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ABSTRACT

We put geographical proximity and type of knowledge collaboration partner as two boundary conditions for innovation in Schumpeterian firms. Extending the evolving literature on knowledge collaboration and regional studies, we use an innovation survey of 1251 Schumpeterian firms from 2002 to 2014 in the UK to examine this relationship. The results show that Schumpeterian firms achieve greater returns to knowledge collaboration in spatial proximity and with suppliers and customers, while the effects change with the partner type and between macro-regions in the UK: Wales, Scotland, Northern Ireland and London. This study has implications for researchers and policymakers.

KEYWORDS
innovation; Schumpeterian firm; knowledge collaboration; knowledge partner; region

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1. INTRODUCTION

The function of the entrepreneur is to innovate beyond familiarity (Schumpeter, 1911/1934, 1942), introduce new combinations of knowledge, break up the old, and disrupt markets and industries (Henrekson & Sanandaji, 2020). In this regard, Schumpeterian entrepreneurship, which is not restricted to technological change in industries and markets, can be useful in understanding the inputs and outputs of the innovation process, and may provide tools for start-ups that aim to develop innovative new products and services. Research has demonstrated that while Schumpeterian entrepreneurs benefit from innovation, there are numerous examples from Europe and the United States (Henrekson & Sanandaji, 2020; Malerba & Orsenigo, 1996; Mthanti & Ojah, 2017) where they have also contributed significantly to the regional economy (Fritsch, 2011), as well as Smart Specialisation and innovation (Colombelli, 2016; Colombelli et al., 2016). However, only a minority of start-ups who formally compare themselves with Schumpeterian entrepreneurs create new-to-market products (Frenz & Ietto-Gillies, 2009).

While innovation is also created by incumbent firms, this innovation is mainly incremental and exploitative (Henrekson & Sanandaji, 2018, 2020). It is important to study innovation in Schumpeterian firms as a great deal of innovation takes place in these innovative start-ups, which introduce new products, processes, and services to the market and industry. Only a small fraction of firms, between 10% and 15% (Office of National Statistics (ONS), 2021b), can introduce new-to-market products and pursue what we know as the creative destruction of entrepreneurship (Fritsch & Wyrwich, 2014, 2018; Schumpeter, 1911/1934, 1942). Drawing on Henrekson and Sanandaji (2020), Estrin et al. (2022) and Audretsch et al. (2021), we define 'Schumpeterian entrepreneurs' as agents of innovation and change in the market who enter a new market by introducing a novel product before their competitors. Most Schumpeterian firms are seven years old and innovate new business models, products and services (Malerba & Orsenigo, 1996).

Therefore, the aim of this study is to examine the role that collaboration partners as sources of external knowledge play in facilitating innovation in Schumpeterian firms. More specifically, our research question is: How does collaboration with different external partners (universities, competitors, customers, suppliers) regionally, nationally and internationally affect innovation in Schumpeterian firms?

There are two aspects to Schumpeterian firms' knowledge-sourcing strategies, based on considerations of the

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type of knowledge collaborator (Beers & Zand, 2014) and the geographical proximity of knowledge collaboration (Boschma, 2005). The first relates to types of collaborative partners that have competitive advantages, new knowledge and superior complementarities (Jaffe et al., 1993), and contribute to knowledge creation and innovation. The second relates to regional proximity based on the localisation of knowledge (Audretsch & Feldman, 1996; Pahnke et al., 2023). Boschma and Frenken (2010) contribute to our understanding of the role of regional collaboration and proximity for creating and maintaining knowledge partnerships by warning about the optimal proximity of knowledge collaboration while being silent on the types of collaboration partner and spatial proximity (Arranz & de Arroyabe, 2008; Balland et al., 2015).

This study draws attention to several perspectives. The first is the geographical perspective, which is associated with geographical proximity of knowledge collaboration in Schumpeterian start-ups (Crescenzi et al., 2016; Rutten & Boekema, 2012) and new firm formation dynamics (Colombelli & Quatraro, 2018). Limited research exists that connects knowledge collaboration to Schumpeterian firms' innovation performance across different geographical dimensions (Miotti & Sachwald, 2003; Nooteboom et al., 2007). The second is the type of external knowledge partner, which is associated with the firm's knowledge creation and transfer (Roper et al., 2017). When considering the knowledge sourcing strategy, a firm also needs to consider (1) its location and (2) the type of collaboration partner it aims to work on innovation with.

This paper makes three contributions. First, we extend the understanding of how and where Schumpeterian firms create knowledge for creative distraction by demonstrating the importance of the regional dimension of knowledge collaboration and embeddedness in regional communities of knowledge. Second, building on the literature on open innovation (Adner, 2017; Teece, 2007, 2018) and the nature of Schumpeterian start-ups (Audretsch et al., 2020; Colombelli, 2016), we examine how knowledge collaboration localisation affects innovation. Third, drawing on the open innovation (Beers & Zand, 2014; Santamaria et al., 2009; Schamberger et al., 2013) and Schumpeterian entrepreneurship literature (Audretsch et al., 2020; Henrekson & Sanandaji, 2020; Estrin et al., 2022), this study articulates the complex relationship between a firm's strategic choices about the type of partner, intensity of collaboration and location of knowledge collaboration.

This paper is organised as follows. The next section briefly reviews the main literature on knowledge collaboration and develops our main hypothesis. The data and empirical methodology are described in the third section, while the results are discussed in the fourth section. Finally, the fifth section discusses and concludes with policy implications, limitations and recommendations for future research.

2. THEORETICAL FRAMEWORK

The causal mechanisms act through multilevel effects. Our framework identifies three levels of analysis: (1) the microlevel related to Schumpeterian entrepreneurs, their strategic behaviour and open innovation strategies; (2) the ecosystem (context) level related to the knowledge collaboration; and (3) spillover across the region, country and global proximity.

2.1. External knowledge collaboration and innovation

The innovation-creating abilities of Schumpeterian entrepreneurs have primarily been associated with the discovery and creation of new knowledge (Shane & Venkataraman, 2000) and the development of valuable opportunities leading entrepreneurs to greater growth aspirations for their new business (Estrin et al., 2013; Estrin et al., 2022; Levie & Autio, 2011). An entrepreneurial opportunity can arise via a discovery or a creation process and may be conditional on the context of external knowledge collaboration (Adner, 2017; Berchicci, 2013; Rogers, 2004).

