 10 ASHE employees and for which we have full financial information, we achieve a sample of approximately 400 firms per annum. It is however possible to use this linked information to study the occupational mix, returns to intangible occupations and wage premia for segments of the firm productivity distribution. We also link the BERD and the ARDX using establishment reference numbers in order to gather information on intramural and extramural R&D. Our final linked data covers the period 2002-2015.

4. The UK productivity distribution

Figure 1 illustrates the productivity profile that results from aggregating up the sample of firms that we focus on using population weights. The profile displays the familiar pattern of productivity stagnation after the financial crisis, despite the exclusion of micro firms and a number of key sectors that aren't adequately covered in the ARDX. We exclude firms that report financial variables for periods other than 12 months. We also exclude imputed responses and this has the effect of delaying in Figure 1 the recovery of productivity levels to pre-crisis levels. We exclude from the sample firms with productivity levels below the 1st percentile or with productivity levels above the 99th percentile, by 2-digit industry code and year.

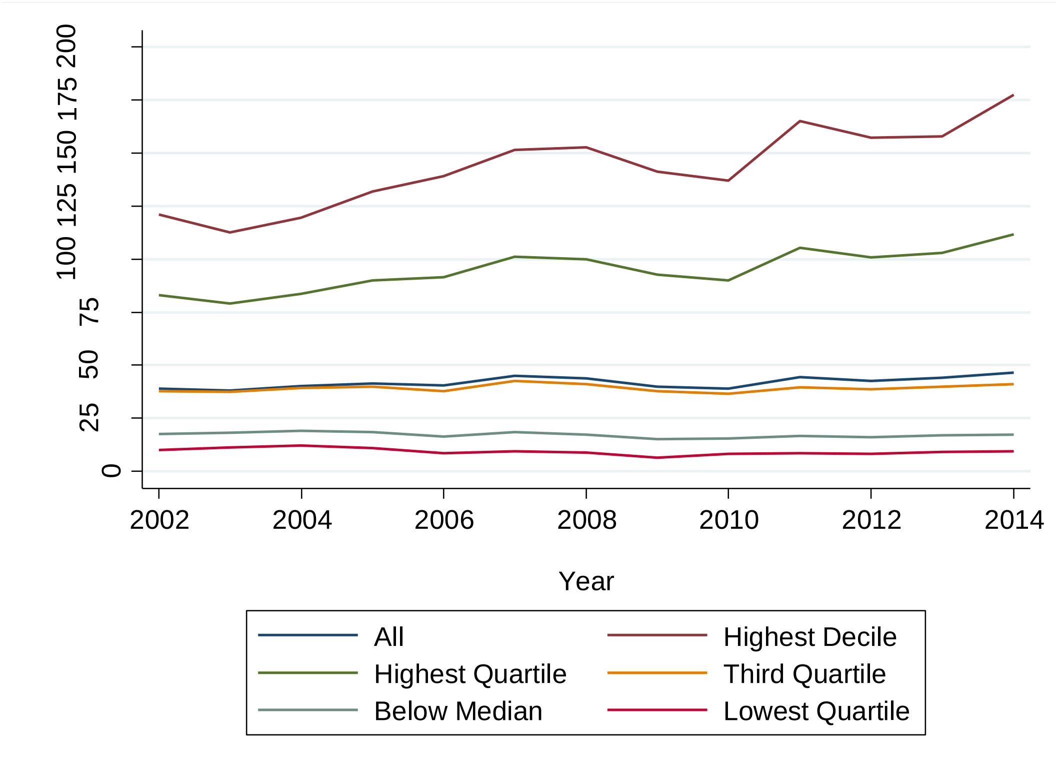
Figure 1: Aggregate labour productivity 2002-2014



Source: ARDX, Own calculations.

Figure 2 shows the simple average of productivity across firms for firms in different segments of the productivity distribution, which we calculate by 2-digit industry code and year.[17] We observe the very significant disparities in mean productivity between firms in the upper parts of the distribution and those elsewhere. What is more, these differences have been widening over time as productivity in the upper part of the distribution has grown faster than elsewhere.

Figure 2: Mean labour productivity by segment of the labour productivity distribution (mean across firms)



