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Abstract

This paper contributes to the literature on regional productivity, complementing previous education and skill level perspectives with a novel approach analysing the impact of regional skill gaps and skill shortages. This allows us to better reflect the idiosyncratic needs of the regional economic structure, considering both the demand and supply side of the skills equation in localised labour markets. Controlling for unobserved time-invariant firm-level heterogeneity and other region-industry effects across a longitudinal dataset for the period 2008 - 2014, our analysis reveals a negative direct effect of skill shortages on firm productivity. We further find negative spillover effects for both skill gaps and skill shortages in related industries and proximate regions. Results are also shown to be heterogeneous with respect to agglomeration levels and industrial sectors. Stronger negative effects are found in industries defined by a knowledge-intensive skill base pointing to the loss of learning effects in the presence of skill deficiencies. Conversely, agglomeration effects appear to moderate the impact of skill deficiencies through more efficient matching in the local labour market. The findings presented thus suggest that policies aimed at improving productivity and addressing the increasing regional productivity divide cannot be reduced to a simple space-neutral support for higher education and skill levels but need to explicitly recognise the presence and characteristics of place-specific skills gaps and shortages.

Keywords
Skill Gaps, Skill Shortages, Regional Productivity, Human Capital

Introduction

One of the striking features of economic activity is the significant heterogeneity characterising inter-regional productivity. In particular, the persistent slowdown which has shaped the so-called productivity puzzle amongst advanced economies in the last few decades (Blundell, Crawford and Jin, 2014) is being increasingly exacerbated by a geographical dimension, with the productivity gap between OECD regions further widening since the last financial crisis (OECD, 2016). Following the seminal insights by Marshall (1890), the literature has long pointed to the role of agglomeration economies and the uneven distribution

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of skills to explain such variation. In particular, scholars have traditionally focused on the provision of higher skill levels - usually proxied by education attainment - and their connections to economic density to investigate the determinants of regional productivity (Glaeser and Resseger, 2010; Harris and Moffat, 2015). However, this approach only captures the supply side of the labour market equation. Crucially, this masks a more nuanced picture of the current skills environment and how the uneven distribution of regional productivity has been partially determined by the place-specific nature of the imbalance between skills demanded and the skills currently available.

This paper aims to complement previous research on the relationship between skill levels and regional productivity by focusing on the impact of region-industry skill deficiencies, reflecting the interval between the skills required in a given local labour market and those available. Following the established terminology from the previous skills literature (see Green, Machin and Wilkinson (1998) for a comprehensive overview), we refer to skill deficiencies in the external labour market as skill shortage vacancies, whilst skill gaps are used to represent internal skill issues, where current employees do not have the required skills to conduct the job proficiently.

To explore the impact of skill shortage vacancies and skill gaps on regional productivity we focus on the case of the UK, which is characterised by persistent regional productivity differentials and a heterogeneous distribution of skill deficiencies (Green and Owen, 2003; HM Treasury, 2006; UKCES, 2015; OECD, 2016), leading to renewed attention from policy-makers on rebalancing the UK economy (BEIS, 2017; Martin, Sunley, Gardiner, Evenhuis and Tyler, 2018). In particular, we exploit a novel longitudinal dataset of 12,875 firms across 40 NUTS2 regions obtained by merging information from the Employers Skills Survey, the Annual Business Inquiry and the Business Structure Database. Controlling for firm-level heterogeneity and other region-industry idiosyncratic effects, we provide the first estimates of the detrimental impact that skill deficiencies, defined at the regional and industry level, exert on firm performance. Following previous insights on the role of geographical and cognitive proximity in labour markets (Boschma, Eriksson and Lindgren, 2009), this relationship is further investigated revealing the presence of spillover effects for both skill shortage vacancies and skill gaps in related industries and proximate regions. Finally, results are also shown to be heterogeneous with respect to agglomeration levels reflecting the moderating effect of density on the skill matching function (Duranton and Puga, 2004).

The rest of the paper is organised as follows. In the following section, we discuss the potential impact of skill deficiencies on firm productivity through a regional perspective. Then we present the unique data

utilised and explore the concepts of skill gaps and skill shortage vacancies, before presenting the empirical approach for the analysis. Results are discussed in the following section. The last section concludes with a summary of the main findings and the policy implications of the paper.

Theoretical framework

In the previous literature, scholars have pointed to a significant relationship between density of economic activity and productivity (Ciccone and Hall, 1996; Ciccone, 2002; Rice, Venables and Patacchini, 2006; Meijers and Burger, 2010; Puga, 2010). Indeed, most evidence points to positive returns documented even when sorting is accounted for (Ciccone, 2002; Fingleton and López-Bazo, 2003; Combes, Mayer and Thisse, 2008). Yet, even though proximity may be conducive to lower costs of information exchange, the estimated coefficients for the importance of density on agglomeration effects and productivity remain modest (Martin et al., 2018). They may even be counterbalanced by negative externalities of larger cities and core regions (Broersma and van Dijk, 2008; Harris, Li and Moffat, 2011). To fully understand the variation in regional productivity, scholars have underlined the increase in aggregate productivity and income in the presence of higher skill levels, pointing to the importance of human capital (Rosenthal and Strange, 2008; Marrocu and Paci, 2012; Abel, Dey and Gabe, 2012; Melachroinos and Spence, 2014) and the tendency of more skilled workers to live in densely populated areas (Glaeser and Resseger, 2010; Di Giacinto, Gomellini, Micucci and Pagnini, 2014). Indeed, complementary national and firm-level evidence indicates low levels of skills negatively impact productivity and growth (Crafts and O'Mahoney, 2001; Machin, Vignoles and Galindo-Rueda, 2003; Webber, Boddy and Plumridge, 2007; Wixe, 2015), while regional level evidence has also shown that the positive relationship between productivity and the effect of agglomeration externalities is stronger in more skilled areas (Glaeser and Resseger, 2010; Harris and Moffat, 2015). Shifting the focus from sectoral to the functional structure of regions (Martin et al., 2018), higher skill levels have been suggested as an essential element in fostering regional productivity, providing stronger capabilities for complex, high-order tasks as well as creating learning effects and knowledge spillovers across spatially bounded interactions. Accordingly, policy makers have traditionally turned their attention to enhancing skill levels in the workforce to boost productivity (Barca, McCann and Rodríguez-Pose, 2012; BEIS, 2017).