A wide body of literature has emphasised the importance of opportunity creation by launching new products through new venture creation (Audretsch et al., 2021), as well as the important role of Schumpeterian entrepreneurs in creating new technologies and new markets (Colombelli, 2016; Colombelli et al., 2016). The role of Schumpeterian entrepreneurs is even more relevant when revolutionary technologies are at stake. Schumpeterian entrepreneurs receive knowledge from within a company and by sourcing from external partners (Audretsch & Belitski, 2020). External knowledge is critical for Schumpeterian firms as it complements their in-house knowledge creation (Beers & Zand, 2014; Schamberger et al., 2013). External knowledge sourcing adds to firm productivity, secures competitive advantages in the market and allows new opportunities to be recognised (Ketchen et al., 2007).

While the mechanisms of external knowledge sourcing, including knowledge flows, seem clear, its empirical identification and measurement are theoretically complex (Mindruta, 2013; Tang et al., 2020). The importance of external knowledge for firms is reflected in many applications in different fields of knowledge management, entrepreneurship and economic geography.

From the perspective of resource-based theory, external knowledge collaboration helps Schumpeterian firms to gain competitiveness by integrating, modifying and creating new combinations of resources with those of other partners (Banal-Estañol et al., 2018; Barney et al., 2001; Miotti & Sachwald, 2003; Mowery et al., 1998).

Schumpeterian firm must have diverse experience and knowledge in order to innovate internally and absorb new knowledge across different external partners (Faems et al., 2005; Sullivan & Ford, 2014) and at various geographical proximities (Lahiri, 2010; Laursen et al., 2011; Nooteboom et al., 2007).

Although several studies have debated whether co-location between a knowledge producer and a knowledge recipient has a positive effect on a firm's productivity and innovation (Audretsch & Feldman, 1996; Iammarino & McCann, 2006; Schamberger et al., 2013), other studies have suggested a negative or neutral relationship (Balland

et al., 2015; Boschma, 2005; Lundvall, 1998). Knowledge collaboration within regional and national markets may prevent novel knowledge spillover in a region, leading to the 'lock-in effect' (Boschma, 2005; Boschma & Frenken, 2010) and significantly limiting the development of a firm's international capabilities and absorptive capacity (Rugman & Verbeke, 2001).

Unlike mature firms, Schumpeterian firms face significant resource constraints that push them to focus on cost-efficient localised networks (Iammarino & McCann, 2006; Jaffe et al., 1993), national institutions (Stenholm et al., 2013) and temporary geographical proximity (e.g., monthly meetings, Skype calls, professional mobility, temporary projects).

Previous studies indicate the endogeneity of partner selection (Banal-Estañol et al., 2018; de Wit-de Vries et al., 2019; Furlotti & Soda, 2018; Mindruta, 2013). Furthermore, past empirical literature suggests that proximity becomes less critical when the research quality of the collaborative partner is important (Mansfield & Lee, 1996; Tang et al., 2020). From these viewpoints, it is important to examine the effect of geographical proximity controlling the characteristics of collaborative partners. In addition, the choice of partners is endogenous, and the decision to collaborate is also endogenous.

For a Schumpeterian firm to be able to innovate, multilateral interdependencies between a variety of ecosystem actors are required, and they must interact in multiple ways (Adner, 2017; Cassia et al., 2009; Mindruta, 2013; Tang et al., 2020).

Colombelli (2016) used the knowledge spillover of entrepreneurship theory and the recombinant knowledge approach to investigate the relationship between the features of local economic systems, represented by the set of knowledge and technological competences accumulated over time in a region, and the creation of innovative start-ups. While this is an important addition to the knowledge spillover of entrepreneurship theory, the origins of knowledge and technological competences such as the type of collaboration partner (e.g., suppliers, universities, customers) and the location of the collaboration partner (regionally versus interregionally versus globally) has remained unknown. In this respect this study further explains the role of external collaboration partner types and their geographical location and how they affect the innovation outcomes of Schumpeterian firms, moving from the aggregated regional level to a more disaggregated firm-level analysis. While firms are the final beneficiaries of localised economic systems, they can also search for knowledge which may directly affect their innovation performance both nationally and internationally. Fritsch and Wyrwich (2018) also demonstrate that the historical distribution of self-employment in science-based industries and regions has a persistent effect on new knowledge creation and its market commercialisation via entrepreneurship in innovative industries today.

There are several reasons why the more substantial positive effect of local knowledge collaboration can overshadow and provide a greater innovative premium compared with other geographical proximities of knowledge collaboration. First, regional and national markets have a degree of familiarity with products and services created by a firm which is located in a region. Colombelli and Quatraro (2018) demonstrated that knowledge spillovers and the configuration of local knowledge bases are important for entrepreneurial dynamics. Second, regional markets (in England, this is also the national market which includes London) are used as testing grounds for new products and services before scaling up internationally (Rugman & Verbeke, 2001). Third, competition is less intense in regional and national markets, and intellectual property rights could be protected faster and more efficiently (Nooteboom et al., 2007). Knowledge collaboration with foreign partners means less control over protection and access to knowledge dissemination overseas, while local collaboration networks will be easier to access and keep control over. Fourth, regional and national partners offer customised services, and supply firms with ready-made solutions that can be quickly incorporated into production processes (Fritsch & Wyrwich, 2014, 2018), lowing the research and development (R&D) investment costs for Schumpeterian firms (Antonelli & Colombelli, 2015). Fifth, Balland et al. (2015) demonstrated that geographical proximity between firms is a necessary condition for learning and interactive innovation, and that it plays a privileged role compared with other drivers of local network formation. Finally, Schumpeterian firms located in developed countries, such as the UK, may access global knowledge locally within the Greater London area as well as other industrial clusters for multinational companies within the UK (Iammarino & McCann, 2006) and within various regional knowledge production modes (Henrekson & Sanandaji, 2020; Mindruta, 2013; Tang et al., 2020). We hypothesise:

Hypothesis 1: Schumpeterian firms will achieve higher innovation outcomes in knowledge collaborations with regional partners than in knowledge collaborations with foreign partners.