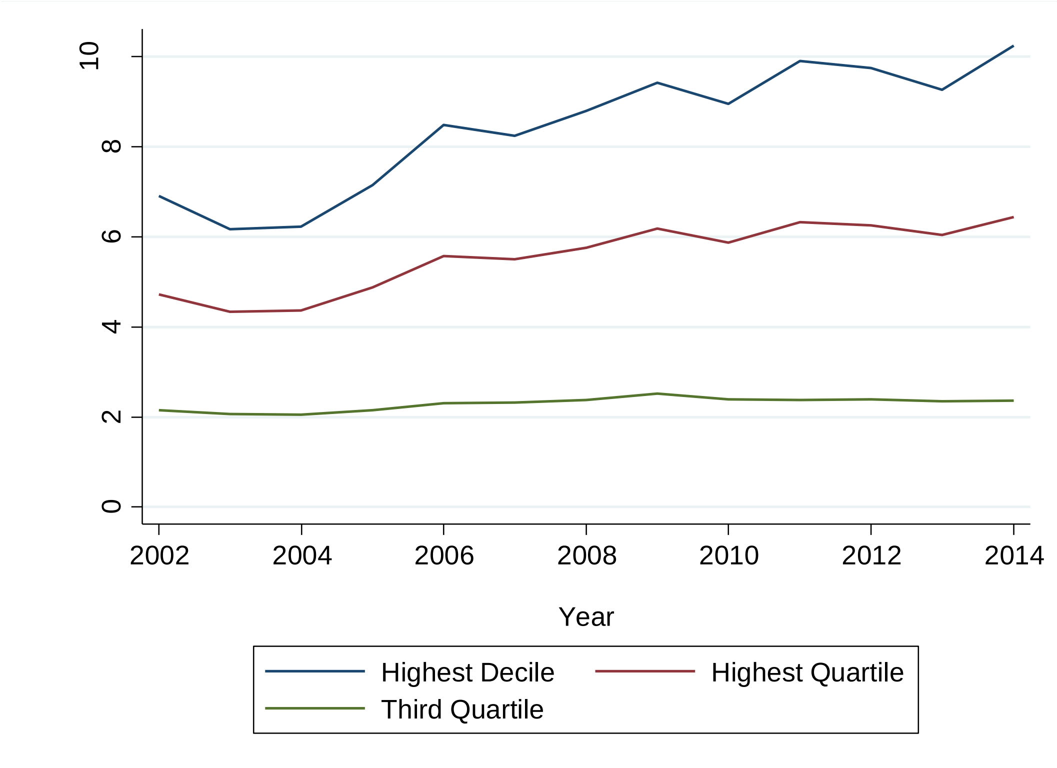
Source: ARDX, Own calculations.
Notes: Labour productivity distribution calculated across establishments. Weighted to the sample population.

The extent of this fanning out of the distribution is easier to see in Figure 3 where we show the ratio of mean productivity of firms in the upper decile, upper (fourth) quartile and third quartile compared to firms in the lower half of the productivity distribution. On average between 2002-2004, mean productivity in the upper quartile of firms was 4.5 times mean productivity amongst firms in the lower half of the productivity distribution. Mean productivity in the upper decile of firms was 6.4 times mean productivity amongst firms in the lower half of the productivity distribution. Ten years later, on average 2012-2014, mean productivity in the upper quartile of firms had risen to 6.2 times mean productivity amongst

[17] This is similar to the industry detail used in Andrews, Criscuolo and Gal (2016).

firms in the lower half of the productivity distribution. In the upper decile of firms mean productivity was now 9.7 times that in the lower half.

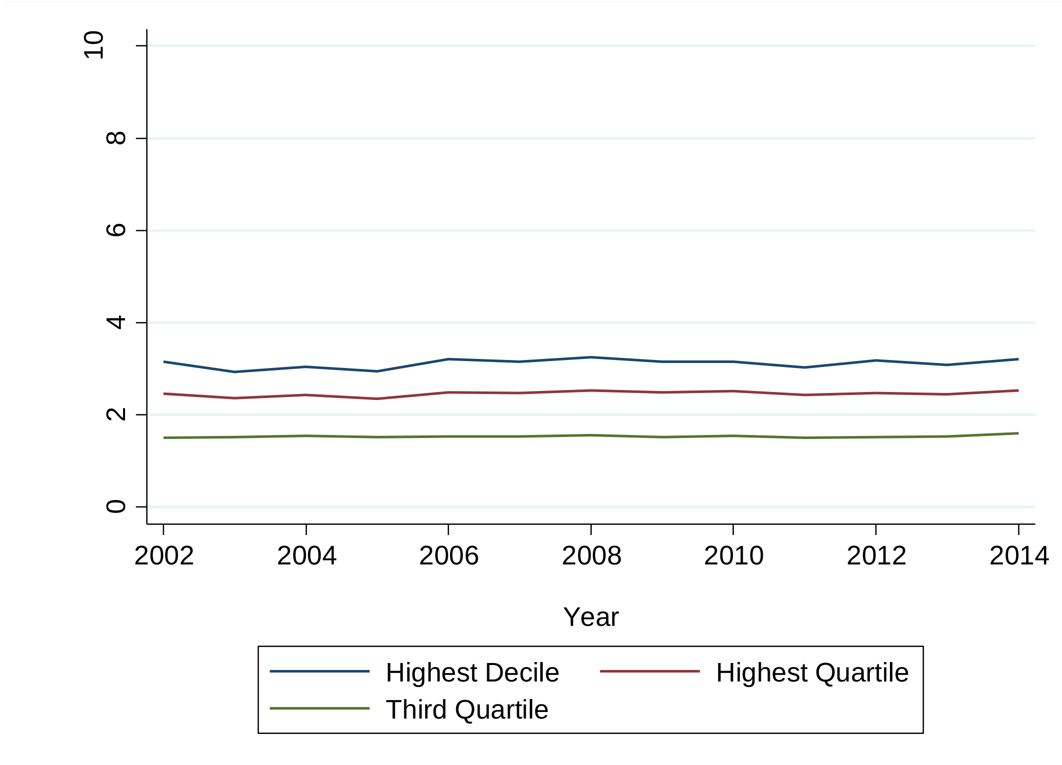
Figure 3: Mean labour productivity by segment of the labour productivity distribution relative to firms with below median productivity



Source: ARDX, Own calculations.
Notes: Labour productivity distribution calculated across establishments. Weighted to the sample population. Ratio of labour productivity in 2010 prices.

