# Agglomeration Spillovers from Intangible Capital: An Analysis of UK City Regions

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**ABSTRACT**

The importance of intangible capital as a driver of productivity growth is being increasingly recognised; however as yet, its importance at a regional level has barely been considered. In this paper we present recently constructed occupationally defined measures of intangible capital at the firm level for the UK within a regional framework. We analyse the extent to which returns to intangible capital exceed their direct value to individual firms and generate regional spillovers. Our regional analysis is defined by City Regions, which reflect the commuting patterns of skilled workers and therefore represent a more economically meaningful unit of geographic delineation. Our measures of intangible capital focus on ICT, R&D and organisational capital, and we separately consider the individual associations as well as considering the aggregate association with productivity. We estimate firm level determinants of productivity, measured not only in terms of labour productivity but also in relation to wages, controlling for regional characteristics that include intangible capital. Our findings suggest there is a positive association between productivity and organisation capital in particular, consistent with the presence of spillovers.

JEL classification: M40, J30, O30, O40, M12, J24

**KEYWORDS:** Intangible capital, R&D, ICT, management, linked employer-employee data, spillovers

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## 1. INTRODUCTION

Intangible assets have long since been recognised for their important contribution to productivity (Veblen, 1908). However, the scope of intangibles has increased considerably in recent years which Lev (2001) argues has been driven by a variety of economic factors, including globalisation, deregulation and technological innovation, which has forced firms to innovate if they are to be profitable. At the same time, there has been increasing recognition of the benefits firms gain from co-location. Reasons given for these benefits largely stem from having a shared pool of skilled labour. The purpose in this paper is to consider the extent to which regional levels of intangibles are associated with higher firm level productivity.

Previous research has constructed intangible capital estimates at the national level (Corrado, Hulten and Sichel, 2009, hereafter CHF) and also at the firm level (Piekkola, 2010). The impact on national accounts, growth and productivity appear to be highly significant; however there has been little consideration of the spatial distribution of intangibles and indeed whether location matters. Given the tacit and non-market orientated nature of these assets, combined with their substantial knowledge component, there is an expectation that they are likely to generate substantial spillovers to local communities.

In this paper, we analyse firm level measures of intangible capital within a regional context and examining whether in addition to firm level effects there are significant spillovers as a result of local intensities of intangibles. Thus we include regional measures as well as firm specific intensities of intangible capital to see how these are associated with firm level performance. In addition, we control for other agglomeration economies separately.

This paper builds on the earlier work of Artis et al (2009) and others who have considered knowledge spillovers in a number of ways. Firstly, our data are firm level, secondly, we use an economically meaningful measure of geography and thirdly, we incorporate directly a firm level measure of intangible capital into the analysis, as well as regional impacts. The paper is structured as follows: we begin with a review of existing evidence, considering the role of intangible capital in generating agglomeration economies. In section 3 we give an overview of data used and how our data have been constructed, including descriptive statistics. Section 4 provides a discussion of the methodological approach adopted and in Section 5 we present our results for the UK. In section 6 we conclude and highlight areas for further research.

## 2. AGGLOMERATION ECONOMIES & INTANGIBLE CAPITAL: EXISTING EVIDENCE

Agglomeration at its most simple may be defined as regional concentration, usually based on some concept of an urban area. Devereux et al (2005) refer to agglomeration as *excess* concentration – i.e. regional concentration over and above that which would be expected, given the industrial structure of the region. Agglomeration economies are generally thought to be benefits that accrue at the geographical level as a result of firms locating close together, but they do not have to be exclusively positive; Swann (1996) emphasises the negative effects of congestion as a result of a concentration of firms. The persistence of areas such as 'Silicon Valley' in the US and 'Silicon Fen' in the UK are modern examples of high technology based clusters of firms, however, more traditional concentrations based around industries such as lace-making in Nottingham and tableware in Derbyshire highlight that benefits are not a new phenomenon. Two main strands to the economies that are associated with agglomeration exist; firstly, those that operate within an industry, and secondly those that operate between industries, usually through forward and backward linkages.

Jaffe (1986) identifies three types of spillovers; Market spillovers, Knowledge spillovers and Network spillovers. Others have looked to defined spillovers operating along different channels. Within-industry economies encourage specialisation and are most akin to those proposed by Marshall (1890). Those that operate across industries would lead to the development of diverse regions and are more closely identified in the work of Jacobs (1968). The source of the economies, regardless of whether they operate within or between industries, can be identified as stemming from either natural advantages or local externalities and diminish over distance. The new economic geography literature (Krugman, 1998) looks at the phenomenon of industry location in terms of increasing returns that can be identified as either being purely technological or pecuniary externalities (Moreno et al, 2006). Technological externalities may be regarded as knowledge spillovers, whilst pecuniary externalities are regarded as factors that operate through a market such as the availability of qualified work force, primary and intermediate inputs.