2.2. Partner types and innovation

2.2.1. Suppliers, customers and innovation in Schumpeterian firms

Collaborations with external partners provide unique opportunities to learn from others (Beers & Zand, 2014). External knowledge may constitute an important decision criterion in Schumpeterian firms' innovation decision-making, specifically regarding whether they should invest in internal R&D or access knowledge spillovers. Prior literature has demonstrated that knowledge from customers and suppliers is most valuable for innovation and has a larger positive impact on innovation than other types of collaboration partners (Cappelli et al., 2014; Un & Asakawa, 2015; Chesbrough, 2003). Unlike Un and Asakawa (2015), collaborations with suppliers dealing with the input side of firm operations are more important than collaborations with clients or customers. Cappelli et al. (2014) argue that collaborations with

clients and customers are likely to promote co-creating new products as a proxy for innovation, therefore better addressing the needs of customers. Knowledge collaborations with customers may range from informal exchanges of ideas to formal co-development projects aiming to launch new products to the market, and can be strongest within localised communities and networks due to an increased level of trust (Pahnke et al., 2023).

What we know is that knowledge collaboration with suppliers and customers facilitates the transformation process of knowledge creation in a focal firm, improving the final innovation outcomes and speeding up the process that enables innovation outcomes to be achieved (Audretsch & Belitski, 2020; Roper et al., 2017). There are several reasons why collaboration with suppliers and customers is particularly valuable for innovation in Schumpeterian firms. First, innovation is a systemic process where changes in one part of the process alter iterations with the other processes, requiring a transformation and adjustment of the systems, which is unlikely to occur within an alliance but more likely to occur within the supply–demand value chains. Knowledge of customers can be easily adapted into business routines and processes at a firm. Collaborations with suppliers will alter their production system, adapting and adjusting its characteristics so that they may easily facilitate innovation and introduce products to market.

Second, process-wise, suppliers and customers can recommend innovation to specific manufacturing processes using spare parts and materials from suppliers. At the same time, customers may compare the firm's products with other products in the industry and recommend desired improvements. Finally, a closer relationship with suppliers and customers enables the integration of firm-specific tacit knowledge and external knowledge to follow best practices and speed up product creation and modification projects (Battke et al. 2016; Chesbrough, 2003), saving time and reducing the cost of new product creation (Audretsch & Belitski, 2020). The integration of explicit and tacit knowledge embodied in suppliers and customers is vital for start-ups lacking resources and time for new product development. We hypothesise:

Hypothesis 2a: Knowledge collaborations with suppliers and customers increase innovation activity in Schumpeterian firms

2.2.2. Coopetition and innovation in Schumpeterian firms

Collaboration with competitors (coopetition) may both facilitate and reduce a firm's innovation efforts. Park et al. (2014) and Mariani and Belitski (2022) developed the conceptual model where they explain the role coopetition intensity plays in a firm's innovation outcomes. Consistently with the typologies of coopetition developed (Bengtsson et al., 2010; Park et al., 2014), these studies have recognised firms can benefit from coopetition through three key mechanisms: co-development, partner resource acquisition and enhanced internal efforts. More broadly, innovation-related coopetition (Ritala & Hurmelinna-Laukkanen, 2009) has been much discussed in the coopetition literature. However, the role of coopetition as a means of expediting innovation is largely underexplored (Nemeh & Yami, 2019) and does not feature at all as a theme in the extant coopetition literature (Dorn et al., 2016).

While coopetition has important learning effects for both parties, coopetition may be often perceived as a direct threat to innovation, and in particular in Schumpeterian firms. Prior research has demonstrated that firms which mainly rely on imitation of their competitors' products and do not have experience of creating new-to-market products and services will benefit from increasing the intensity of coopetition (Mariani & Belitski, 2022). However, Schumpeterian firms on the forefront of innovation may be disadvantaged by coopetition as knowledge spillovers that are created as a result of coopetition may dissipate the exclusivity of knowledge and competitive advantage of Schumpeterian firms. Coopetition for young firms serves as a ticket to competitive advantage, allowing them to absorb knowledge from more powerful and mature competitors. Young firms can thus level up or copy products from their competitors, and in doing so introduce new products to their firms and increase sales due to imitation. Young firms and imitators in coopetition may increase their sales by reaching new markets and by exploiting the technology of competitors.

There are several reasons why coopetition is likely to have a negative effect on innovation activity in Schumpeterian firms. First, coopetition may reduce the sales of Schumpeterian firms. If competitors are able to learn from the most innovative Schumpeterian firms through coopetition, this threatens further investment in R&D, innovation by Schumpeterian firms and will lead to sales reduction. As firms make disclosures due to coopetition, and in particular with an increase in coopetition intensity, trade-offs are made with regards to firm-level competitiveness on the one hand and coopetition on the other. Therefore, we argue that Schumpeterian innovative firms who interact with competitors and transfer knowledge (Hamel, 1991; Park et al., 2014) may face a trade-off between coopetition and the ability to retain their competitive advantage in coopetition (Nooteboom et al., 2007). Second, there is a risk attached to coopetition as knowledge spillovers increase. More frequent interactions between economic agents, which are more likely to occur with local proximity, develop mutual trust (Dyer & Singh, 1998; Schilling & Phelps, 2007), but also increase the level of knowledge spillovers which may make new knowledge obsolete for the top innovators. Third, competitors in collaboration are often locked into a code of conduct of decision coordination which increases transaction costs and prevents either of the collaborators from independently introducing new-to-market products (Ahuja, 2000). Fourth, while an increase in coopetition intensity leads to the co-development of new products, it is Schumpeterian firms who are expected to bear the cost of new product development, for example, intramural R&D.

Finally, opportunism could be the outcome of intense and close coopetition with the most innovative Schumpeterian firms who invest heavily in technology and competences (Salvetat & Géraudel, 2012), resulting in knowledge leaks (Estrada et al., 2016) and 'snapping off' innovative ideas from Schumpeterian firms. Accordingly, we hypothesise:

Hypothesis 2b: Knowledge collaboration with competitors decreases innovation activity in Schumpeterian firms.

2.2.3. Universities and innovation in Schumpeterian firms

Prior research suggested that institutional partnerships with universities and (or) research institutes play an important role in the emergence of a Schumpeterian-type start-up. Fritsch and Aamoucke (2013) found a strong positive association between innovative start-ups and the presence of universities and other public research institutes in a region (Etzkowitz & Leydesdorff, 2000).