In Figure 4 we plot the ratio of labour costs per employee (average across firms) for firms in the higher parts of the productivity distribution compared to firms in the lower half of the productivity distribution. Two things stand out. First, firms in the upper parts of the productivity distribution by industry pay better wages (proxied here by labour costs per head) on average than do other firms. This is most likely because these top firms employ more highly skilled workers, something which we aim to explore using the linked ASHE data. But, the wage premium in these firms is much less than the productivity premium. For example, on average between 2002-2004, mean labour costs per employee for firms in the upper quartile of the productivity distribution were 2.4 times mean labour costs per employee amongst firms in the lower half of the productivity distribution. This compares to a productivity ratio of 4.5 between these two groups. Mean labour costs per employee amongst firms in the upper decile of the productivity distribution were 3.1 times that amongst firms in the lower half of the productivity distribution. This compares to a productivity ratio of 6.4 between these two groups. Because top firms are not very different in size to other firms this means their labour share is relatively small. Second, the wage premium in these top firms has not been rising over time, in sharp contrast to the productivity premium, which will contribute to a lessening of the aggregate labour share.

Figure 4: Mean labour costs per employee by segment of the labour productivity distribution relative to firms with below median productivity



Source: ARDX, Own calculations.
Notes: Labour productivity distribution calculated across establishments. Weighted to the sample population. Ratio of labour costs per employee in current values.

What is clear from this analysis is that what happens to firms at the top of the productivity distribution is crucial for aggregate productivity. This is not because they are particularly large firms. Indeed the top 10 per cent of firms account for around 10 per cent of employment (see Table 2). Rather this is because productivity at the top is so far from productivity amongst the bulk of the firm population. Table 2 also shows that the lower half of the productivity distribution accounts for a little more than 40 per cent of employees. Thus, firms in the lower half of the productivity distribution are smaller (on average) than firms in the upper half of the productivity distribution. Weighted to the population the sample covers around 15 million employees on average per year, just under half of UK employees.

Table 2. Total employment share of firms in different segments of the labour productivity distribution

Year	Highest Decile	Highest Quartile	Third Quartile	Below Median	Lowest Quartile
2002	0.11	0.29	0.29	0.42	0.18
2003	0.11	0.29	0.31	0.40	0.18
2004	0.11	0.28	0.31	0.41	0.17
2005	0.10	0.28	0.29	0.43	0.18
2006	0.10	0.27	0.32	0.41	0.15
2007	0.11	0.28	0.29	0.43	0.17
2008	0.10	0.26	0.32	0.42	0.18
2009	0.09	0.25	0.32	0.43	0.18
2010	0.09	0.28	0.32	0.40	0.17
2011	0.10	0.28	0.30	0.42	0.18
2012	0.11	0.29	0.30	0.41	0.17
2013	0.10	0.29	0.32	0.40	0.15
2014	0.11	0.28	0.32	0.40	0.16

Table 3 shows other characteristics of firms in the different parts of the productivity distribution, on average between 2002 and 2004 and on average between 2012 and 2014. Firms in the upper parts of the productivity distribution are much more likely to be foreign owned and are much more likely to be part of a multi-establishment group than other firms. These differences between firms in the upper and lower parts of the productivity distribution have increased over time. Top firms also invest more per employee than other firms. For example, on average between 2002-2004 in 2010 prices, mean investment per employee for firms in the upper decile of the productivity distribution was £8000 compared to £1000 for firms with below median productivity. In absolute terms these differences have increased over time, but not in relative terms.

Table 3. Characteristics of firms in different segments of the labour productivity distribution

	All	Highest Decile	Highest Quartile	Third Quartile	Below Median	Lowest Quartile
Average 2002-2004						
GVA/employment	39.1	117.8	81.9	38.2	18.3	11.2
Labour cost per employee	25.0	51.3	40.8	25.7	16.9	14.3
Employment	81	91	93	98	67	58
Age	17	16	16	17	17	17
Foreign owned	0.05	0.12	0.09	0.05	0.04	0.04
Part of multi-establishment group	0.20	0.32	0.28	0.20	0.17	0.17
Ratio of investment to employment	2.4	8.0	5.3	2.2	1.0	0.6
Average 2012-2014						
GVA/employment	44.5	164.2	105.2	39.9	16.8	8.9
Labour cost per employee	23.9	50.1	39.4	24.6	15.8	13.6
Employment	78	86	91	97	62	49
Age	20	19	20	20	20	19
Foreign owned	0.07	0.16	0.13	0.07	0.04	0.04
Part of multi-establishment group	0.20	0.36	0.30	0.19	0.15	0.15
Ratio of investment to employment	3.7	12.9	8.1	2.9	1.9	2.0
Observations (average per year)	23171	2513	6197	6013	10961	5246

Source: ARDX, Own calculations.
Notes: All financial variables are in £thousand, 2010 prices. Investment includes tangible investment including land and buildings, as well as software and databases. Population weighted. Firms with 10 or more employees in the non-farm non-financial business sector.

5. Intangibles and productivity

As discussed above, we calculate intangible investment for larger firms with 250 or more employees. Table 4 shows the characteristics of larger firms at different points in the labour productivity distribution. The labour productivity distribution is still calculated from the sample including smaller firms. Comparing Table 4 to Table 3, we note among large firms similar patterns to what we see among the full sample: disparities in productivity are larger than wage disparities and are rising over time; higher productivity firms are much more likely to be foreign owned and part of a multi-establishment group, and invest more per employee. These disparities have been rising over time.