Against this background, a growing strand of research building on the framework defined by search and mismatch theories has suggested that, even in the presence of high skill levels, skill gaps and skill shortage vacancies may have important implications in terms of economic performance and productivity

(Tobin, 1972; Lucas Jr and Prescott, 1974; Allen and Van der Velden, 2001; Shimer, 2007). Looking at skill deficiencies would better reflect the idiosyncratic needs of the regional economic structure, considering both the demand and supply side of the skills equation. While a few studies have offered some initial evidence on the impact of skill deficiencies on productivity, they follow an intra-industry or firm-level perspective, overlooking the spatial nature of labour markets (Green and Owen, 2003; Forth and Mason, 2006; Bennett and McGuinness, 2009; Weaver and Osterman, 2017). Yet, the majority of skill deficiencies are not a firm or industry-specific issue. Rather, they are defined within a local labour market embedded in a given geographical area, in line with the regional perspective adopted to explore many other labour market dynamics. This includes pooling effects with firms locating close together gaining access to a larger labour supply (Combes and Duranton, 2006; Andini, de Blasio, Duranton and Strange, 2013); poaching externalities whereby firms are reluctant to train workers in general skills in case these will be then poached by nearby rival firms (Muehlemann and Wolter, 2011; Mohrenweiser, Zwick and Backes-Gellner, 2013); and the impact of skilled labour mobility mainly consisting of moves within a proximate geographic area (Boschma, Eriksson and Lindgren, 2014; Cappelli, Boschma and Weterings, 2019; Fratesi and Percoco, 2014).

From a regional perspective, there are different yet connected pathways through which regional skill deficiencies may impact firm performance. To begin with, where there is a higher share of skill gaps and shortages, firms face larger hiring costs due to increasing search costs, increased competition for skilled workers and weaker skill matching effects (Haskel and Martin, 1993; Puga, 2010). At the same time, when some regions are characterised by a higher share of skill shortages or skill gaps, establishments may substitute away from skilled labour towards less productive labour (Haskel and Martin, 1993) potentially leading to low skill traps (Finegold and Soskice, 1988; Gospel, 1998). While difficult to empirically estimate, the idea of low skill traps as originally envisioned by Finegold and Soskice (1988) and tested by Wilson and Hogarth (2003), suggests that firms adapt their investment strategies to accommodate the skills present in the local labour force. Thus, skill gaps result in firms not investing in more advanced production techniques and further capital deepening, as they do not have the appropriate workforce to best exploit these tools. Furthermore, external skill deficiencies may impact firms' productivity through reduced opportunities for localised learning effects. Many of the positive externalities of spatially bounded labour markets rest on the assumption of available skilled workers defining processes of knowledge creation and diffusion through interaction in the local milieu (Marshall, 1890; Capello, 2002; Rosenthal and Strange, 2004). Productivity can be further enhanced through intra-regional mobility of skilled labour shaping knowledge spillovers in the locality (Malmberg, 2003; Boschma et al., 2014). Yet, if the regional knowledge space becomes deprived of the requisite skills, even in the presence of high skill levels, the strength of learning opportunities may

be reduced, implying knowledge-intensive activities would be the most exposed to the presence of skill deficiencies.

These dynamics need to be considered whilst also taking into account the role of inter-regional mobility as a potentially important adjustment mechanism for localised labour markets - even though the evidence suggests that labour mobility remains, for the most part, intra-regional due to social and institutional reasons (Eriksson and Lindgren, 2009; Boschma et al., 2014), and the place-specific nature of relational capital (Capello, 2002; Eriksson and Lengyel, 2019). At the same time, a growing strand of research on the importance of relatedness in the industrial structure of regions indicates labour matching and learning processes may be also defined by cognitive proximity between related industries (Boschma, 2005; Boschma et al., 2009). In this sense, firms' productivity is not solely affected by skill deficiencies in the region and industry where they operate, but there may be a significant simultaneous effect of skill deficiencies across related industries and locations. This is demonstrated in the mounting evidence reflecting the important differences in the effect skill-relatedness in inter-regional mobility of labour has on plant performance (Timmermans and Boschma, 2014; Cappelli et al., 2019). These aspects require moving beyond the intra-industry perspective of previous studies to capture the effect of regional skill shortage vacancies and skill gaps across related industries, developing a measure of spillover effects for skill deficiencies accounting for the geographical proximity and industrial relatedness with all other region-industry combinations.

Finally, we posit these effects may be moderated by the presence of a higher density of economic activity reflecting the non-linear relationship between agglomeration and firm performance (Knoben, Arikan, van Oort and Raspe, 2016). In particular, the literature has suggested the presence of increasing returns to scale for the skill matching function as one of the key features of agglomeration economies (Duranton and Puga, 2004; Rosenthal and Strange, 2004). While a higher density may increase competition for workers, potentially making any skill deficiencies harder to fill (Moretti, 2004; Combes and Duranton, 2006), a higher density of firm location implies a more heterogeneous demand and supply across the skill space, reducing search costs (Helsley and Strange, 1990) and increasing both the probability as well as the quality of matches (Puga, 2010). This may hamper substitution effects towards low skill trajectories and offset the potential loss from learning opportunities through the higher density of interaction. Furthermore, it would suggest that thicker labour markets associated with stronger agglomeration economies would compensate for the negative impact of skill deficiencies, dampening their effect.

Measuring productivity and skill deficiencies

This study draws upon the Employers Skills Survey, the Annual Business Inquiry and the Business Structure Database. The Employers Skills Survey (ESS) is a representative cross-sectional survey of establishments conducted biennially covering all sectors, regions and establishment sizes above sole working proprietors conducted by the Department for Business, Energy and Industrial Strategy. The survey contains around 80,000 workplaces per wave, covering approximately four per cent of the establishments in the UK. The ESS offers detailed information on the skill gaps and skill shortage vacancies experienced by firms, in addition to other key establishment information such as workplace size (number of employees), industry and region of the establishment and whether the establishment is part of a larger organization.

We also collate firm-level data from the Annual Business Survey (ABS), a large survey of firms in the UK based on the Inter-Department Business Register (IDBR). The ABS contains the population of firms with more than 250 employees and a sample of firms which are smaller than this, stratified by size, region and sector. The ABS is an annual survey of businesses covering both manufacturing and service industries in the UK, accounting for about two-thirds of the UK's whole economy in terms of Gross Value Added (GVA)[1]. It includes key information on output, employment, input materials, investments, wage costs and many other detailed firm characteristics. The final dataset used in this work is the Business Structure Database (BSD), which holds the population of businesses in the UK. This dataset contains details on both enterprises and local units, with information on employment, turnover and foreign ownership included, as well as the age of the enterprise.