Universities are interested in contributing to private sector innovation and they develop a set of mechanisms by which universities can transfer knowledge to industry.

First, spinoffs from universities and incubators when university discoveries are commercialised with the help of private capital. Scholars describe the emergence of new organisational forms, such as research laboratories, university–industry research centres, corporate incubators, and accelerator programs (Banal-Estañol et al., 2018; Radko et al., 2023), where knowledge is created and tested before it can be applied in the industry in the form of a spin-off or as a new product by an incumbent firm.

Second, people move from universities to the private sector. Universities are involved in a region's ecosystem via educating students and professionals, and nurturing human capital and preparing an industry workforce by doing so (Audretsch et al., 2022b). University graduates are employed by private industry in a region and country. An increase in high-quality human capital, in particular in the science, technology, engineering and mathematics (STEM) fields, may attract Schumpeterian-type entrepreneurs to a region (e.g., Stanford University high-tech cluster, University of Cambridge engineering cluster).

Third, knowledge spillovers from university to industry (Carree et al., 2014) by employing scientists part-time or as consultants to Schumpeterian firms. University professors perform consultant roles as well, as they organise research workshops, conferences and panel discussions for communities of scholars and businesses, and Schumpeterian firms may participate in these events.

Furthermore, joint research projects between universities and industry generate knowledge spillovers which can be exploited by collaborators, and also by third parties such as public and private firms, entrepreneurs, and government. Government initiates university–industry collaboration by financing calls for applied projects with Schumpeterian-type private firms and engaged universities, for example, via the InnovateUK programme in the UK, that address demand for knowledge across specific sectors prioritised by industry and government.

Fourth, formal and informal knowledge collaboration between university researchers and practitioners exposes university researchers to a wide range of technological problems identified by industry, creating research opportunities which can be fed back to the industry. At the same time greater engagement in a variety of interactions with industry will facilitate the application of research created at universities, since industry practitioners are well-informed about industry needs and customer wants (Siegel et al., 2003).

Researchers working in a specific scientific discipline develop common perceptions and practices (D'Este & Patel, 2007), and these could be adapted to a specific industry through R&D collaboration agreements, technology transfer partnerships, or knowledge transfer partnership agreements between technology transfer offices at universities and in the private industry. The outcomes of knowledge spillovers and collaborations between universities and Schumpeterian firms can be patented, licensed, or used to create new spin-offs. We hypothesise:

Hypothesis 2c: Knowledge collaboration with universities increases innovation activity in Schumpeterian firms.

2.3. Regional collaboration and partner typology

Collaboration with external partners within close geographical proximity is an efficient mechanism for Schumpeterian firms to nurture innovative ideas and commercialise them by starting a new business (Audretsch & Feldman, 1996). The efficiency of regional collaboration emanates from the localised advantages for Schumpeterian firms, given their paucity of resources and experience at the venture and growth stages (Estrin et al., 2022). Schumpeterian firms will prioritise localised collaborations with different stakeholders (suppliers, customers, universities, etc.) within specific knowledge clusters (Feldman, 2014). Prior research has indirectly emphasised the role of localised knowledge on innovation performance in Schumpeterian-type start-ups, including the role of local knowledge stock for entrepreneurial entry and innovation (Audretsch & Keilbach, 2007), the role of university research activity for innovative spin-offs (Cassia et al., 2009), and the role of stakeholders in regional entrepreneurial ecosystems (Audretsch & Belitski, 2017) and innovation ecosystems for Schumpeterian innovation and entrepreneurship (Audretsch et al., 2020; Colombelli et al., 2016).

Schumpeterian firms can better govern innovation collaborations with a variety of collaboration partners locally compared with non-Schumpeterian firms and mature counterparts. However, these unique characteristics and their associated advantages prevail first and foremost

when Schumpeterian firms collaborate with suppliers and customers within their region. For a young Schumpeterian firm, knowledge from customers could be transferred through face-to-face interactions leading to the creation and exchange of tacit knowledge (Audretsch & Feldman, 1996). Knowledge collaboration with suppliers enables firms to minimise transportation and transaction costs and make the most use of spatial and cognitive affordances in a region (Belitski et al., 2023). We would like to outline three key reasons why collaboration between Schumpeterian firms and external partners within close spatial proximity will be most beneficial for innovation in Schumpeterian firms.

First, Schumpeterian firms are most visible due to their innovativeness, growth orientation and higher reputation (Beck & Prügl, 2018), and therefore their innovation strategy is supported by and embedded in local communities and regions (Audretsch & Vivarelli, 1996; Colombelli, 2016). These frequent interactions allow firms to gain first-hand experience 'on the floor' through personal and often informal relationships (Intihar & Pollack, 2012), leading to trust and therefore a greater transfer of localised tacit knowledge (Audretsch & Feldman, 1996) between Schumpeterian firms and different types of external partners (e.g., competitors, consultants, suppliers, customers and universities). The trust relationship provides the associated knowledge advantage based on more frequent and open meetings between firm representatives and external stakeholders, alleviating or at least minimising transaction, coordination and management of collaboration costs.

Second, spatial proximity to external collaboration partners is a prerequisite for infrastructure and resource sharing which minimises innovation costs, especially under the resource constraints associated with the start and venture stage of business. Knowledge spillovers between collaboration partners will take place first and foremost within a region (Audretsch & Feldman, 1996; Baù et al., 2019; Boschma & Frenken, 2010), especially the exchange of tacit knowledge (Audretsch & Feldman, 1996; Breschi & Lissoni, 2001).

Furthermore, greater spatial proximity between a Schumpeterian firm and an external partner leads to a stronger local knowledge network (Broekel & Boschma, 2012), which adds to cognitive–cultural proximity (Balland et al., 2015; Korosteleva & Belitski, 2017) as an important driver of localised knowledge, traditions, routines, and ways and models of collaboration between people and economic agents. We hypothesise:

Hypothesis 3: Schumpeterian firms will receive greater benefits from knowledge collaboration with a variety of external partner types within close geographical proximity.