Table 4. Characteristics of firms in different segments of the labour productivity distribution (Firms with 250 or more employees)

	All	**Highest Decile**	**Highest Quartile**	**Third Quartile**	**Below Median**	**Lowest Quartile**
Average 2002-2004						
GVA/employment	46.4	118.8	88.2	41.2	18.1	8.9
Labour cost per employee	29.5	49.0	42.1	28.9	20.3	18.2
Employment	1363	1187	1336	1686	1178	1025
Age	21	22	22	22	20	20
Foreign owned	0.27	0.37	0.33	0.26	0.22	0.22
Part of multi-establishment group	0.70	0.78	0.76	0.71	0.63	0.62
Ratio of investment to employment	4.43	12.62	8.81	3.41	1.79	1.66
Machinery & Equipment	3.78	10.49	7.37	3.03	1.56	1.44
Intangibles	3.19	8.04	5.81	2.34	1.76	2.36
Software & Databases	0.26	0.67	0.49	0.20	0.13	0.13
Research & Development	1.54	3.28	2.48	1.24	1.02	1.51
Advertising & Marketing	1.39	4.10	2.85	0.90	0.60	0.71
Average 2012-2014						
GVA/employment	55.0	163.4	112.6	43.8	16.3	4.7
Labour cost per employee	31.9	55.3	46.8	30.4	20.9	19.6
Employment	1578	1210	1469	1944	1409	1165
Age	28	30	30	29	27	25
Foreign owned	0.34	0.47	0.44	0.34	0.26	0.27
Part of multi-establishment group	0.69	0.81	0.77	0.70	0.61	0.62
Ratio of investment to employment	6.01	16.41	11.73	4.79	2.22	2.29
Machinery & Equipment	5.13	14.02	10.01	3.92	2.01	2.17
Intangibles	4.41	11.10	8.51	2.93	2.14	3.15
Software & Databases	0.60	1.57	1.12	0.49	0.26	0.30
Research & Development	2.27	5.54	4.35	1.31	1.26	2.17
Advertising & Marketing	1.54	3.99	3.05	1.13	0.62	0.68
Observations (average per year)	4889	684	1571	1355	1964	848

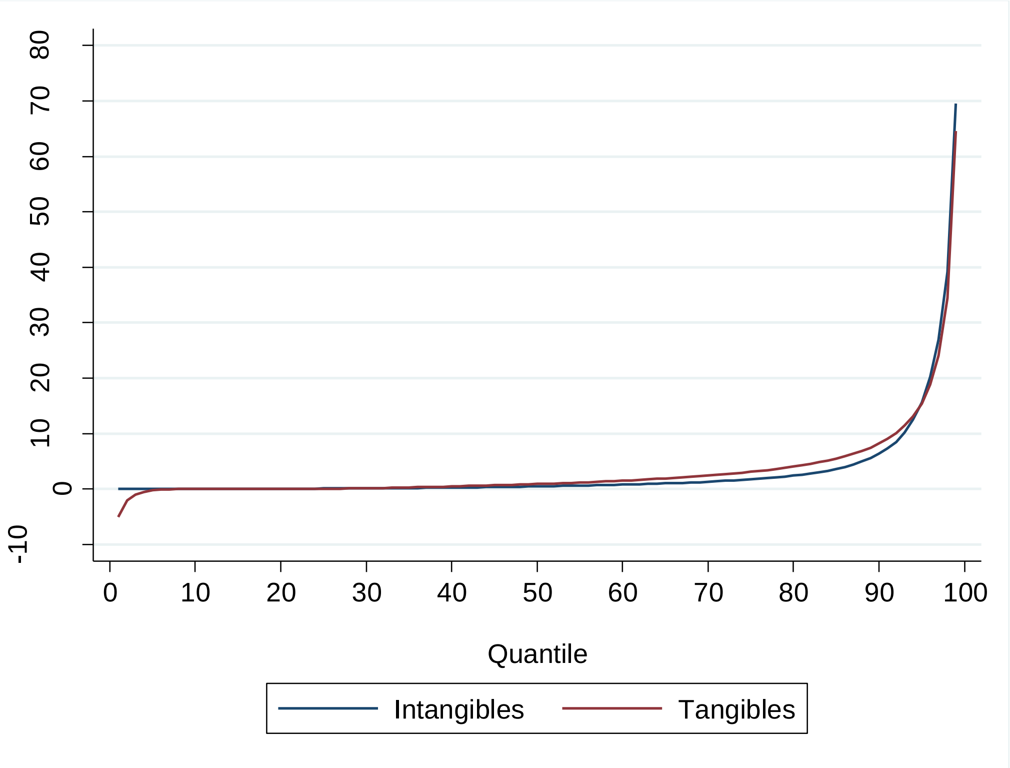
Source: ARDX, BERD, Own calculations.

Notes: All financial variables are in £thousand, 2010 prices. Population weighted. Characteristics of firms with 250 or more employees in the non-farm non-financial business sector. The productivity distribution is calculated on firms with 10 or more employees. Investment includes tangible investment including land and buildings, as well as software and databases, therefore investment is not the total of tangible and intangible investment. It is included for comparability to Table 3, which includes smaller firms.