A large proportion of the empirical agglomeration and clusters literature concentrates on innovation and manufacturing industries. Linking agglomeration to productivity is complicated by the direction of causality. It is as plausible to think that productivity is high because of agglomeration as it is to think that agglomeration occurs because of high regional productivity. Notwithstanding these problems, Ciccone (2002) develops a regional productivity model and compares findings for France, Germany and the UK to those for the US. He finds a 5 per cent increase in average labour productivity as a result of a doubling of employment density, with little difference across European countries. His findings are similar to those for the US. Remedies for combating the causality question are used, including an instrumental variable of the area of the NUTS3 regions, which, Ciccone argues are appropriate given that they are geographic areas that are historically determined. In addition, he includes detailed regional fixed effects.

Using European Patent Office (EPO) data, Abramovsky et al (2008) match innovative activity to data on firm performance from the AMADEUS database to look at the location of innovation across Europe. They argue that the use of EPO data as a measure of innovative activity allows for a better understanding of the location, since it pinpoints the inventor and permits the consideration of innovative activity in a number of countries. In terms of the relationship between innovation and national location, they find similar patterns in France, Germany and UK.

Audretsch and Lehmann (2006) explore the relationship between geography to knowledge sources and performance using firm level German data. They find that the nature of the relationship depends very much on the precise nature of the type of knowledge produced. Thus, we see the importance of taking into account the multifaceted nature of knowledge and the extent to which spillovers may arise.

From a resource based view of the firm, intangible assets are those inputs into the production process for which there is little traceable evidence in a standard accounting sense. By its very nature, defining an intangible asset is difficult, but these include (tacit) knowledge and organisational characteristics and are thought to affect the innovativeness of the firm. In a firm level analysis of the productivity impact Lev and Radhakrishnan (2004) define organisational capital as an agglomeration of technologies – business practices, processes and designs and incentive and compensation systems. Some view it as being embodied in the workforce (Becker, 1993), others view it as a "firm-specific capital good jointly produced with output and embodied in the organisation itself", Atkeson and Kehoe (2002). Intangible assets, because they do not fully operate through a market, are thought to generate gains over and above their 'value' and not always appropriated by the source firm. This component of productivity from intangibles can be termed a spillover; knowledge transfers that are not traded but spread more organically through a common infrastructure – be it a region or an industry (Artis, et al, 2009).

In recent years, the importance of these intangible assets has grown, in part a response to technologically driven changes with the advent of the ICT driven productivity growth and partly the shift in industrial structure, away from the production of goods and a move towards services. This has led to increasing calls to change the way intangibles are captured within the national accounts framework (Corrado, Hulten and Sichel, 2005), as well as the growth in literature that has explored the direct impact of intangibles on productivity growth (Haskel et al, 2009).

At the sectoral level in the UK, Artis et al (2009) use patent data as a measure of innovation in their study of agglomeration economies in Great Britain and their impact on productivity performance at a regional level. Their point of departure is the Ciccone (2002) study and using local area data (NUTS3) they construct a variety of indicators to capture intangibles and model their effect on GVA per job filled at the regional level. They find a significant effect of agglomeration economies on productivity which diminishes slightly when the more intangible assets are taken into account and even more so when account is taken of the spatial autocorrelation, that is, the extent to which variables (GVA per job filled) display patterns over geography[1]. However, they are still significant.

Thus we see that increasingly there has been recognition that R&D and innovation data alone do not adequately capture knowledge and the external benefits to local firms that stem from it. We add to the literature by providing a more complete view of knowledge assets in a firm and test for associations between performance and regional spillovers.

## 3. DATA CONSTRUCTION

The data sources that have been used to construct our measure of intangible assets are an exhaustive collection of UK data and include the Annual Survey of Hours and Earnings (ASHE)

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[1] They do this by adopting a feasible generalised two stage least squared approach.

and the Labour Force Survey (LFS). These surveys contain detailed information on occupations and earnings for a sample of individuals in the UK. Our data on individuals have been linked to business surveys held by the ONS at the Virtual Microdata Laboratory. The business datasets that we have to link to, are the Annual Business Inquiry (ABI or ARD) and the Business Structure Database. The latter contains very basic information on all UK registered firms (based on VAT and PAYE registers). The former contains a sample of UK firms (a census of large firms) with detailed financial information.

Data cover the period 1998-2006 and so this will be our period of analysis. This is an interesting period of analysis for the UK, since it is a period when there was a sharp increase in investment in ICT technologies. There are of course limitations to any data. In the case of the occupationally based measures of intangibles for the UK, our data are based on a detailed industry and firm size matrix. This is because, with the exception of very large firms, the AHSE contains only a very small number of workers for each firm. The robustness of our findings have been compared with a sample of very large firms, and our method appeared to be the most suitable (Riley and Robinson, 2010).