The merged dataset consists of a panel of firms and their performance information observed every two years from 2008 to 2014. These four waves of our panel are obtained by matching the skill information available biennial from the ESS at the region (NUTS2) and industry (SIC2) level to the ABS and BSD at the firm-level. The skill information from the ESS is lagged one year behind the firm-level information to account for the fact that deficiencies will likely impact on future performance more than present performance (Frogner, 2002).

Theoretical differences between skill deficiencies and skill levels

To measure skill deficiencies, defined as the gap between the required skills and the present skills, knowledge is needed of both the demand and supply of skills for a given job simultaneously. This type of

measure does differ from the typical educational qualifications measures used in the skills levels literature, with both having their relative strengths and weakness. In particular, measures of skill deficiencies are based on survey data[2] and potentially suffer some subjective bias (Richardson and Law (2009)). Further to this, the consistency by which employers interpret the issue of a shortage is also questioned by Green et al. (1998) which adds further difficulty in measuring skills in this way. At the same time, they avoid some of the shortcomings of traditional measures of skill levels such as educational attainment.

Firstly, educational qualifications do not capture variation in the skills across the workforce with the same level of education. As Bacolod, Blum and Strange (2010) point out, students in a class would be considered as equally skilled when they graduate with a given education measure. Furthermore, as most individuals cease their full-time education before they enter the labour market, utilising qualifications as a proxy for skills provides a static measure that fails to capture the developing acquisition of skills as individuals gain experience, adapt to technological progress and switch jobs. Skill deficiencies on the other hand capture experience and training on the job in line with the employer's expectations of the role.

Secondly, qualifications are not effective in capturing the job-specific skills needed in the labour market, including softer skills which are increasingly seen as important. This distinction is evidenced by employers in the ESS, where three times as many establishments report dealing with hard-to-fill vacancies caused by a lack of skills in applicants than hard-to-fill vacancies caused by a lack of qualifications. Crucially for this study, while educational attainment is a useful, if imperfect, measure for skill levels, it does not capture the imbalance between the skills demanded and the skills available in the labour market. High skill levels may be present in a region, but this level of skills may still be below the requirements of the labour market. Likewise, low skill levels may not limit performance, if the demand for skills is lower still.

Measurement of Skill Deficiencies

We exploit information from two key questions in the ESS to build our skills deficiencies variables. Firstly, we define our measure of skill shortage vacancies as the share of hard-to-fill vacancies due to skill reasons. Secondly, we define the internal skill gaps variable as the share of existing staff that the firm does not deem as fully proficient at their job. The two key questions from the ESS used to build our skills variables are: 1) "What are the main causes of having a hard-to-fill vacancy (where skill shortage vacancies are hard-to-fill vacancies due to skill reasons)?"; and 2) "How many of your existing staff would you regard as

fully proficient at their job? (a proficient employee is someone who is able to do the job to the required level)". We expect these measures to capture different mechanisms. A high level of skill shortages in the local labour market suggests operational issues, whereby production is constrained as firms are not able to bring their staffing levels up to their optimal, hampering immediate productivity. High levels of local skill gaps on the other hand, captures how much knowledge is lacking within firms, inhibiting knowledge spillovers and learning effects between firms. To highlight the difference between the two measures of skill deficiencies ESS averages are plotted for the UK by region (NUTS2 classification) in Figure 1. While there does appear to be a positive correlation between skill gaps and skill shortages, there are also regions which are characterised by high levels of skill shortage vacancies and low levels of skill gaps (and vice versa). We find particularly severe skill shortage vacancies in peripheral and less agglomerated regions of the UK, mainly in eastern Scotland, and western Wales. They are also observed in Leicestershire, Bedfordshire (both in the East of England and mainly rural) and affluent counties bordering London such as Hertfordshire, Hampshire and Outer London. Skill gaps co-occur in some areas including Outer London and Merseyside but overall show a different distribution, with particularly high intensities both in peripheral areas, such as western Wales and Cornwall, as well as more agglomerated urban areas such as Inner London and the West Midlands. Skill gaps, therefore, appear to dichotomous, observed both in rural areas and former industrial centres.

To distinguish between a direct measure and a spillover effect of skill deficiencies we derive two different variables based on the above questions. The direct effect is measured as the average intensity of these skill vacancies and gaps for the region r industry s where firm i is located, measured as the market average share of non-proficient workers and the average share of skill shortage vacancies experienced by firms within the rst cell:

$$Direct\ skill\ deficiency_{rst} = \frac{\sum_{i=rst} Skill\ Deficiency_{it}}{N_{rst}} \tag{1}$$

This regional-industry aggregation should allow any firm-level subjective bias in the skill gaps reported to be averaged out across cells where it is uniform, with any systematic region or industry differences being captured by the inclusion of fixed effects terms. Further to this, we attempt to also control for potential spillover effects originating from neighbouring regions and related industries sharing similar labour market conditions and production processes. To achieve this, we create a matrix of region-industry cells in which the measures of skill gaps and vacancies are weighted by the geographical proximity between each pair of regions