In Table 4 we are also able to contrast firms in different parts of the productivity distribution in terms of their investments in intangibles. We see that top performers in terms of productivity invest more in intangibles than their less productive counterparts. On average between 2002-2004, large firms in the top decile of the productivity distribution invested (per employee, on average across firms in 2010 prices) £670 on Software & Databases, £3280 on Research & Development and £4100 on Advertising & Marketing. The equivalent numbers for firms in the lower half of the distribution were £130 on Software & Databases, £1020 on Research & Development and £600 on Advertising & Marketing. Differences in Advertising & Marketing investment between low and high productivity firms are particularly stark. One decade later these differences in intangible investments across firms in the upper and lower parts of the productivity distribution remain. In the case of investments in Research & Development and in Software & Databases these differences have become more stark. On average between 2012-2014, large firms in the top decile of the productivity distribution invested (per employee, on average across firms in 2010 prices) £1570 on Software & Databases, £5540 on Research & Development and £3990 on Advertising & Marketing. Intangible investment amongst firms in the lower half of the distribution remained relatively low: £260 on Software & Databases, £1260 on Research & Development and £620 on Advertising & Marketing. Thus it would appear that, much as tangible investment, intangible investment is relatively concentrated amongst higher productivity firms.

The skewedness of investment is also illustrated in Figure 5. There we show the cumulative density of both tangible and intangible investment per employee. From Figure 5 it is evident that the distribution of investment is highly skewed, such that investment is concentrated amongst relatively few firms. Intangible investment appears even more concentrated amongst a few firms than tangible investment. From Table 4 we know that these firms are likely to be much more productive than other firms. Of course, firms may be productive in some years and less productive in others, moving between different parts of the productivity distribution. On average over our sample period, 68% (77%) of large firms in the top decile (quartile) of the productivity distribution remain in the top decile (quartile) from one year to the next (see Table 5). After five years around half (two thirds) of these firms are in the top decile. The bottom quartile is less sticky. On average over our sample period, 63% of the 25% lowest productivity firms are likely to remain in this position from one year to the next and two fifths find themselves in this position after five years. However, between the early 2000s and the early 2010s, the top and bottom quartiles of the productivity distribution have become stickier (Table 5). Firms that are relatively high productivity became more likely to remain high productivity, and firms that were relatively low productivity became more likely to remain low productivity.

Figure 5: Cumulative distribution of investment per employee
(Firms with 250 or more employees)



Source: ARDX and BERD, Own calculations.
Notes: Years 2002-2015.

Table 5. Productivity distribution dynamics (Firms with 250 or more employees)

	Probability of staying in the same part of the productivity distribution after:				
	2002-2014			*2002-2003*	*2012-2013*
	1 year	2 years	5 years	2 years	2 years
Highest Decile	0.68	0.61	0.52	0.60	0.55
Highest Quartile	0.77	0.71	0.64	0.70	0.75
Lowest Quartile	0.63	0.54	0.41	0.59	0.65

Source: ARDX, Own calculations.
Notes: Population weighted. Firms with 250 or more employees in the non-farm non-financial business sector. The productivity distribution is calculated on firms with 10 or more employees.

More formally, we investigate the role of intangibles within a production function framework. We start by examining the relationship between firm productivity and intangible investment within a simple production function framework as in equation (4):

$$(1) \qquad Y_{it} = aY_{it-1} + \sum_j \sum_{l=0}^{2} b_l^j X_{i,t-l}^j + d_i + u_{it}$$

where Y_{it} is gross value added per employee and $X^j_{i,t-l}$ is a vector of investment per employee, where *j* denotes the type of investment. The d_i are firm level fixed effects and u_{it} is the error term, which includes a firm and a random component.[18] All variables are measured in logs.

We estimate equation (4) for firms in four different sectors: high-tech manufacturing, low-tech manufacturing, knowledge intensive services, and other services (descriptive statistics are reported in appendix B1). These sectors are defined using Eurostat definitions. Results are shown in Table 6. The regressions there also include additional controls: interactions between year and 2-digit industry dummies, foreign ownership, part of a multi-establishment group, age. We report the long run coefficients on investment per employee. In Table 6 we see in the first column, looking at all intangibles as one category, that the returns to investment are similar for tangibles and intangibles, with long run coefficients of 0.077 and 0.073 respectively. When we look at the four different sectors, we find that the long run coefficient on intangible investment is not statistically significant in the manufacturing sectors, but remains significant in the services sectors. Looking at intangible investment disaggregated into the three components (digitized assets, intellectual property and economic competencies), for the market sector as a whole, we find variation in the returns to investment. The largest returns are to advertising & marketing. By sector these returns are similar, although do not signify outside lower-tech manufacturing. The coefficient on investment in software and databases is significantly higher in services than in manufacturing.

Next, we capitalise investment expenditures and estimate a more traditional production function. Now, in equation (4), Y_{it} is gross value added and $X^j_{i,t-l}$ is a vector of production inputs, including capital stocks and employment (descriptive statistics are reported in appendix B2). In Table 7 we report the results of estimating this model using OLS. Interactions between year and 3-digit industry dummies are included, as well as indicators of foreign ownership, part of a multi-establishment group, and age. We report the long run coefficients on capital and employment. In Table 7 we find the coefficients on advertising & marketing capital and on software & databases capital are higher in services than in manufacturing. Tangible capital is relatively more important in manufacturing. Now capitalised, research & development is statistically significant in most sectors. In Table 8 we introduce firm-level fixed effects. With this specification, the industry detail and inclusion of

[18] We can think of this as an approximation to a standard production function, where the firm-level fixed effects absorb persistent differences in capital stocks. The benefit of this specification over what follows is that we do not introduce measurement error from starting stocks.

disaggregated intangibles the coefficients are no longer statistically significant. However, the coefficient on advertising & marketing capital remains statistically significant in lower tech manufacturing and the coefficients on research & development and software & databases remain statistically significant in knowledge intensive services.