### 3.1 Constructing Intangible capital

We measure intangible investment and capital following the methodology adopted in INNODRIVE (European Commission FP7 project), which is described in full in Görzig et al. (2011). Here we outline briefly the methodology described there. We assume that in addition to any traded goods and services each firm produces intangible goods of the three types discussed above: IT, R&D and Organisational capital (OC) goods. The production of these types of goods is exclusively directed towards firms' own use. If the uses are not in the current year, these types of goods can be classified as intangible capital goods. In order to produce these types of capital goods, firms apply resources supplied by different factors of production: labour, intermediate, and capital services. To assess labour services that go towards the production of these intangibles, we distinguish three types of labour input: IT-, R&D-, and OC-related personnel (see Appendix 1 for the SOC classification). We assume that only a fraction of workers in these occupations are engaged in the production of intangible capital goods; with the remainder of these workers engaged in current production (i.e. production of goods and services with a service life less than a year). Specifically, we assume that 50% of IT workers' time, 70% of R&D workers' time and 20% of organisational workers' time is spent on the production of intangible capital goods (see investment share of labour in Table 3.2). To account for the capital services and materials that complement this labour in the production of intangible assets we scale the relevant labour expenditures with the ratio of total production to labour costs in the IT, R&D and Business services sectors; SIC 72, 73 and 74 respectively. These are shown as the factor multiplier in Table 3.2. The product of this factor multiplier and the investment share of labour yields the combined multiplier in Table 3.2, which is essentially the scaling factor we apply to firms' expenditures on 'intangible' workers. Intangible investment for firm *i* at time *t* is then derived as:

$$I_{ICit} = M_{IC} w_{ICit} L_{ICit} \tag{1}$$

where $IC = OC, R\&D, IT$, $M_{IC} = h_{IC} \cdot m_{IC}$ is the combined multiplier (shown in Table 3.2), $w_{ICit}$ is the wage cost for workers engaged in the production of intangible assets (deflated by the earnings index, which is assumed to represent the deflator for intangible assets) and $L_{ICit}$ is the respective labour input of these workers.

Table 3.2: INNODRIVE Assumptions

| | IT | R&D | OC |
|---|---|---|---|
| Investment share of labour $h_{IC}$ | 0.5 | 0.7 | 0.2 |
| Factor multiplier $m_{IC}$ | 1.48 | 1.55 | 1.76 |
| Combined multiplier $M_{IC} = h_{IC} \cdot m_{IC}$ | 0.7 | 1.1 | 0.35 |
| Depreciation rate | 0.33 | 0.20 | 0.25 |

Source: Görzig et al. (2011).

We capitalise these investments according to the perpetual inventory model:

$$K_{ICit} = I_{ICit} + (1 - \delta_{IC}) K_{ICit-1} \tag{2}$$

with depreciation rate $\delta_{IC}$, which varies by type of asset $IC = OC, R\&D, IT$ (see Table 3.2), and gross capital formation in the current year $I_{ICt}$. $K_{ICt}$ denotes the closing stock (at the end of the year). The opening stock, $K_{ICt-1}$, is the stock a firm starts with (at the beginning of the year). Note that the depreciation rates we assume for intangible capital goods are much higher than the depreciation rates typically assumed for tangible capital; intangible assets are assumed to have relatively short service lives. For years where firms are absent from the sample investment is constructed using a simple linear interpolation. This mostly concerns SMEs (enterprises with less than 250 employees), which are not required to respond to the Annual Business Inquiry every year.

We need to assume an initial capital stock in the year before we observe a firm in the data, $K_{ICi}^{start}$. We assume constant investment growth $g$ (set at 2% per annum) in the period before we observe a firm. This means that we can that write:

$$K_{ICi}^{start} = I_{ICi}^{start} \frac{1-(1-\delta_{IC}-g)^T}{1-(1-\delta_{IC}-g)} \tag{3}$$

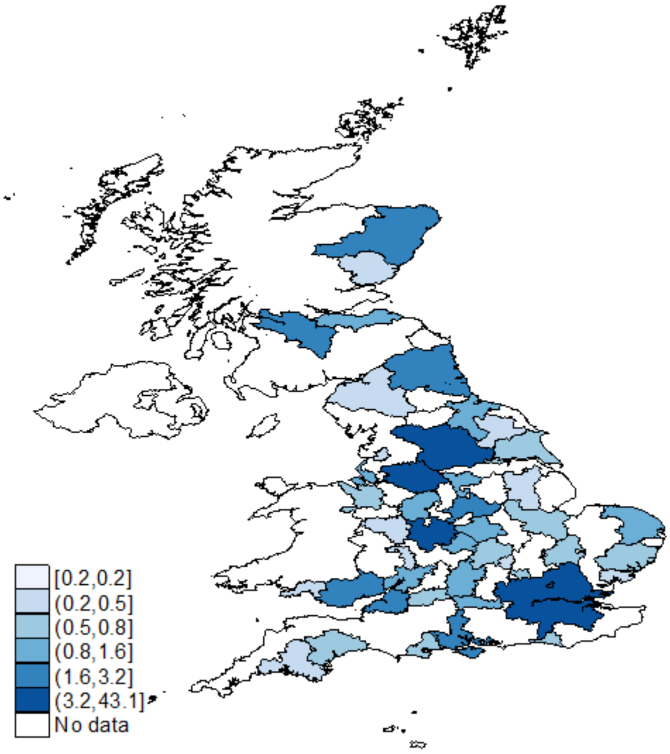
where $I_{ICi}^{start}$ denotes intangible investment in the year before we observe a firm, and T is set to 100. In practice we proxy $I_{ICi}^{start}$ with the sample average for firm $i$ (discounted appropriately).