3. DATA AND METHOD

3.1. Sample

Our sample consists of two matchable datasets collected by the Office for National Statistics (ONS) (2021a, 2021b), the Business Structure Database (BSD) and the Community Innovation Survey (UKIS). First, we matched six consecutive BSD and UKIS surveys during the period 2002–14. Each wave of BSD data was matched to the initial year of the UKIS survey. The innovation survey data were often anonymous and thus may not provide the names of any firms, which were codified with identifiers (ru_ref and entref).

The UKIS provides statistical survey-based information on the innovativeness of business economy sectors, and enables understanding the innovation drivers and constraints to evaluate firm innovation inputs and outputs. The UKIS is mainly focused on the following sections: innovation expenditure; product, process, and organisational innovation; innovation development and activities; employment and sales; innovative products and services; incentives for innovation; cooperation on innovation across different partners and geographical regions; barriers to innovation; and exploration and exploitation activities by firms leading to innovation. The BSD is the annual extract of the Inter-department Business Register (IDBR) which represents organisations used throughout government offices, and was used in scholarly research on the geography of innovation.

Organisations that are registered for value added tax (VAT) or pay at least one member of staff through the Pay-As-You-Earn (PAYE) tax system appear on this register. Information on turnover, employment, industry, geographical location, foreign ownership, firm age and export status is available. Our data match resulted in 1251 Schumpeterian firms and 3675 observations that follow at least two of the criteria outlined below. The following criteria were used in prior research to distinguish Schumpeterian firms (Audretsch et al., 2022; Henrekson & Sanandaji, 2020; Schumpeter, 1911/1934). First and foremost, a firm invests in any form of internal or external R&D. Second, a firm introduces a new-to-market product before its competitors. Third, firm age should be less than eight years since establishment. Fourth, a firm collaborates on innovation with external partners and benefits from knowledge sourcing via collaboration and spillovers (Audretsch et al., 2020, 2021). Finally, a firm uses formal (patent, copyright, trademark, design) protection. The distribution of the sample by region and industry is presented in Table 1.

3.2. Variables

3.2.1. Dependent variable

The dependent variable is innovation sales measured as a percentage of new-to-market product and service sales in total sales. This indicator was used as a proxy for new-to-market innovation (Kleinknecht et al., 2002; Estrin et al., 2022; Santamaria et al., 2009) and including for the UK businesses (Audretsch & Belitski, 2020a; Giovannetti & Piga, 2017). We use innovation sales as mentioned by Audretsch et al. (2021, p. 978): 'The use of this variable comes from Schumpeter's use of language (i.e., his identification of this activity as disruptive)', instead of exploitative behaviour that non-Schumpeterian firms may

Table 1. Sector divisions (by SIC 2007) and geographical regions.

Sector divisions	Total observations	%	Total firms	%	Region	Total observations	%	Total firms	%
Mining and quarrying	22	0.60%	11	0.88%	Northeast	219	5.96%	129	7.19%
Manufacturing basic	206	5.61%	53	4.24%	Northwest	360	9.80%	90	10.31%
High-tech manufacturing	455	12.38%	135	10.79%	Yorkshire and Humber	287	7.81%	87	6.95%
Electricity, gas and water supply	42	1.14%	25	2.00%	East Midlands	301	8.19%	110	8.79%
Construction	458	12.46%	108	8.63%	West Midlands	307	8.35%	57	4.56%
Wholesale, retail trade	450	12.24%	250	19.98%	Eastern England	279	7.59%	59	4.72%
Transport, storage	270	7.35%	110	8.79%	London	348	9.47%	241	19.26%
Hotels and restaurants	310	8.44%	110	8.79%	Southeast	444	12.08%	188	15.03%
Information and communication technology (ICT)	268	7.29%	68	5.44%	Southwest	313	8.52%	73	5.84%
Financial intermediation	232	6.31%	82	6.55%	Wales	267	7.27%	77	6.16%
Real estate and other business activities	386	10.50%	146	11.67%	Scotland	272	7.40%	72	5.76%
Public administration, defence	514	13.99%	112	8.95%	Northern Ireland	268	7.29%	68	5.44%
Education	13	0.35%	12	0.96%					
Other community, social active	49	1.33%	29	2.32%					

Note: Number of total observations in the basic sample = 3675 observations; number of observations in the Office for National Statistics (ONS) original sample = 36,673.
Sources: ONS: Business Structure Database (BSD), Business Expenditure on Research and Development (BERD) and Community Innovation Survey (UKIS) (2002–14).

demonstrate (Kirzner, 1973). The average value of innovation sales is 0.047 (SD = 0.150), which means that on average a firm's new-to-market sales constitute 4.7% of all market sales.

3.2.2. Explanatory variables

We use a set of explanatory variables related to the geographical dimensions of collaboration following Boschma (2005) to test Hypothesis 1. We included four binary variables which equal 1 if a Schumpeterian firm collaborates on innovation with at least three interdependent economic agents within each geographical dimension regionally, nationally, in Europe and other countries, and 0 otherwise.

A similar indicator was used in earlier studies related to measuring collaboration proximity (Boschma, 2005; Boschma & Frenken, 2010). To test Hypothesis 2, we use collaboration variables for four main external partners: suppliers, customers, universities and competitors (Cassiman & Veugelers, 2002). For each partner, firms indicated whether and to what extent the collaboration with an external partner was efficient from 0 (collaboration not used) to 3 (very high). The development of the scale of collaboration followed Roper et al. (2017) and Kobarg et al. (2019). Based on the synthesis of the extant literature, we interacted the set of variables that represented knowledge collaboration across four spatial dimensions with four partner types to test Hypothesis 3.

3.2.3. Control variables

Audretsh et al. (2023) suggest that small sized firms are more flexible and innovative than larger firms, so we included three binary variables to control for firm size: small, medium and large firms, with the latter as a reference category. We controlled for firm age, calculated as the logarithm of the number of years since firm establishment. We controlled for the set of constraints to innovation, such as perception about the level of risk, cost and incumbents (Nooteboom et al., 2007) as impediments to innovation from 0 (not used) to 3 (very high). We introduced control variables for the export activity as a binary variable which equals 1 if firms export their products and services, 0 otherwise (Rugman & Verbeke, 2001). To control for foreign ownership of a Schumpeterian firm, which is often associated with access to advanced technology and resources, we added a binary variable which equals 1 if a firm has headquarters in a foreign country, 0 otherwise.