Finally, we explore the relationship between intangible capital and productivity using the small sample of very large firms for which we develop occupational based measures of intangible capital stock. These are own-account measures. Using a system-GMM approach to estimating the production function we report long-run coefficients in Table 9. Here we find that tangible capital is important for output in manufacturing and services outside high-tech manufacturing and knowledge intensive services. Digitised information signifies in these knowledge intensive sectors as does management capital. Research & Development is important in high-tech manufacturing. In other manufacturing advertising & marketing appears important.

To summarise our estimation results, we find evidence to suggest that intangible capital is an important driver of firm-level productivity alongside tangible capital. The importance of these investments appears to vary across sectors and types of intangible capital.

Table 6. Productivity and investment per employee, Fixed-effects regression

	Non-Farm Non-Finance Market Sector			**High Tech Manufacturing**			**Low Tech Manufacturing**			**Knowledge Intensive Services**			**Other Services**		
	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val
Ratio of investment to employment															
Machinery & Equipment	0.0773	7.16	0.000	0.0511	1.78	0.076	0.1037	4.46	0.000	0.1001	4.32	0.000	0.0534	3.09	0.002
Intangibles	0.0728	3.78	0.000	-0.0021	0.05	0.957	0.0550	1.23	0.220	0.1010	2.92	0.004	0.1053	2.41	0.016
R-squared		0.53			0.38			0.29			0.44			0.30	
Ratio of investment to employment															
Machinery & Equipment	0.0754	7.02	0.000	0.0494	1.76	0.078	0.1026	4.44	0.000	0.0963	4.17	0.000	0.0541	3.11	0.002
Intangibles															
Software & Databases	0.0614	2.26	0.024	0.0208	0.23	0.819	0.0112	0.18	0.860	0.0963	2.29	0.022	0.0592	1.23	0.218
Research & Development	0.0252	1.19	0.233	-0.0141	0.35	0.729	-0.0096	0.22	0.829	0.0491	1.34	0.179	0.0522	1.10	0.272
Advertising & Marketing	0.1041	3.14	0.002	0.1063	1.23	0.219	0.1167	2.04	0.041	0.0982	1.58	0.113	0.0897	1.36	0.174
R-squared		0.53			0.38			0.26			0.55			0.30	
Observations		32116			3589			5832			7788			12391	
Establishments		6948			805			1260			1824			2757	

Table 7. Production function estimates, OLS regression

	High Tech Manufacturing			Low Tech Manufacturing			Knowledge Intensive Services			Other Services		
	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val
Employment	0.8692	14.47	0.000	0.8186	11.88	0.000	0.6390	8.93	0.000	0.6250	15.42	0.000
Capital stock												
Machinery & Equipment	0.1876	5.26	0.000	0.1826	4.72	0.000	0.1334	3.16	0.002	0.1675	6.30	0.000
Software & Databases	0.0106	0.76	0.447	0.0071	0.65	0.512	0.0300	1.08	0.279	0.0348	2.86	0.004
Research & Development	0.0319	3.76	0.000	0.0122	1.44	0.149	0.0384	2.21	0.027	0.0214	2.28	0.023
Advertising & Marketing	0.0261	1.78	0.074	0.0531	4.67	0.000	0.1612	4.34	0.000	0.1163	6.04	0.000
R-squared		0.89			0.86			0.95			0.91	
Observations		3589			6021			5849			9798	
Establishments		703			1125			1194			2224	

Source: ARDX and BERD.

Note: Years 2003-2015. OLS regression. Clustered errors (by establishment).

Table 8. Production function estimates, Fixed-effects regression

	High Tech Manufacturing			**Low Tech Manufacturing**			**Knowledge Intensive Services**			**Other Services**		
	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val	Coeff.	t-stat	p-val
Employment	0.6038	7.28	0.000	0.4298	6.36	0.000	0.4181	6.04	0.000	0.5185	9.53	0.000
Capital stock												
Machinery & Equipment	0.1247	2.54	0.011	0.0660	2.43	0.015	0.0766	2.83	0.005	0.0735	3.01	0.003
Software & Databases	0.0127	0.84	0.403	0.0061	0.57	0.567	0.0237	1.82	0.068	0.0087	1.01	0.312
Research & Development	0.0043	0.44	0.662	-0.0106	1.08	0.282	0.0243	1.92	0.054	-0.0117	1.19	0.235
Advertising & Marketing	-0.0072	0.31	0.756	0.0299	1.92	0.055	0.0465	1.56	0.118	0.0188	1.15	0.252
R-squared (overall)		0.72			0.57			0.86			0.73	
Observations		3589			6021			5849			9798	
Establishments		703			1125			1194			2224	

Source: ARDX and BERD.

Note: Years 2003-2015. Fixed effects regression. Clustered errors (by establishment).

Table 9. Production function estimates, System GMM, very large firms

	Manufacturing				Services			
	High-tech		**Other**		**Knowledge intensive**		**Other**	
Employment	0.625	***	0.431	***	0.637	***	0.795	***
Physical capital	0.056		0.248	**	0.022		0.146	***
Digitised information	0.076	***	-0.032		0.071	**	0.03	
Intellectual property	0.044	*	0.027		-0.025		0.005	
Brand	-0.018		0.129	**	0.006		0.061	*
Management	0.073	***	0.019		0.041	**	-0.025	
HRM	0.015		0.048	**	0.002		0.002	
Observations	394		435		1078		2007	

Source: Annual Respondents Database and Annual Survey of Hours and Earnings; Machinery & Equipment capital stocks made available by Richard Harris; Authors' calculations.
Notes: Large firm sample; 1998-2012; manufacturing & business services excl. finance; tangibles include machinery & equipment; firms with a minimum of 4 observations; GMM system estimation; DPV is log GVA; * 10%, ** 5%, *** 1% statistical significance.