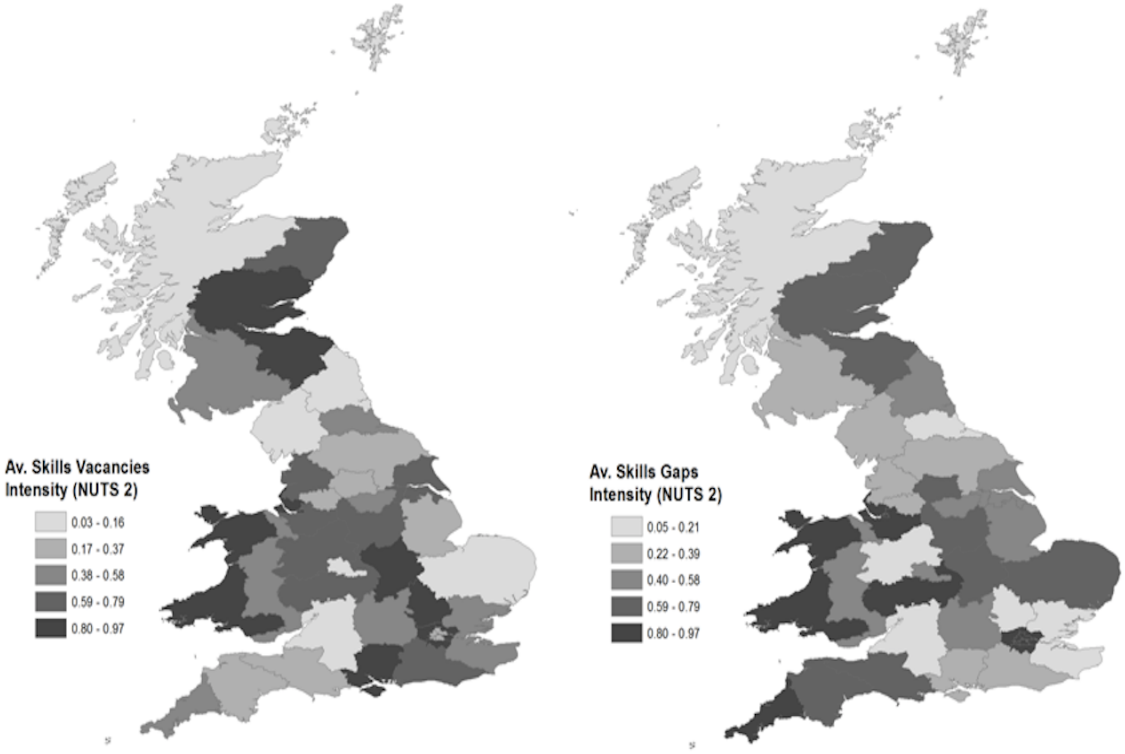

Figure 1. Skill Shortage Vacancies and Skill Gaps per region (NUTS2): Data on skill shortage vacancies and gaps derived from the ESS dataset.

r and k and by the relatedness between each pair of industries s and j. In this way we are able to derive region-industry spillover variables for both skill shortage vacancies and skill gaps, weighting the deficiency in each region-industry by the geographical proximity and industrial relatedness with all other region-industry combinations:

$$Spillover\ skill\ deficiency_{rst} = \underbrace{\frac{\sum_{j \neq s} s_{sjt} Skill\ Deficiency_{rjt}}{N_{rjt}}}_{\text{Regional}} + \underbrace{\frac{\sum_{k \neq r} d_{rk} Skill\ Deficiency_{kst}}{N_{kst}}}_{\text{Industrial}} + \underbrace{\frac{\sum_{k \neq r} \sum_{j \neq s} d_{rk} s_{sjt} Skill\ Deficiency_{kjt}}{N_{kjt}}}_{\text{External}} \quad (2)$$

This measure includes skill deficiencies in other industries within the same region (the first "regional" component in the above equation), shortages within the same industry across different regions (the second "industrial" component), as well as the skill deficiencies in other industries across different regions (the final "external" component). In order to consider only the potential spillovers originating from the most relevant region-industry skill deficiencies, we calculate the above metrics for each rs region-industry combination

while only considering regions k in the top first quartile of the geographical proximity d_{rk} and industries in the top first quartile of the industrial relatedness s_{sjt}[3]. We measure geographical proximity d_{rk} as the normalised value of the inverse of the square root of the Euclidean distance between the centroids of each rk NUTS2 regions combination. The second weight s_{sjt} is a normalised measure of relatedness between each pair of industries s and j using co-occurrence analysis, as started by Jaffe (1989) and broadly developed since (Teece, Rumelt, Dosi and Winter, 1994; Hidalgo, Klinger, Barabási and Hausmann, 2007; Bryce and Winter, 2009). The assumption made in co-occurrence measures is that the frequency by which two industries are jointly located in the same region can be interpreted as a sign of the strength of their relationship, in terms of production processes implemented, inputs of production used, technologies developed, skills required and final markets envisaged.

$$S_{sj} = \frac{\sum_r C_{sr} C_{jr}}{\sqrt{\sum_r {C_{sr}}^2} \sqrt{\sum_r {C_{jr}}^2}} \tag{3}$$

Thus, we indicate the number of co-occurrences between industries s and j across regions r as $C_{sr}C_{jr}$. By applying this count of joint occurrences to all possible pairs of industrial classifications, we obtain a square symmetrical matrix of co-occurrences (C), whose generic cell C_{sj} reports the number of times these industries are jointly located in the same regions. This matrix of co-occurrences can then be used to derive a measure of relatedness between industries using the cosine index S_{sjt} which measures the angular separation between the vectors representing the co-occurrences of industries s and j. As the simple correlation coefficient, the cosine index provides a measure of the similarity between two industries in terms of their mutual relationships with all the other sectors, with S_{sjt} being greater the more the two industries s and j co-occur in the same regions.[4]

Estimation Approach

To estimate how local labour market skill deficiencies affect firms' productivity, while controlling for firm heterogeneity and other region-industry idiosyncratic effects, we estimate equation 4 using a firm-level panel regression model with time, industry and region fixed-effects. In particular, we control for different aspects related to firms performance and the local markets conditions, identifying in this way the effect of skills deficiencies at the region-industry level on TFP at the firm-level:.

$$Y_{irst} = \beta_0 + \beta_1 DS_{rst-1} + \beta_2 SS_{rst-1} + \beta_3 Z_{it-1} + \beta_4 X_{rst-1} + k_{rs} + k_t + \varepsilon_{it} \quad (4)$$

The dependent variable Y_{irst} is the level of productivity of firm i operating in industry s and region r at time t. To ensure robustness we measure productivity as both TFP and GVA, with TFP estimated using the Wooldridge (2009) method with standard errors clustered by NUTS2 regions and SIC2 industries. The main variables of interest are the direct measure DS_{rst-1} and the spillover of skills gaps and skill shortage vacancies SS_{rst-1} derived from the ESS database. The direct effect DS_{rst-1} takes into account the average intensity of these skill deficiencies for the region-industry the firm operates in, measured as the market average share of non-proficient workers and the average share of skill shortage vacancies experienced by firms within the cell. As previously described, SS_{rst-1} includes region-industry skills deficiencies spillovers, measuring the extent of skills gaps and skill shortage vacancies in industries technologically related and regions located geographically close to any given NUTS2 region r and SIC2 industry s at time t. The inclusion of these variables allows us to capture both the direct effect of skill deficiencies at the region-industry level on the productivity of firms as well as the regional and industrial spillover effects deriving from the labour markets of neighbouring regions and related sectors. Table I presents a summary of the key variables used in this study, split across the different industries investigated.