To control for the role of process innovation in product and service innovation, we added the following variable related to the introduction and orchestration of new processes. We used a binary variable *Process innovation external,* which equals 1 if a firm introduced new methods of organising external relationships with other firms, and a *Process innovation internal* variable which equals 1 if the firm introduced process innovation (March, 1991; Schamberger et al., 2013).

The human capital of a firm (Eisenhardt & Martin, 2000) was measured as the share of employees with university degrees in STEM in total full-time employment. Some studies have found that firms investing in R&D are more innovative (Cassiman & Veugelers, 2002; Zahra & George, 2002), so we also included R&D intensity calculated as R&D expenditure to sales ratio.

Finally, we included four binary variables which represent the macro-region where a firm is located, such as Wales, Scotland, Northern Ireland and Greater London.

Each model included controls for year, industry (two-digit SIC 2007) and regional fixed effects. All variables are illustrated and explained further in Table 2. Table 3 presents the correlation table.

3.3. Model specification

The econometric model we adopted caters for the role of knowledge collaboration in facilitating innovation in Schumpeterian firms. Faems et al. (2005) and Kobarg et al. (2019) introduced a similar approach to estimate a firm's knowledge production function:

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 \varphi_{it} + \beta_3 x_{it}\varphi_{it} + u_{it} \qquad (1)$$

where y_{it} is innovation sales and is a fractional dependent variable that varies from 0 to 100; x_{it} is a vector of explanatory variables related to the geography of knowledge collaboration (regional, national, Europe, worldwide) of a firm i at time t; β_i is the coefficient of interest to be estimated; φ_{it} is a vector of variables related to the type of knowledge collaborator (supplier, customer, competitor, consultant, university, local and/or national government) of a firm i at time t; $x_{it}\varphi_{it}$ is a vector of interactions between the type of external knowledge partner and the geographical proximity where this partner is located for a firm i in time t; finally, u_{it} is an error term; and x_{it} and φ_{it} are exogenous and not correlated with u_{it} (Wooldridge, 2003). Furthermore, when estimating equation (1), it was necessary to control for sample selection bias by carrying out a two-stage Heckman (1979) approach to control for sample selection from the product innovation and business research literature.

We apply the Tobit model due to the characteristics of our dependent variable, which is double censored, as firms can have none or all sales from new-to-market products. There are several different ways of estimating such models (Wooldridge, 2003).

3.3.1. Sample selection bias

We followed Heckman's (1979) two-stage selection approach, and also applied sample selection bias correction in the knowledge production function for innovative firms (Audretsch & Belitski, 2020a). Departing from the full sample of 89,518 observations collected by matching BSD and UKIS 2002–14 surveys (ONS, 2021a, 2021b), we applied Heckman's procedure using all available n observations to control for potential change in a sample and the likelihood of firms in the original sample of 89,518 observations to be included in a final 3675-observation sample for Schumpeterian firms. Our dependent variable is y_{it}, which equals 1 if innovation was reported by a firm i in the overall sample of 89,518 observations, and 0 if innovation was not reported. Importantly, we

Table 2. Descriptive statistics.

Variable label (data source)	Description of variables	Mean	SD	Mean	SD
		Sample = 3675 observations		Original sample from the ONS	
Innovation sales (UKIS)	Share of a firm's total turnover from goods and services, new to the market (%)	0.047	0.159	0.043	0.127
Firm age (BSD)	Age of a firm (years since the establishment), log	1.373	0.506	2.681	0.795
Process innovation external (UKIS)	New methods of organising external relationships with other firms or public institutions	0.267	0.442	0.203	0.402
Process innovation internal (UKIS)	Binary variable = 1 if a firm introduced any new or significantly improved processes for producing or supplying goods or services, 0 otherwise	0.236	0.425	0.161	0.365
Costs (UKIS)	Binary variable = 1 if a firm states excessive perceived economic risks, direct innovation costs too high, cost and availability of finance, 0 otherwise	0.331	0.470	0.430	0.495
Knowledge (UKIS)	Binary variable = 1 if a firm states a lack qualified personnel, lack of information on markets, lack of information on techs markets, 0 otherwise	0.141	0.337	0.267	0.422
Incumbents (UKIS)	Binary variable = 1 if a firm states the market dominated by established firms, uncertain demand for goods or services, 0 otherwise	0.160	0.369	0.302	0.456
R&D intensity (UKIS)	Ratio of internal research and development expenditure (£) to total sales	0.019	0.171	0.012	0.050
Scientists (UKIS)	Proportion of employees who hold a degree or higher qualification in science and engineering at BA/BSc, MA/PhD, PGCE levels	8.800	20.163	5.897	15.341
Exporter (UKIS)	Binary variable = 1 if a firm sells its products in foreign markets, 0 otherwise	0.290	0.453	0.285	0.451
Foreign ownership (BSD)	Binary variable = 1 if a firm has headquarters abroad, 0 otherwise	0.174	0.379	0.313	0.462
London (BSD)	Binary variable = 1 if a firm is located and operates in Greater London, 0 otherwise	0.008	0.091	0.011	0.105
Regional collaboration (UKIS)	Binary variable = 1 if a firm cooperates on innovation with at least three types of partners (customers, suppliers, consultants, university, competitors, university, government) regionally, 0 otherwise	0.125	0.331	0.128	0.339
National collaboration (UKIS)	Binary variable = 1 if a firm cooperates on innovation with at least three types of partners (customers, suppliers, consultants, university, competitors, university, government) nationally, 0 otherwise	0.143	0.350	0.153	0.360
European collaboration (UKIS)	Binary variable = 1 if a firm cooperates on innovation with at least three types of partners (customers, suppliers, consultants, university, competitors, university, government) in Europe, 0 otherwise	0.049	0.216	0.067	0.250
World collaboration (UKIS)	Binary variable = 1 if a firm cooperates on innovation with at least three types of partners (customers, suppliers, consultants, university, competitors, university, government) in other countries, 0 otherwise	0.041	0.198	0.061	0.239

(*Continued*)

Table 2. Continued.