7. Concluding remarks

This paper develops a comprehensive dataset on UK firms, their inputs and outputs, in order to explore the relationship between intangible investment and productivity. We find that the distribution of intangible capital is skewed, with much concentrated in few firms. For those firms that do make investments in intangibles the rewards are potentially high. Firms that invest significantly in intangibles tend to be in the higher end of the productivity distribution. Within a dynamic production function framework we also find evidence that these investments are associated with significant returns. Our analysis points to a role for intangible assets in the widening of the productivity distribution, although many other factors are likely at play here too. In further analysis we aim to explore the role of workers in intangible occupations in the firm-level productivity distribution.

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APPENDIX A

Table A1. Occupations involved in the production of knowledge assets by each Standard Occupation Classification (SOC)

	SOC90	**SOC00**	**SOC10**
ICT	Computer systems and data processing managers, Software engineers, Computer analysts, programmers	Information and communication technology managers, IT strategy and planning professionals, Software professional	Information technology and telecommunications directors, Information Technology and Telecommunications Professionals (IT specialist managers, IT project and programme managers, IT business analysts, architects and systems, designers, Programmers and software development professionals, Web design and development professionals, Information technology and telecommunications professionals nec
ICT_B	Computer systems and data processing managers, Software engineers, Computer analysts, programmers.	IT operation technicians, IT user support technicians	Information Technology Technicians (IT operations technicians, IT user support technicians)
R&D	Other managers in farming, horticulture, forestry and fishing, Natural scientists (Chemists, biological scientists and biochemists, physicists, geologists and meteorologists, other natural scientists), Civil structural, municipal, mining and quarrying engineers, mechanical engineers, electrical engineers, electronic engineers, chemical engineers, design and development engineers, process and production engineers, planning and quality control engineers, other engineers and technologists, University and polytechnic teaching professionals, Architects, Town planners, Other social and	Research and development managers, Natural environment and conservation managers, Science professionals (Chemists, biological scientists and biochemists, physicists, geologists and meteorologists), Engineering professionals (civil engineers, mechanical engineers, electrical engineers, electronics engineers, chemical engineers, design and development engineers, production and process engineers, planning and quality control engineers, engineers and professional nec, Research professionals (Scientific researchers, social science researchers, researchers nec), Architects,	Natural and Social Science Professionals (Chemical scientists, Biological scientists and biochemists, Physical scientists, Social and humanities scientists, Natural and social science professionals nec), Engineering Professionals (Civil engineers, Mechanical engineers, Electrical engineers, Electronics engineers, Design and development engineers, Production and process engineers, Engineering professionals nec), Conservation and Environment Professionals, Conservation professionals, Environment professionals Research and Development Managers, Business and related research professionals,,

	behavioural scientists, Artists, commercial artists and graphic designers, industrial designers, clothing designers, actors entertainers, stage managers, producers and directors	town planners, Artists, Art officers, producers and directors, Design associate professionals (graphic designers, product clothing and related designers), Broadcasting associate professionals, Conservation and environmental protection officers	Architects, Town planning officers, Quality control and planning engineers, Artists, Arts officers, producers and directors, Design Occupations, Graphic designers, Product, clothing and related designers
R&D_B	Scientific technicians (laboratory technicians, engineering technicians, electrical, electronic technicians, architectural and town planning technicians, building and civil engineering technicians, other scientific technicians), Draughtspersons, Routine laboratory testers	Science and engineering technicians (laboratory technicians, electrical/electronic technicians, engineering technicians, building and civil engineering technicians, quality assurance technicians, science and engineering technicians nec), Architectural technologists and town planning technicians, Draughtspersons, Countryside and park rangers, Routine laboratory testers	Laboratory technicians, Electrical and electronics technicians, Engineering technicians, Building and civil engineering technicians, Quality assurance technicians, Science, engineering and production technicians n.e.c., Draughtspersons and Related Architectural Technicians, Architectural and town planning technicians, Draughtspersons, Conservation and Environmental associate professionals
HRM	Personnel training and industrial relations managers, Personnel and industrial relations officers, Vocational and industrial trainers	Personnel training and industrial relations managers, Personnel and industrial relations officers, Inspectors of factories, utilities and trading standards	Human resource managers and directors, Human resources and industrial relations officers, Vocational and industrial trainers and instructors
BRAND	Marketing and sales managers, Advertising and public relations managers	Marketing and sales managers, Advertising and public relations managers, Public relations officers, Marketing associate professionals	Marketing and sales directors, Advertising and public relations directors, Marketing associate professionals, Sales accounts and business development managers, Public relations professionals, Advertising accounts managers and creative directors
BRAND_B	Buyers (retail trade), Buyers and purchasing officers (not retail)	Buyers and purchasing officers	Buyers and procurement officers
MAN	General managers large companies and organisations, Production managers in manufacturing, construction, mining and	Directors and chief executives of major organisations, Production managers (production, works and maintenance	Chief executives and senior officials, Production Managers and Directors (Production managers and directors in manufacturing, Production managers and