### 3.2 Unit of Geography: UK City Regions

As previously stated, there are a number of possibilities when it comes to defining regions in the UK. Traditional tests of agglomeration have used administratively defined areas, such as regions (Wales, Scotland, the North East, etc), or at a much more disaggregated level local authorities. Regardless of the level of detail, all administrative regions have little to do with the way in which economies behave. We therefore adopt a more meaningful structure by using the UK City Regions, constructed on the basis of the commuting patterns of the highly skilled although residual regions such as 'Other Wales' are excluded from our analysis. Thus, our coverage of the UK is note complete.

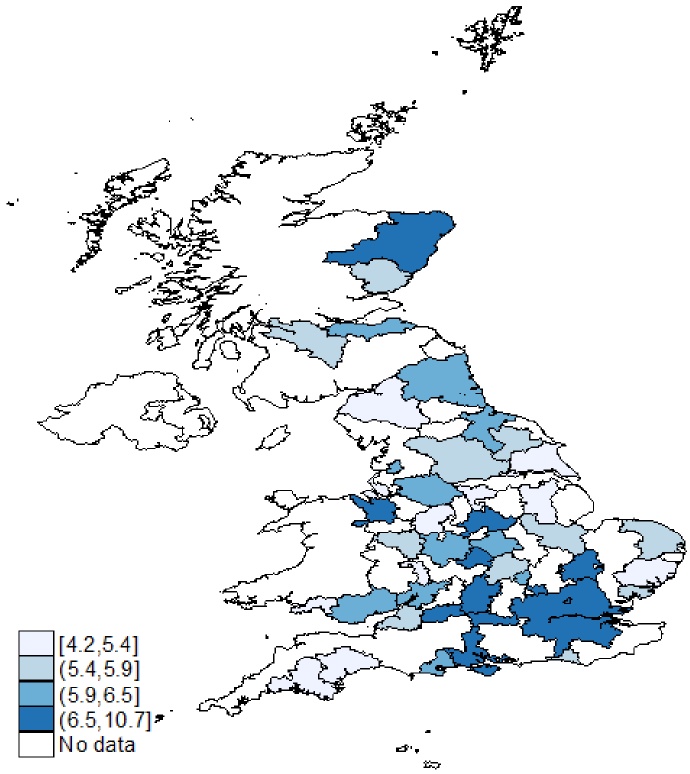
Figures 1 and 2 provide an illustration of the UK City-Regions included in our analysis. Note that the regions differ from standard definitions, looking specifically at the Greater London City-Region, which encompasses a much larger proportion of the South East. This is a feature of the data construction, since it is quite likely that a significant proportion of high skilled workers in the South East will commute within this Greater London area. Figure 1 displays the geographic distribution of intangible capital. Note that the major conurbations, London, Birmingham and Manchester have a relatively high concentration of intangible capital. Figure 2 shows the intensity of intangible capital, so the share divided by hours worked. Taking into account the various density in each region alters the concentration of intangibles somewhat, although not drastically – along the M4 corridor (Reading/Swindon) we see a higher intensity than Figure 1 perhaps suggests and a lower intensity in the Leeds area.

Figure 1: Regional shares of national intangible capital (%).




Source: Non-farm business sector firms, BSD, ONS; 1998-2006 average

Figure 2: Intangible capital per hour worked (£)




Source: Non-farm business sector firms, BSD, ONS; 1998-2006 average

Our figures suggest there are certain agglomerations to intangibles, however the extent to which they are associated with improved firm performance is of interest here.

## 4. METHODOLOGY

Our model is similar to that presented in Geppart and Neumann (2010) and based on the key production variables, employment, capital and output data. We also include capital disaggregated firstly into intangible and tangible capital and in a later stage, separate intangible capital into its three component parts: R&D, organisational and IT capital. In addition, we include variables to capture agglomeration effects which include: industrial diversity within a city region (diversity), and industrial concentration within a city region (own plants). As well, we include a term that reflects the overall level of economic activity in an area, defined as employment per square kilometre (density).

We estimate the following function:

$$\ln Y_{it} = Empsize_{it} + \ln IntK_{it} + \ln K_{it} + \ln Density_{ct} + \ln Diversity_{ct} + \ln Ownplant_{ct} + Metro2 + Metro3 + Metro4 + \ln(\text{int}\, K / hr)_{ct} + \varepsilon_{ict}$$

Where Y is one of 4 measures of productivity; either hourly wage, GVA per worker of the hourly wage of (non) intangible workers by firm i in year t. Employment size band (EmpSize). Capital is comprised of intangible, constructed as discussed above, and tangible plant and machinery capital, kindly provided by Richard Harris, constructed as in (Harris and Drinkwater, 2000). Density is measured as employment per square kilometre. Our measure of urbanisation is captured in diversity, which is constructed in the following way, following Duranton and Puga, 2005):

$$D_c = 1/\sum_i \left(\frac{E_{ic}}{E_c} - \frac{E_i}{E}\right)^2$$

Following Henderson (2003), we use the number of other own-industry establishments in the region as a measure of localisation in order to capture industry specific spillovers. We estimate random effects regressions over the period 1998-2006, across 45 industrial sectors (broadly 2 digit) and across 44 City Regions (excluding 'other' areas). We cluster on the basis of year and city regions and include year and sector dummies, as well as year*sector to pick up any business cycle effects.