Variable label (data source)	Description of variables	Mean	SD	Mean	SD
		Sample = 3675 observations		Original sample from the ONS	
Supplier collaboration (UKIS)	How efficient was collaboration on innovation with suppliers from 0 – not used to 1 – low, 2 – medium and 3 – high	1.463	1.117	1.565	1.101
Customer collaboration (UKIS)	How efficient was collaboration on innovation with customers from 0 – not used to 1 – low, 2 – medium and 3 – high	1.752	1.202	1.800	1.184
Competitor collaboration (UKIS)	How efficient was collaboration on innovation with competitors from 0 – not used to 1 – low, 2 – medium and 3 – high	1.290	1.061	1.360	1.075
University collaboration (UKIS)	How efficient was collaboration on innovation with universities from 0 – not used to 1 – low, 2 – medium and 3 – high	0.439	1.763	0.503	1.784
Small firm (1–49 FTEs) (BSD)	Binary variable = 1 if the number of FTEs is < 50, 0 otherwise	0.709	0.453	0.491	0.499
Medium firm (50–249 FTEs) (BSD)	Binary variable = 1 if the number of FTEs is between 50 and 249, 0 otherwise	0.203	0.402	0.277	0.477
Large firm (249 + FTEs) (BSD)	Binary variable = 1 if the number of FTEs ≥ 250, 0 otherwise	0.087	0.281	0.230	0.421
Instruments used in the selection equation of Heckman two-step estimation procedure					
Government requirements (UKIS)	Importance for innovation activity to meet government regulatory requirements (0 – not applicable, 3 – very important)			0.934	0.904
Local firm tax unit (BSD)	Number of live local units within a company that are value added tax (VAT) registered			0.723	1.126
Mills ratio	Inverse Mills ratio calculated from the first-stage Heckman (1979) and used on the second-stage equation	0.496	0.649		

Note: Number of total observations in the basic sample = 3074 observations; number of firms in the basic sample = 1251; number of observations in the Office for National Statistics (ONS) original sample = 36,673. FTE, full-time equivalents.
Sources: ONS: Business Structure Database (BSD), Business Expenditure on Research and Development (BERD) and Community Innovation Survey (UKIS) (2002–14).

are only interested in the reported values of innovation sales (including zeros).

As explained by Audretsch and Belitski (2020a), bias could arise because of the willingness of firm i to report innovation in the very first sample (survey). We employed two variables to correct for selection bias: number of active plant units in logs and the importance of regulatory requirements for innovation (Table 2). The number of plant units increases the size of a firm, and may affect innovation activity and speed of innovation. Changes in regulatory requirements will drive a firm to new ways of addressing the process of creating knowledge, and potentially change their decision-making on innovation and the extent of their innovation effort. In addition to these two selection variables, which we used as instruments, we included a set of controls: exogeneous variables x_i, reflecting firm age, employment sales and other characteristics. The two variables affect the innovation effort of a firm but may not directly affect innovation intensity.

In the first stage of our Heckman procedure, we estimate a probit model where the dependent variable is whether a firm reports innovation. We follow the generalised Heckman approach to calculate the inverse Mills' ratio ($\hat{\lambda}_{it}$), which will be used in equation (1) to correct for potential sample selection bias. The first stage of the two-step Heckman approach is reported in Table 4.

4. EMPIRICAL RESULTS

Table 5 reports the estimated Tobit regression model as the second stage of Heckman's (1979) procedure. We included four binary variables to test Hypothesis 1, which states that Schumpeterian firms will achieve higher innovation outcomes in knowledge collaboration with regional partners. The coefficient of interest is positive and statistically significant when a Schumpeterian firm collaborates with regional partners ($\beta = 0.02$–0.06, $p < 0.05$), and insignificant for other national and international partners (specifications 1–5 in Table 5). This result adds to what we know from Audretsch and Feldman (1996), Iammarino and McCann (2006) and Balland et al. (2015) regarding the role of regional proximity in innovation. In Table 5 we produced a t-test to examine the statistical differences in means of estimated coefficients between regional and other coefficients for innovation. All F-statistics are > 1.96 and p-values < 0.05. The hypothesis that coefficients are equal is rejected, which means that regional collaboration has a greater effect on

Table 3. Correlation matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Innovation sales	1																			
2. Firm age	−0.10	1																		
3. Process innovation external	0.14	0.06	1																	
4. Process innovation internal	0.22	0.01	0.26	1																
5. Costs	0.15	0.01	0.16	0.20	1															
6. Knowledge	0.08	0.03	0.06	0.11	0.31	1														
7. Incumbents	0.09	0.01	0.07	0.09	0.38	0.40	1													
8. R&D intensity	0.44	−0.04	0.09	0.17	0.15	0.13	0.10	1												
9. Scientists	0.32	0.01	0.11	0.16	0.12	0.06	0.07	0.44	1											
10. Exporter	0.16	0.01	0.13	0.12	0.12	0.08	0.11	0.22	0.23	1										
11. Foreign ownership	−0.06	0.16	0.07	−0.01	−0.04	−0.04	−0.02	−0.05	0.01	0.10	1									
12. Regional collaboration	0.17	0.03	0.14	0.24	0.21	0.16	0.12	0.19	0.13	0.09	−0.04	1								
13. National collaboration	0.29	0.01	0.16	0.27	0.18	0.16	0.16	0.26	0.23	0.15	−0.01	0.05	1							
14. European collaboration	0.27	0.04	0.08	0.14	0.14	0.11	0.11	0.38	0.90	0.23	−0.01	0.01	0.44	1						
15. World collaboration	0.19	0.01	0.12	0..07	0.28	0.12	0.11	0.35	0.26	0.20	−0.02	−0.02	0.40	0.43	1					
16. Supplier collaboration	0.21	0.02	0.26	0.26	0.29	0.20	0.19	0.17	0.13	0.15	0.02	0.02	0.30	0.39	0.53	1				
17. Customer collaboration	0.14	−0.01	0.23	0.22	0.27	0.17	0.18	0.15	0.17	0.22	0.04	0.04	0.20	0.26	0.13	0.15	1			
18. Competitor collaboration	0.22	0.03	0.17	0.21	0.25	0.18	0.17	0.31	0.31	0.20	0.03	0.03	0.23	0.25	0.14	0.14	0.52	1		
19. University collaboration	0.07	−0.10	−0.05	0.01	0.05	0.03	0.08	0.08	0.38	0.01	0.01	−0.01	0.19	0.31	0.12	0.12	0.56	0.50	1	
20. Small firm	−0.06	0.07	−0.01	0.04	0.02	−0.02	−0.06	−0.06	−0.06	0.01	−0.30	−0.02	0.26	0.01	0.01	0.21	0.34	0.32	0.36	1
21. Medium firm	−0.04	0.05	0.09	−0.03	−0.04	−0.03	−0.05	−0.05	−0.04	0.04	0.12	−0.01	0.03	−0.01	−0.02	−0.03	0.03	0.02	0.01	−0.60

Note: Number of total observations in the basic sample = 3675 observations. R&D, research and development.
Sources: Office of National Statistics (ONS): Business Structure Database (BSD), Business Expenditure on Research and Development (BERD) and Community Innovation Survey (UKIS) (2002–14).