	Manufacturing		High-Tech		Low-Tech	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Skill Shortage: Direct	0.574	0.957	0.666	0.95	0.534	0.957
Skill Gap: Direct	4.932	3.088	4.698	3.034	5.034	3.106
Skill Shortage: Spillover	0.52	0.239	0.529	0.202	0.516	0.253
Skill Gap: Spillover	3.784	0.599	3.688	0.526	3.826	0.624
TFP	5.652	0.924	5.833	0.893	5.572	0.927
GVA	9.116	1.556	9.274	1.487	9.047	1.581
Observations	2,386		727		1659	
	Services		KIS		Non-KIS	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Skill Shortage: Direct	0.72	0.997	0.946	1.117	0.654	0.949
Skill Gap: Direct	5.094	2.558	4.688	2.492	5.213	2.565
Skill Shortage: Spillover	0.604	0.309	0.757	0.44	0.56	0.24
Skill Gap: Spillover	3.951	0.661	3.881	0.551	3.972	0.689
TFP	5.778	1.238	6.159	1.305	5.665	1.194
GVA	9.406	1.697	9.863	1.695	9.272	1.674
Observations	10,451		2,377		8,074	

Table I. Skills deficiencies, TFP and GVA by Industrial classification: Statistics derived from our pooled full sample covering the period 2008-2014.

Name	Definition	Level	Source
Total Factor Productivity (TFP)	Log of Total Factor Productivity estimated using the Wooldridge (2009) methodology using total salary bill, capital and cost of intermediate inputs, with standard errors clustered by NUTS 2-digit regions and SIC 2-digit industries.	Firm	ABS
Gross Value Added (GVA)	Log of gross value added estimated using production approach in basic prices by the ONS as differences between turnover and total costs of production.	Firm	ABS
Av. Salary	Log of total cost of salaries divided by number of full-time equivalent employees.	Firm	ABS
Employment	Log of firm total employment.	Firm	ABS
Age	Log of age of firm.	Firm	ABS
Foreign Ownership	Dummy variable equal to 1 if the firm is owned by a foreign company and 0 otherwise.	Firm	BSD
Group	Dummy variable equal to 1 if the firm is part of a business group and 0 otherwise.	Firm	BSD
Exporter	Dummy variable equal to 1 if the firm is an exporter and 0 otherwise.	Firm	ABS
Intermediate Inputs	Log of total cost of intermediate goods and services for production.	Firm	ABS
Capital Expenditure	Log of firm capital expenditure in land, buildings and machineries.	Firm	ABS
Skill Shortage Vacancy: Direct	Average intensity of skill shortage vacancies measured as the share of skill shortage vacancies experienced by firms within the region r and industry s where firm i is located.	Reg-Ind	ESS
Skill Gap: Direct	Average intensity of skill gaps measured as the market average share of non-proficient workers experienced by firms within the region r and industry s where firm i is located.	Reg-Ind	ESS
Skill Shortage Vacancy: Spillover	Measures of skill shortage vacancies weighted by the geographical proximity between each pair of regions r and k and by the relatedness between each pair of industries s and j.	Reg-Ind	ESS
Skills Gap: Spillover	Measures of skill gap weighted by the geographical proximity between each pair of regions r and k and by the relatedness between each pair of industries s and j.	Reg-Ind	ESS
Agglomeration Index	Log of Ellison and Glaeser (1997) index of region-industry agglomeration measured as the difference between the squared share of employment of an industry in a given region and the squared share of employment of a region in the country, divided by the squared share of employment of the industry in the country, divided by the Herfindhal Index of industrial concentration.	Reg-Ind	BSD
Education	Share of population with a university degree or equivalent.	Reg	Eurostat
GDP	Regional GDP per capita growth.	Reg	Eurostat
Average Salary	Average salary paid by firms in region r and industry s.	Reg-Ind	ABS
Unemployment	Rate of regional unemployment.	Reg	Eurostat
Trade Union Intensity	Share of total workforce member of a trade union.	Ind	ONS
Manufacturing	Dummy variable equal to 1 for all firms in the SIC (2007) sectors between code 10 and code 33, and 0 otherwise.	Ind	ABS
Services	Dummy variable equal to 1 for all firms in the SIC (2007) sectors between code 35 and code 99, and 0 otherwise.	Ind	ABS
High-Tech (HT)	Dummy variable equal to 1 for all firms with a SIC (2007) code equal to 20, 26, 27, 28, 29, 30 and 33, or 0 otherwise, according to the Eurostat definition.	Ind	ABS
Knowledge Intensive Services (KIS)	Dummy variable equal to 1 for all firms with a SIC (2007) code equal to 50-53, 60-66, 68-75, 85, 86, 90 and 91, or 0 otherwise, according to the Eurostat definition	Ind	ABS
Industry Dummy	SIC 2007 2-digit level.	Ind	ABS
Region Dummy	NUTS 2-digit level.	Reg	ABS

Table II. Definition, level and source of variables included in the study.

We control for a set of firm-level control variables (Z_{it-1}) such as total employment, average salaries paid, cost of intermediate inputs of production, export status, capital expenditure, foreign ownership, affiliation to a company group and age. In addition, to avoid omitted variables bias, we add a set of control variables at the region and industry level X_{rst-1} controlling for other region-industry specific factors which could influence the productivity of firms. First, we include the Ellison and Glaeser (1997) agglomeration index to control for the impact of external increasing returns to scale and potential Marshallian spillover effects. To control for potential agglomeration spillover effects originating from neighbouring regions and related industries, we weight the agglomeration forces of other region-industry cells by their geographical proximity with region r and by their relatedness with industry s[5]. We further include the overall economic growth of the region using GDP per capita and tertiary education attainment to control for the different role of skills and education in affecting firms performance[6]. For clarity the definition, level of analysis and source of all the variables included in this study are available in Table II.