## 5. RESULTS

In table 1 we present the findings from the wage equations. Columns 1 to 3 relate to the log hourly wage. Here we see that the firm level variables behave in line with expectations in all specifications. Hourly wages are positively related to employment size (the excluded category is those firms employing less than 250 workers). We see that intangible capital intensity is highly significantly positive; this is also true for tangible capital.[2] We concentrate on the City-Region variables in order to identify the potential for spillovers, but the inclusion of the City-Region variables do not detract from the coefficients at the firm level, which remain the same over the various specifications. We see in model (2) that the standard measure of agglomeration – the employment density – is significant and positive in our baseline model (1). In model (2) we band density into 4 groups. The excluded group here are the least dense areas, with less than 100 em-

[2] Relative to the tangible capital, the coefficients on intangible capital intensity are large. This is in part due to the fact that we do not control here for labour quality, and given that intangible capital is knowledge worker intensive, the measure is likely to be combination of these two factors. In addition, we acknowledge that our tangible capital measure relates only to plant and machinery capital. These limitations are corrected for elsewhere and are not the focus of this analysis.

ployees per square kilometre. This reveals that for the less dense areas, agglomerations are not significant. However, where there are more than 500 employees per square kilometre, there is a clear indication of positive agglomeration economies. This suggests that the intensity of clustering has to be quite high before benefits from collocation pay off.

If we turn to the results in model (3), we are able to consider the role of additional factors at the City-Region level, including intangible capital intensity. The inclusion of the additional factors reduces the value of the coefficient attached to the standard measure of agglomeration, however it is still positive and highly significant. We find that being located in a City-Region that has a concentration of firms in the same NACE3 industry has a significantly positive association with hourly wages and conversely, the diversity of sectors in the City-Region has a significantly negative association. The coefficient attached to the intangible capital intensity in the City-Region is significant and positive. This indicates that there is a clear, positive association between higher hourly wages and the level of intangible capital in the city-region.

Of course, there is a danger that this association could be regarded as evidence of complementarity between workers and not of significant gains from higher regional levels intangible capital. For this reason, models (4) to (9) separate the hourly wages of intangible workers (models (4) to (6)) from those of other workers (models (7) to (9)). Firm level variables behave similarly to the aggregate model, except in the case of the employment size band for intangible workers....this implies a negative association with the log hourly wages of intangible workers in medium sized firms. Considering the City-Region effects, in the case of other workers, we do not observe significant effects on own sector concentration or diversity, although diversity is significant at the 10 per cent level of significance – still, the effect is weaker. In the case of intangible workers, all spillover variables behave as they did in the aggregated hourly wage specification, which slightly larger coefficients, so the association with the wages of the intangible workers is more marked.

**Table 1: Regression results for the determinants of firm wages, 1998-2006 (random effects)**

| | **log hourly wage** | | | **log hourly wage of intangible workers** | | | **log hourly wage of other workers** | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| **Firm level variables** | | | | | | | | | |
| Employment size band (250-2000) | 0.0196*** | 0.0197*** | 0.0191*** | -0.0187*** | -0.0185*** | -0.0192*** | 0.0372*** | 0.0373*** | 0.0369*** |
| | (0.00313) | (0.00312) | (0.00311) | (0.00495) | (0.00492) | (0.00492) | (0.00438) | (0.00437) | (0.00439) |
| Employment size band (2000+) | 0.0768*** | 0.0761*** | 0.0745*** | 0.0550*** | 0.0544*** | 0.0526*** | 0.0993*** | 0.0987*** | 0.0977*** |
| | (0.00873) | (0.00873) | (0.00858) | (0.0190) | (0.0189) | (0.0188) | (0.00905) | (0.00906) | (0.00899) |
| log firm intangible capital intensity (per hour) | 0.633*** | 0.633*** | 0.631*** | 0.595*** | 0.595*** | 0.593*** | 0.584*** | 0.583*** | 0.582*** |
| | (0.00557) | (0.00555) | (0.00561) | (0.00757) | (0.00755) | (0.00753) | (0.00605) | (0.00604) | (0.00621) |
| log firm tangible capital intensity (per hour) | 0.00849*** | 0.00844*** | 0.00843*** | 0.00654*** | 0.00647*** | 0.00646*** | 0.00881*** | 0.00876*** | 0.00878*** |
| | (0.000947) | (0.000945) | (0.000940) | (0.000917) | (0.000914) | (0.000907) | (0.00114) | (0.00114) | (0.00113) |
| **City-Region variables** | | | | | | | | | |
| Metro area (100-200 per km2) | | 0.00235 | 0.00158 | | 0.00344 | 0.00251 | | 0.00197 | 0.00234 |
| | | (0.00572) | (0.00580) | | (0.00682) | (0.00699) | | (0.00661) | (0.00673) |
| Metro area (200-500 per km2) | | 0.00660 | 0.00638 | | 0.00762 | 0.00715 | | 0.00752 | 0.0104 |
| | | (0.00555) | (0.00614) | | (0.00670) | (0.00739) | | (0.00646) | (0.00718) |
| Metro area (500+ per km2) | | 0.0423*** | 0.0331*** | | 0.0492*** | 0.0390*** | | 0.0439*** | 0.0441*** |
| | | (0.00748) | (0.00901) | | (0.00854) | (0.0108) | | (0.00869) | (0.0112) |
| log employment per sqkm in CR | 0.0234*** | | | 0.0277*** | | | 0.0243*** | | |
| | (0.00375) | | | (0.00415) | | | (0.00433) | | |
| log number of own NACE3 plants in CR | | | 0.00658*** | | | 0.00718*** | | | 0.00270 |
| | | | (0.00181) | | | (0.00211) | | | (0.00228) |