	energy industries, Treasurers and company financial managers, Purchasing managers, Transport managers, Managers in warehousing and other materials handling, Garage managers and proprietors, hairdressers and barbers, Other managers and administrators	managers, managers in construction, managers in mining and energy), Financial managers and chartered secretaries, Purchasing managers, Managers in distribution, storage and retailing (transport and distribution managers, storage and warehouse managers, retail and wholesale managers), Hotel and accommodation managers, Restaurant and catering managers, publicans and managers of licensed premises, leisure and sport managers, travel agency managers, Garage managers and proprietors, hairdressing and beauty salon managers and proprietors, shopkeepers and wholesale/retail dealers, recycling and refuse disposal managers, managers and proprietors in other services nec.	directors in construction, Production managers and directors in mining and energy) Financial managers and directors, Purchasing managers and directors, Managers and Directors in Transport and Logistics (Managers and directors in transport and distribution, Managers and directors in storage and warehousing), Managers and directors in retail and wholesale, Managers and Proprietors in Hospitality and Leisure Services (Hotel and accommodation managers and proprietors, Restaurant and catering establishment managers and proprietors, Publicans and managers of licensed premises, Leisure and sports managers, Travel agency managers and proprietor), Garage managers and proprietors, Hairdressing and beauty salon managers and proprietors, Shopkeepers and proprietors – wholesale and retail, Waste disposal and environmental services managers, Managers and proprietors in other services nec
MAN_B	Legal professional (judges and officers of the Court, Barristers and advocates, Solicitors), Business and financial professional (chartered and certified accountants, management accountants, actuaries, economists and statisticians, management consultants and business analysts), Legal service and related occupations, Organisation and methods and work study officers	Legal professionals (Solicitors and lawyers, judges and coroners, legal professionals nec), Business and statistical professionals (chartered and certified accountants, management accountants, management consultants, actuaries, economists and statisticians), Legal associate professionals	Legal Professionals (Barristers and judges, Solicitors, Legal professionals nec) Chartered and certified accountants, Management consultants and business analysts, Actuaries, economists and statisticians, Legal associate professionals

APPENDIX B

Table B1. Descriptive statistics on investment and other firm characteristics (by broad sector)

	Non-Farm Non-Finance Market Sector			**High Tech Manufacturing**			**Low Tech Manufacturing**			**Knowledge Intensive Services**			**Other Services**		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Ratio of investment to employment															
Machinery & Equipment	4.6	1.0	28.9	5.0	2.2	15.2	4.8	2.2	11.2	2.9	0.3	19.4	4.6	1.0	36.4
Intangibles	4.0	0.5	18.7	7.1	2.1	16.2	3.0	0.7	9.0	6.6	0.5	31.2	2.5	0.4	10.9
Software & Databases	0.4	0.0	2.9	0.3	0.0	1.4	0.2	0.0	0.9	0.8	0.0	4.8	0.3	0.0	2.1
Research & Development	2.1	0.0	16.1	5.5	1.2	14.4	1.2	0.0	5.9	4.1	0.0	28.8	0.4	0.0	4.7
Advertising & Marketing	1.5	0.2	8.2	1.4	0.1	6.8	1.6	0.2	6.3	1.6	0.2	9.8	1.8	0.2	8.9
GVA/employment	53	36	76	64	50	66	53	41	64	58	40	80	41	27	67
Employment	1503	513	6304	837	452	1463	727	443	926	1376	539	3607	2194	569	9632
Age	26	28	11	26	29	10	28	30	9	23	24	11	26	28	11
Foreign owned	0.32	0.00	0.47	0.60	1.00	0.49	0.40	0.00	0.49	0.26	0.00	0.44	0.26	0.00	0.44
Part of multi-establishment group	0.70	1.00	0.46	0.89	1.00	0.31	0.81	1.00	0.39	0.60	1.00	0.49	0.65	1.00	0.48
Observations		66595			7225			11447			17554			25340	
Establishments		13477			1383			2230			3930			4881	

Source: ARDX and BERD, Own calculations.
Notes: Years 2002-2015. SD is standard deviation. All financial variables are in £thousand, 2010 prices.

Table B2. Descriptive statistics on investment and capital (by broad sector)

	High Tech Manufacturing			Low Tech Manufacturing			Knowledge Intensive Services			Other Services		
	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median	Mean	SD
Ratio of investment to employment												
Machinery & Equipment	2.5	5.8	14.4	2.5	5.2	10.7	0.5	3.4	19.1	1.1	6.1	55.2
Software & Databases	0.0	0.2	0.8	0.0	0.2	0.8	0.0	0.7	9.8		0.0	0.4
Research & Development	1.5	4.9	10.7	0.0	1.0	4.4	0.0	0.7	5.3	0.0	0.2	2.3
Advertising & Marketing	0.1	1.4	6.9	0.2	1.7	6.5	0.2	1.7	9.1	0.3	2.2	15.1
Ratio of capital stock to employment												
Machinery & Equipment	20.6	39.8	78.1	21.0	35.6	53.5	3.8	20.5	353.5	8.5	32.6	241.5
Software & Databases	0.2	0.7	1.8	0.2	0.6	1.8	0.3	1.8	16.5	0.2	1.2	37.9
Research & Development	7.7	22.2	45.2	0.8	4.4	17.8	0.0	3.0	21.6	0.0	1.0	9.7
Advertising & Marketing	0.3	2.5	12.4	0.4	3.1	11.5	0.4	3.0	16.1	0.5	4.0	27.0
Observations		5499			9178			9718			16108	
Establishments		795			1251			1394			2513	

Source: ARDX and BERD, Own calculations. Years 2003-2015. SD is standard deviation. All financial variables are in £thousand, 2010 prices.