To test the potentially moderating effect of agglomeration economies on the impact of skill deficiencies, we explore their marginal impact at different quartiles of the regional-industry agglomeration index following the specification in equation 5, where both the direct skill deficiencies (DS) and the spillover effects are interacted with the agglomeration index ($Agglo_{rst-1}$):

$$Y_{irst} = \beta_0 + \beta_1 DS_{rst-1} + \beta_2 SS_{rst-1} + \beta_3 Agglo_{rst-1} + \beta_4 DS \times Agglo_{rst-1} + \beta_5 SS \times Agglo_{rst-1} + \beta_6 Z_{it-1} + \beta_7 X_{rst-1} + k_{rs} + k_t + \varepsilon_{it} \quad (5)$$

To ensure robustness in our estimates, several alternative models have been tested. This includes estimating our model using a multi-level regression with firm fixed-effects, relaxing the stringent assumption that observations within sub-units are zero-correlated and avoiding endogeneity issues between the observational unit and the variables of interest (Srholec, 2010). Results are consistent across both approaches and are available from the authors upon request.

Results

The main findings from our analysis are evidenced in Table III where we estimate our model using a fixed effects panel regression model (as reflected in equation 4). Column 1 displays our results with only the

direct impact of skill gaps and skill shortage vacancies included. Column two expands the specification to also include the spillover effects of skill shortage vacancies and skill gaps in surrounding region-industries, simultaneously capturing the effect of interconnected regions and related industries. Columns 3 & 4 replicate these results using GVA rather than TFP as the dependent variable.

	TFP		GVA	
	(1)	(2)	(3)	(4)
	Direct	Overall	Direct	Overall
Skill Shortage Vacancy: Direct	-0.0146**	-0.0132**	-0.0122*	-0.0119*
	-0.00624	-0.00633	-0.00691	-0.00606
Skill Gap: Direct	0.00247	0.00268	0.00258	0.0027
	-0.00197	-0.00197	-0.00218	-0.00218
Skill Shortage Vacancy: Spillover		-0.0468*		-0.0487*
		-0.0244		-0.0267
Skill Gap: Spillover		-0.0288**		-0.0208
		-0.0134		-0.0148
Agglomeration Index	0.106**	0.116**	0.282**	0.152**
	-0.048	-0.0524	-0.134	-0.017
Education	0.24	0.377*	0.303	0.416*
	-0.221	-0.221	-0.247	-0.248
GDP	0.102**	0.0812*	0.0132***	0.0359
	-0.0473	-0.0423	-0.00503	-0.0922
Observations	12,869	12,837	12,869	12,837
No. Firms	6,145	6,138	6,145	6,138

Table III. Impact of skill gaps and skill shortage vacancies on firms productivity: Direct and Spillover Effects
Regressions include time, firm, region and industry fixed effects. Robust standard errors clustered at the region-industry level are provided in parentheses, * p <0.1, ** p <0.05, *** p <0.01. Firm-level controls included are; firm employment, firm capital stock, average salaries, intermediate inputs of production, age of the firm, exporter status of the firm, foreign ownership, and an indicator for being part of a larger organisation.

In column 1 of Table III, we observe the presence of a negative and statistically significant coefficient for the direct effect of region-industry skill shortage vacancies on firm productivity, with the magnitude of the coefficient proving to be consistent across the four columns of Table III. This supports the hypothesis that the imbalance between the supply and the demand of skills plays an important role in understanding differences in firm productivity across regions, ceteris paribus.

Interestingly, the skill gap measures are not significant when considered as a direct effect. This may be a consequence of skill gaps and skill shortages representing different mechanisms as previously suggested. Whereas skill shortage vacancies directly affect firms' productivity through loss of required knowledge and operational issues, skill gaps represent a lack of potential knowledge and proficiency in the workforce and

thus a more indirect decrease in learning and spillovers effects. The fact that the learning effects captured by skill gaps are not significant as a direct effect likely suggests that firms are learning from a much wider sphere than just their own region and industry. Accordingly, if the surrounding regions or related sectors have a high number of skill gaps then the decreased learning effects should have a negative impact on productivity. Similarly, higher levels of skill gaps in related industries and regions reflect reduced poaching opportunities in the wider markets and forcing firms to face the full extent of the skills deficiency. This is indeed what is observed when controlling for the externalities originating from both proximate regions and related industries (column 2), where we find a negative and significant spillover effect of both skills gaps and skill shortages on firm productivity.

The estimated coefficients for the other covariates are as expected in all columns, with regional GDP and the Ellison & Glaeser agglomeration index found to have a positive effect on productivity, corresponding with the previous literature on the topic (Ciccone and Hall, 1996; Ciccone, 2002). Region-industry education levels are interestingly not significantly associated with firm productivity when just the direct impact of skill deficiencies are controlled for. This is likely due to a spurious effect created by including direct skill measures but omitting the related spillover effects. In this sense, the spillover effects of skill deficiencies are likely acting as confounding variables, masking the effect that actually exists between education and productivity. Consistent with this, once the spillover effects are also included, the education variable is positive and significant, in line with the previous literature (Webber et al., 2007; Wixe, 2015; Glaeser and Resseger, 2010; Harris and Moffat, 2015) and demonstrating an expected interlinked relationship between skill deficiencies and education. The fact that both skill deficiencies and skill levels are significant in these regressions highlights the need to effectively consider and reduce skill deficiencies within regions, even in areas which may be traditionally considered to have high skill levels. The results are fully robust to different productivity measures, with GVA used as the dependent variable in columns 3 & 4, and also to differing agglomeration measures).

Heterogeneity Analysis

Given the limited understanding of the differential impact skills have on industries and firms, an attempt is made to determine the nuances of our previous finding with subsample analysis in Table IV. As highlighted earlier in the work, our ex-ante hypothesis, based on the previous regional level human capital investigations, is that skill deficiencies would be most detrimental to firms where learning effects are larger,

and in markets where the efficiency trade-off of substituting a skilled worker for an unskilled worker is higher. To investigate this, we break our sample based on manufacturing vs service industries (columns 1 & 2), high-tech and low-tech (columns 3 & 4) as well as knowledge-intensive services (KIS) vs Non-KIS industries (columns 5 & 6). All regressions are run with our fixed effects estimation with results again shown to be robust and consistent with both TFP (Table IV) and GVA (available upon request) as dependent variables.