| Table 2 continued... | log hourly wage | | | log hourly wage of intangible workers | | | log hourly wage of other workers | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| log CR intangible capital intensity (per hour) | | | 0.0331*** | | | 0.0352*** | | | 0.0390*** |
| | | | (0.0108) | | | (0.0127) | | | (0.0126) |
| log diversity (NACE3) | | | -0.00884*** | | | -0.00941*** | | | -0.00799* |
| | | | (0.00343) | | | (0.00359) | | | (0.00411) |
| | | | | | | | | | |
| Constant | -1.354*** | -1.244*** | -1.037*** | -0.951*** | -0.821*** | -0.600*** | -1.849*** | -1.736*** | -1.489*** |
| | (0.0477) | (0.0448) | (0.0755) | (0.0610) | (0.0557) | (0.0887) | (0.0526) | (0.0480) | (0.0853) |
| | | | | | | | | | |
| Observations | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 |
| Number of firms | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 |

Robust standard errors in parentheses; *** p<0.01, **p<0.05, *p<0.1

**Table 2: Labour productivity regression results (random effects)**

| | log GVA per hour | | | log gross output per hour | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **Firm level variables** | | | | | | |
| Employment size band (250-2000) | 0.0191*** | 0.0192*** | 0.0187*** | 0.0127*** | 0.0128*** | 0.0128*** |
| | (0.00556) | (0.00556) | (0.00554) | (0.00331) | (0.00333) | (0.00333) |
| Employment size band (2000+) | 0.0876*** | 0.0867*** | 0.0852*** | 0.0509*** | 0.0505*** | 0.0506*** |
| | (0.0174) | (0.0174) | (0.0174) | (0.00902) | (0.00902) | (0.00906) |
| log firm intangible capital intensity (per hour) | 0.684*** | 0.684*** | 0.682*** | 0.401*** | 0.401*** | 0.401*** |
| | (0.00662) | (0.00663) | (0.00667) | (0.00705) | (0.00704) | (0.00694) |
| log firm tangible capital intensity (per hour) | 0.0188*** | 0.0188*** | 0.0188*** | 0.0105*** | 0.0105*** | 0.0105*** |
| | (0.00177) | (0.00177) | (0.00177) | (0.00131) | (0.00131) | (0.00131) |
| **City-Region variables** | | | | | | |
| Metro area (100-200 per km2) | | -0.00932 | -0.00902 | | -0.00304 | -0.00323 |
| | | (0.0105) | (0.0104) | | (0.00682) | (0.00710) |
| Metro area (200-500 per km2) | | -0.00665 | -0.00354 | | -0.00793 | -0.00640 |
| | | (0.0102) | (0.0107) | | (0.00716) | (0.00727) |
| Metro area (500+ per km2) | | 0.0280** | 0.0263* | | 0.0189** | 0.0235** |
| | | (0.0124) | (0.0134) | | (0.00810) | (0.0102) |
| log employment per sqkm in CR | 0.0193*** | | | 0.0143*** | | |
| | (0.00564) | | | (0.00374) | | |
| log number of own NACE3 plants in CR | | | 0.00412 | | | -0.00201 |
| | | | (0.00278) | | | (0.00192) |
| log CR intangible capital intensity (per hour) | | | 0.0450** | | | 0.0270** |
| | | | (0.0182) | | | (0.0114) |
| log diversity (NACE3) | | | -0.00988* | | | -0.000419 |
| | | | (0.00590) | | | (0.00433) |
| log intermediate inputs | | | | 0.387*** | 0.387*** | 0.387*** |
| | | | | (0.00880) | (0.00880) | (0.00880) |
| Constant | -0.329*** | -0.230*** | 0.0542 | 0.539*** | 0.614*** | 0.769*** |
| | (0.0855) | (0.0804) | (0.128) | (0.0484) | (0.0452) | (0.0752) |
| | | | | | | |
| Observations | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 | 73,904 |
| Number of firms | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 | 27,727 |

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

We are concerned mostly with the coefficients on the City-Region intangible capital intensity variable in both wage types ((6) and (9). Here we see that in both cases, the hourly wages are positively affected by the intangible capital intensity in the City-Region. Thus, we can say with some

confidence that our findings are not simply a reflection of labour complementarity but do seem to reflect the presence of positive spillovers to regional concentrations of intangible capital.
Table 2 provides estimates of determinants of labour productivity measures (GVA per hour and gross output per hour). Our firm level variables behave consistently, all are positive and significant and once again we observe dominance of intangible capital over tangible capital. Model (1) includes the standard density variable to capture agglomeration economies. We see that this is significant and positive. When we include a more banded measure of density it again becomes apparent that this is driven by economies in the most densely populated areas.

Model (3) incorporates variables to capture diversity and specialisation, along with our intangible intensity in the City-Region. We note here than specialisation (number of plants from the same NACE3) in the City-Region does not appear to significantly affect labour productivity. Diversity is observed to have a negative and significant effect only at the 10 per cent level of significance. At the 5 per cent level of significance, we see that intangible capital intensity in the City-Region is again positive. Our gross output specification reveals a similar picture (models (4) to (6)) however, we note that diversity is no longer weakly significant. Note that incorporating intermediate inputs reduces the magnitude of the firm level intangible capital intensity coefficient suggesting that this measure is proxying for a number of missing variables.

Finally, table 3 contains our findings for labour productivity measures when we have disaggregated our intangible capital input into R&D, ICT and Organisation capital intensity, both at the firm level and the City-Region level. This enables us to consider in greater detail, what is driving the intangible capital component. Considering the firm level variables firstly, we see that all components are significant and positively associated with higher labour productivity, regardless of whether a value added or a gross output specification is used. In addition, the intangible asset that has the biggest contribution to make to labour productivity is organisation capital by a significant margin. Turning to the City-Region variables, we note that with respect to intangible capital intensity, once again the dominant component is organisation capital. ICT capital intensity in a City-Region also has a significantly positive association with labour productivity, but this is about a third of the size of organisation capital intensity. R&D capital intensity is not significant in either specification.

**Table 3: Productivity results, disaggregated intangible capital (random effects)**

| | **log GVA per hour** | **log gross output per hour** |
|---|---|---|
| | (1) | (2) |
| **Firm level variables** | | |
| Employment size band (250-2000) | 0.0845*** | 0.0470*** |
| | (0.00693) | (0.00408) |
| Employment size band (2000+) | 0.158*** | 0.0912*** |
| | (0.0190) | (0.00984) |
| log firm R&D capital intensity (per hour) | 0.0589*** | 0.0310*** |
| | (0.00326) | (0.00194) |
| log firm organisation capital intensity (per hour) | 0.618*** | 0.364*** |
| | (0.00838) | (0.00898) |
| log firm ICT capital intensity (per hour) | 0.0215*** | 0.0137*** |
| | (0.00246) | (0.00137) |
| log firm tangible capital intensity (per hour) | 0.0182*** | 0.0103*** |
| | (0.00184) | (0.00136) |
| **City-Region variables** | | |
| log number of own NACE3 plants in the CR | -0.0268*** | -0.0189*** |
| | (0.00342) | (0.00223) |
| log CR R&D capital intensity (per hour) | -0.0165 | -0.0132 |
| | (0.0160) | (0.00942) |
| log CR organisation capital intensity (per hour) | 0.121*** | 0.0670*** |
| | (0.0366) | (0.0230) |
| log CR ICT capital intensity (per hour) | 0.0332*** | 0.0226*** |
| | (0.00994) | (0.00745) |
| log diversity (NACE 3) | 0.00266 | 0.00615 |
| | (0.00616) | (0.00437) |
| Metro area (100-200 per km2) | 0.00570 | 0.00407 |
| | (0.0118) | (0.00779) |
| Metro area (200-500 per km2) | 0.0119 | 0.00177 |
| | (0.0121) | (0.00795) |
| Metro area (500+ per km2) | 0.0697*** | 0.0451*** |
| | (0.0164) | (0.0117) |
| log intermediate inputs | | 0.386*** |
| | | (0.00918) |
| Constant | 1.198*** | 1.415*** |
| | (0.233) | (0.143) |
| | | |
| Observations | 73,904 | 73,904 |
| Number of firms | 27,727 | 27,727 |

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

There are a number of alternatives or refinements that we might try in order to test the robustness of our findings. Firstly, we test whether our findings are sensitive to the sample period chosen by analysing the results across different time periods within the overall period. Our findings indicate that our results are robust to sample period changes. Reported results are generated using a random effects estimator. As an additional sensitivity check we run the same regressions using OLS. In comparison to the random effects coefficients, the OLS coefficients point to a larger effect of regional intangible capital intensity on firm productivity, and a smaller effect of own-firm intangible capital intensity. Using OLS, the association between firms' productivity and regional R&D becomes negative and statistically significant. However, we find there to be a positive association between a firm's productivity and regional IT and organisation capital, in line with the results presented above, and the associations are not negligible.