	(1) Manuf	(2) Service	(3) HT	(4) LT	(5) KIS	(6) Non-KIS
Skill Shortage Vacancy: Direct	-0.000672	-0.0180**	-0.0317**	-0.0136	-0.0192**	0.0109
	-0.0091	-0.00747	-0.0134	-0.00922	-0.00788	-0.0137
Skill Gap: Direct	-0.00285	0.00436	0.00645	0.00488	-0.00419	0.00457
	-0.00338	-0.00237	-0.00473	-0.00284	-0.00485	-0.00244
Skill Shortage Vacancy: Spillover	-0.0345	-0.0398	-0.0987**	0.0323	-0.117**	-0.0398
	-0.0446	-0.0279	-0.0441	-0.0383	-0.0527	-0.0258
Skill Gap: Spillover	-0.00536	-0.0309**	-0.0543***	-0.00128	-0.0890***	-0.0127
	-0.0331	-0.015	-0.0184	-0.0238	-0.0313	-0.0151
Agglomeration Index	0.409**	0.124	0.279	0.295**	0.368*	0.0749
	-0.199	-0.17	-0.4	-0.145	-0.178	-0.173
Education	0.386	0.454*	0.640**	0.248	1.253**	-0.0115
	-0.499	-0.239	-0.275	-0.5	-0.529	-0.259
GDP	0.0653***	0.000915	0.319**	0.079	0.00747	0.0149
	-0.0163	-0.0956	-0.154	-0.111	-0.24	-0.0863
Observations	2,386	10,451	2,377	8,074	4,725	8,112
No. Firms	1,283	4,918	1,165	3,850	2,956	3,668

Table IV. Impact of skill gaps and skill shortage vacancies on firm productivity (TFP): Sub-sample analysis
Regressions include time, firm, region and industry fixed effects. Robust standard errors clustered at the region-industry level are provided in parentheses, * p <0.1, ** p <0.05, *** p <0.01. Firm-level controls included are; firm employment, firm capital stock, average salaries, intermediate inputs of production, age of the firm, exporter status of the firm, foreign ownership, and an indicator for being part of a larger organisation.

It is evident that firms in services industries, and in knowledge-intensive service industries more specifically, are the most negatively affected by skill shortage vacancies, both in terms of direct effects and in terms of spillover effects. Given the assumption that these industries will require higher skill levels, it is perhaps harder to fill any given skill shortage vacancy than in other industries, where a less skilled worker may still be able to conduct the job to a certain standard. It may also reflect the fact that learning effects are stronger in these industries and missing out on this knowledge sharing is more detrimental to performance. This is seen in Table IV with skill shortage vacancies having a relatively large and significant impact on productivity for high-tech and KIS firms. Similarly, we find a significant spillover effect for skill gaps. The direct impact of

skill gaps again does not appear to be significant in any of our regressions, consistent with results in Table III.

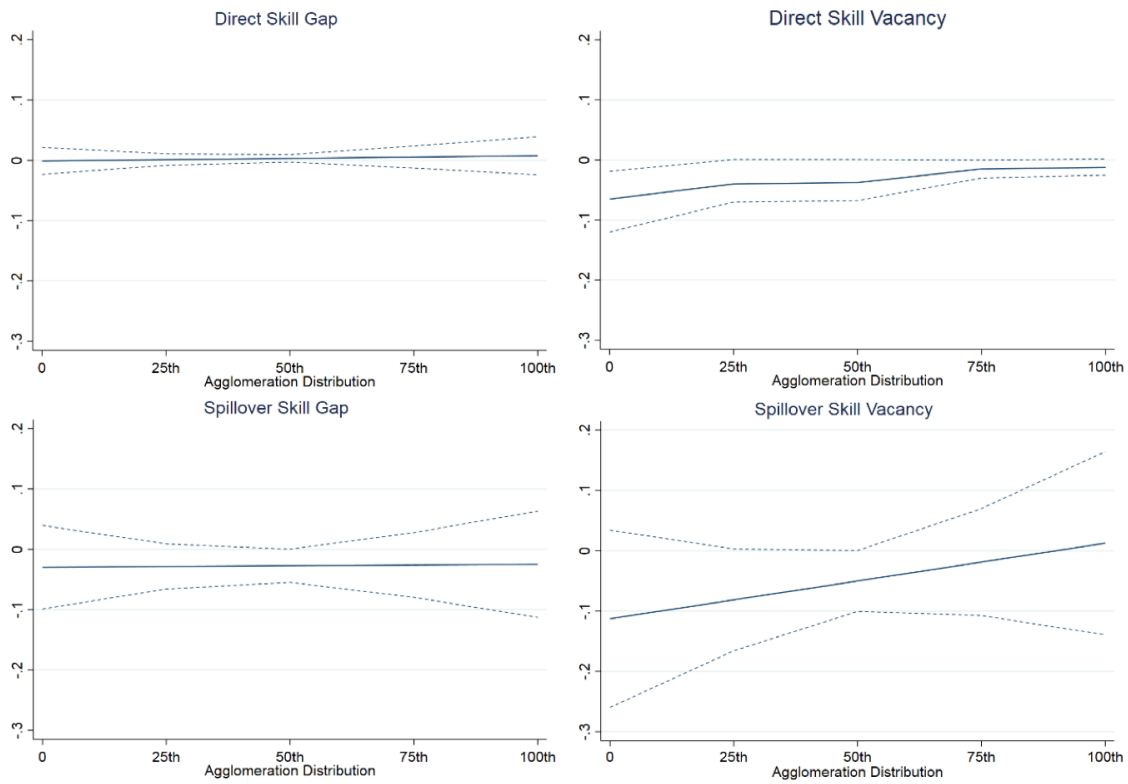

Figure 2. Impact of the skill shortage vacancies upon Total Factor Productivity by Ellison and Glaeser agglomeration index quartile Results derived from our full sample covering the period 2008-2014. Dashed lines show 95% confidence intervals.

To further disentangle how skill deficiencies fit within a complex regional framework, we consider the marginal impact of skill shortage vacancies and skill gaps vacancies at different quartiles of the regional-industry agglomeration index. Figure 2 reports the results of including interactions between the skill measures and the Ellison and Glaeser (1997) agglomeration index, as shown in equation 5. It is evident that direct skill shortage vacancies affect the least agglomerated regions and industries the strongest, with a negative effect on productivity decreasing as the agglomeration becomes stronger. We find a similar trend for indirect skill shortage vacancies, again having stronger spillover effects in the least agglomerated region-industries and a weakening impact as agglomeration increases, until being not statistically different from zero in markets with above the mean agglomeration levels. On the contrary, agglomeration does not seem to play any role in mediating the effect of direct skills gaps on productivity, or for indirect skill gaps. Given the coefficient on direct skill gaps is consistently insignificant in our main results, this was expected. These results suggest a substantial labour pooling effect as firms' agglomeration induces "thick" labour markets where firms and workers may match more easily in densely agglomerated markets, with stronger

knowledge spillovers resulting in a weaker effect of skill deficiencies on productivity (Overman and Puga, 2010; Gabe and Abel, 2010). Conversely, low levels of agglomeration increase employee-employer mismatch and hinder learning effects due to co-location, which will in turn negatively affect firms' productivity. These findings seem consistent with Marshallian labour market pooling and previous evidence in the relationship between learning effects and density (Glaeser and Resseger, 2010; Andini et al., 2013; Harris and Moffat, 2015).