When we including firm-level fixed effects, we find no evidence of agglomeration effects. This is not surprising as these fixed effects essentially remove all variation in the regional variables (because firms do not tend to move very frequently, and because we also control for all industry-year interactions (NACE 2 level)). Indeed, 94 per cent of the variation in the City-Region level variables can be explained by City-Region and year dummies alone, suggesting that the fixed effects estimator is less appropriate for our purposes. Firm-level intangible capital remains statistically significant. Similarly, when we include City-Region fixed effects we find no evidence of agglomeration economies. However, in some instances we then find a statistically significant negative association between City-Region intangible capital intensity and firm-level wages. This may be picking up a regional labour supply effect. In other words, in City Regions where intangible capital intensity is rising relatively quickly (and hence the supply of high-skilled labour is rising quickly), we observe a reduction in average labour costs (once we control for firm-level intangibles).

We model the association between regional intangible capital and firm-level productivity, controlling for firm-level intangible capital. We are unable to say whether the positive associations we find between regional intangible capital and firm-level productivity arise because of spillover effects from the local environment to the firm or because high productivity firms, that are highly productive for reasons that we do not observe in the data, are drawn to City Regions with high levels of intangible assets, for example. As an attempt to get at the causal nature of the relationship we discuss, we instrument City-Region intangible capital intensity with lagged City-Region intangible capital intensity (3-5 year lags). Our findings are not dramatically different from those reported above. However, we acknowledge that lagged values are not the strongest instruments, given the persistence over time in the regional distribution of intangibles.

## 6. CONCLUSIONS

The benefits to co-location have long been recognised however evidence on the channels through which these spillovers operate have been frustratingly vague. In this paper, we analyse these by using a firm level dataset and combining data to construct City-Region level measures that not only incorporate ways in which these agglomerations might occur; through the workforce (density), through clusters of firms from the same or similar industries or through diversity in the local area.

Our analysis shows that there is evidence supporting the existence of agglomeration spillovers in the UK, 1998-2006 but that the regions have to be pretty concentrated to feel benefits in the form of higher productivity. We find that firms in the most densely populated City Regions pay higher wages (around 4 per cent above average) and are around 2.5 per cent more productive than average.

Including City-Region intangible capital intensity in the equation has a significant and positive effect over and above that of agglomeration, suggesting that there are spillovers to intangible capital also. When we break intangible capital into its components, we see that the lion's share of this is attributable to organisation capital. It is interesting to note that we observe much less evidence of spillovers to R&D than any other form of intangible capital. Our findings are generally consistent with those in Germany and Finland (see Geppart and Neumann, 2010; Piekkola and Lintamo, 2011).

Whilst encouraging, at present, given the nature of the data, we can only provide indicative associations. With improved time series we would hope to deal with selection and endogeity issues. Moreover, it is important to note that the measure of intangible capital used here is based on firms' own account production, not purchased intangibles. We also acknowledge that the indicator we use to capture intangible capital is likely to be bound up with human capital. Disentangling these effects at a regional level is not straightforward but is the sensible next step in our research agenda.

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## Appendix 1: Appendix: List of City-Regions

1 "Birmingham /Sandwell/Wolverhampton"
2 "Bournemouth/Poole"
3 "Brighton/Hove"
4 "Bristol/S. Gloucestershire"
5 "Cambridge"
6 "Carlisle"
7 "Chester"
8 "Colchester"
9 "Coventry"
10 "Exeter"
11 "Greater London"
12 "Gloucester/Cheltenham"
13 "Ipswich"
14 "Kingston upon Hull"
15 "Leeds/Bradford"
16 "Leicester"
17 "Lincoln"
18 "Liverpool"
19 "Luton"
20 "Manchester/Salford/Trafford"
21 "Middlesbrough/Stockton"
22 "Milton Keynes"
23 "Newcastle/Gateshead/Sunderland"
24 "Northampton"
25 "Norwich"
26 "Nottingham/Derby"
27 "Oxford"
28"Peterborough"
29 "Plymouth"
30 "Portsmouth/Southampton"
31 "Preston"
32 "Reading"
33 "Sheffield"
34 "Stoke on Trent"
35 "Swindon"
36 "Telford and Wrekin"
37 "Worcester"
38 "York"
39 "Cardiff"
40 "Swansea"
41 "Aberdeen"
42 "Dundee"
43 "Edinburgh"
44 "Glasgow"
45 "Belfast"
46 "Other NE"
47 "Other NW"
48 "Other Y&H"
49 "Other EM"
50 "Other WM"
51 "Other Eastern"
52 "Other SE"
53 "Other SW"
54 "Other Wales"
55 "Other Scotland"
56 "Other NI"