Conclusions

In this paper, we contribute to the literature on the regional determinants of firm productivity complementing previous perspectives based on the importance of education and skill levels with analysis of the impact of skill deficiencies. This allows us to better reflect the idiosyncratic needs of the regional economic structure, considering both the demand and supply side of the skills equation.

Merging region-industry skill data for a longitudinal panel of 12,875 firms across 40 NUTS2 regions in the UK, covering the period 2008-2014, our study offers novel evidence of a significant negative impact of regional skill shortage vacancies on firm-level productivity. As expected, this effect is found to be stronger in industries defined by a knowledge-intensive skill base. Similarly, we found such impact to be stronger in less agglomerated regions, suggesting that learning effects and better skill matching usually associated with these areas may be partly compensating for regional skill deficiencies and inefficiencies in the local labour market. We further considered how localised skill deficiencies may be overcome by looking for resources in other industries and regions. Following recent evidence on the importance of skill-relatedness in labour mobility (Boschma et al. (2009); Timmermans and Boschma (2014); Cappelli et al. (2019)) and considering possible labour pooling across regions to compensate for skill deficiencies, we have explored the indirect impact of skill gaps and skill shortage vacancies defined by geographical proximity and industrial relatedness. The results point to a negative spillover effect of both skill gaps and skill shortage vacancies, suggesting skill deficiencies cannot be compensated by pooling resources from related industries and regions when these are characterised by skill gaps or shortages in their workforce.

The market failures related to skill provision are already well documented (see Booth and Snower (1996) for a review) but while previous empirical evidence has focused on the importance of skills levels in the workforce, our analysis offers a more nuanced perspective revealing a significant impact of regional skill

deficiencies upon firm performance. These findings point to relevant policy implications in the current debate over the increasing divergence in inter-regional productivity. Sustaining long term regional development and escaping low skill traps requires addressing structural weaknesses that define local demand for skills, together with supply-side approaches that are not limited to a traditionally spatially-blind provision of higher skill levels regardless of the regional environment. Intervention without context risks exacerbating the divergence across regional productivity by increasing mobility towards the strongest regions. This may end up sustaining the conditions for a low skill equilibrium in lagging areas. Complementing support for higher skill levels and tackling place-specific skill deficiencies would allow synergies for additional productivity growth, leading to further investment and competitiveness across heterogeneous regions. To this end, policy intervention should explicitly recognise and work on localised skills gaps or shortages to address the specific needs of the regional economic structure, through engagement with different levels of governance (Barca et al., 2012). Similarly, while agglomeration effects may enhance skill matching and moderate the impact of skill deficiencies, policies based on such approach are only applicable to few already stronger regions and would end up further increasing the regional productivity divide. A place-based approach evolving with the idiosyncratic and specific needs of regions would enable more effective strengthening of spatially-bound learning dynamics and local capabilities for more balanced regional growth. In this sense, a stronger regional embeddedness in the support for skills development may be particularly important to support or upgrade competencies in lagging regions (McCann and Ortega-Argilés, 2015), especially in the context of significant structural changes in labour and technology markets (Bailey, Pitelis and Tomlinson, 2018).

Clearly, additional research is needed to better understand the spatial dynamics between the skills equation and firm productivity. While we attempted to account for inter-regional labour market areas through spatial lags, our models do not explicitly control for inter-regional mobility. In this sense, the impact of skill gaps and skill shortage vacancies should be further explored focusing on the growing evidence that suggests a differential impact across degrees of relatedness between the inflows of skills and the regional knowledge base (Boschma et al., 2009). Furthermore, our results point to the importance of complementary analysis on regional dynamics of overeducation and overskilling for future research. Similarly, more granular information on skills typologies may offer the opportunity to explore the impact of specific types of skills gaps or shortages across occupations, to better understand their impact within the functional structure of regions. However, in line with recent contributions (Martin et al., 2018), this paper does offer important further evidence that the importance of skills in solving the so-called productivity puzzle cannot be reduced to a simple space-neutral support for higher skill levels.

Notes

1. A detailed description of the ABS can be found in Criscuolo, Haskel and Martin (2003).
2. Employer-based measures of skill deficiencies, such as those offered by the ESS, have been associated to lower levels of subjective bias than employee measures (McGuinness and Ortiz, 2016).
3. For robustness we re-estimate the skills shortages spillover variables taking into account industries located in regions at different points in the geographical proximity distribution (5th, 25th, 50th and 75th percentiles). While it is possible to notice a distance decay effect in these results, overall they are consistent with our main findings. Results are available from authors upon request.
4. As a robustness test, in our analysis we use alternative measures of industrial relatedness instead of the cosine index, such as the simple correlation between industrial employment across regions, the Teece et al. (1994) index of industrial relatedness and the Neffke and Henning (2013) measure of revealed relatedness. The use of different industrial relatedness weights yields consistent results which are available from the authors upon request.
5. As robustness checks, we have used alternative measures of agglomeration to test the sensitiveness of our results to the inclusion of different indexes. First, we have calculated the absolute number of firms in each region-industry cell. For robustness, we have also measured industrial density as the number of firms per region-industry weighted by the total population in the region, which yields consistent results. Further robustness checks included repeating the regression analysis without London to ensure this was not dominating the result, with no significant change in the main results suggesting this is not driving our findings.
6. To ensure our skill gap measure is not capturing other phenomena that may increase the difficulty for employers to replace existing employees where they are not fully proficient, we have conducted robustness checks including in our main specification additional control variables, such as the level of unemployment in the region at NUTS2 level, the average salary paid at the region-industry level and the share of workforce unionised at the industry level. To ensure that other region or industry-specific factors are also not at play (and are not captured by the variables included so far), we have also included region and industry time trends in our specification to account for additional unobserved sources of variability. Results are consistent and robust to both of these checks and are available upon request.

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