Table 4. Heckman first stage using probit regression.

	Innovation reported ($D = 1$)	
Two-step Heckman approach	**Coefficient**	**SE**
Firm age, logs	−0.046	0.014***
Employment, logs	−0.021	0.014***
Turnover, logs	0.062	0.011***
Government requirements	0.437	0.011***
Local firm tax unit	−0.044	0.018***
Constant	3.744	0.320***
Sigma *u*	0.583	0.031
Rho	0.253	0.024
Time fixed effects	Yes	
Industry fixed effects	Yes	
Regional fixed effects	Yes	
Observations	36,673	
Firms	23,800	
Wald chi^2 test	2797.77	
Log-likelihood ratio	−12,312.58	
LR test for rho = 0	107.52	

Note: Number of observations in the Office for National Statistics (ONS) original sample = 36,673.
Sources: ONS: Business Structure Database (BSD), Business Expenditure on Research and Development (BERD) and Community Innovation Survey (UKIS) (2002–14).

innovation performance than national or even international collaboration.

Table 5 (specifications 1–5) illustrates the relationship between knowledge collaboration with customers and innovation with the coefficient varying from 0.08 to 0.09 ($\beta = 0.08$–0.09, $p < 0.01$) and is positive and significant. The coefficient of knowledge collaboration with suppliers on innovation is also positive and significant and varies from 0.05 to 0.07 ($\beta = 0.05$–0.07, $p < 0.01$), supporting Hypothesis 2a. The direct effect of knowledge collaboration with competitors on innovation outcomes is negative with the coefficient varying from −0.03 to −0.04, supporting Hypothesis 2b. Finally, collaboration with universities neither increases nor decreases innovation with the coefficients not statistically significant, not supporting Hypothesis 2c. Hypothesis 3, which states that Schumpeterian firms will receive greater benefits from knowledge collaboration with a variety of external partner types within close geographical proximity, is partly supported. Collaboration with suppliers in close geographical proximity increases innovation ($\beta = 0.04$, $p < 0.05$), while collaboration with customers decreases collaboration by ($\beta = 0.10$, $p < 0.05$). Collaboration with competitors and universities in close proximity is not associated with innovation outcomes.

Interestingly, we find that local suppliers are important partners in facilitating innovation. The reason for this could be a reduction in transportation and transaction costs, customers' interest and support for products that are locally manufactured, and the creation of innovative solutions that are locally driven and adapted for the local market (Balland et al., 2015). On the contrary, collaboration with customers reduces innovation if these customers are local. Over-collaboration with customers creates a regional locked-in effect (Balland et al., 2015) as firms start creating products that are customised for a very narrow market, limiting their market potential elsewhere. The limitation in technological proximity but close cognitive proximity may lock in the firms to collaborate with local customers.

Interestingly, when we control for a firm's location across macro-regions, we find that collaboration with customers increases innovation activity if companies are located in London. We also find a similar positive effect for Scotland. However, the origins of these effects differ greatly between London and Scotland. In London, the large market size and agglomeration economy create a market for firm innovation, while the diversity of international knowledge enables firms to develop products with customers originating from different countries and industries. While collaboration with customers in Scotland is also important, it has different benefits compared with returns to customers collaboration in London. As Scotland is geographically more distant from London and also from European cities, innovators may consider the local market as their first target. Understanding local customers and their preferences could be important for innovators. It is particularly important for new Schumpeterian firms in Scotland to understand customers and adjust their innovation for the Scottish market. Innovative firms will collaborate with customers regionally, as the products they create target local markets. Collaboration with competitors was also found important locally in Northern Ireland, with firms very likely collaborating with their potential competitors in the Republic of Ireland. As Scotland and Northern Ireland are less integrated into the UK trade and innovation space, Schumpeterian firms in those countries would rely on local embeddedness of knowledge and local markets where both customers and competitors facilitate localised knowledge creation and innovation (Feldman, 2014; Marshall, 2009). We found that Schumpeterian firms in Wales are highly innovative, and their innovation sales are on average greater than innovation sales in other UK countries. These firms do not prioritise any specific customer type.

4.1. Post-hoc analysis

Given the fact that not all firms that innovate in the country are included in the biannual survey and in our sample, which may result in selection bias, the ONS in the UK developed a stratified sample of innovative firms. Therefore, the sample available for analysis is preliminarily stratified by firm size (employment total), industry and region, with weights made available for each firm in the survey. Weights may vary from 1 to 23. One means the firm is unique in the sample, given the characteristics of its employment (size) in a specific industry and a specific

Table 5. Tobit estimation of innovation function.

Specification	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Sample weighting	**No**	**No**	**No**	**No**	**No**	**Yes**
Firm age	−0.03*	−0.05*	−0.04*	−0.05*	−0.05*	−0.06**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Process innovation external	0.12**	0.07**	0.07**	0.07**	0.06**	0.08**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Process innovation internal	0.25***	0.18***	0.18***	0.18***	0.18***	0.21***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)
Costs	0.07*	0.04	0.04	0.04	0.04	0.03
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Knowledge	−0.01	−0.01	−0.01	−0.01	−0.01	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)
Incumbents	−0.01	−0.01	−0.01	−0.01	−0.01	−0.02
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
R&D intensity	1.15***	0.84***	0.83***	0.85***	0.81***	0.67***
	(0.15)	(0.16)	(0.16)	(0.16)	(0.16)	(0.13)
Scientists	0.003***	0.002***	0.002***	0.002***	0.002***	0.003***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Exporter	0.10***	0.07**	0.08**	0.07**	0.07**	0.09**
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
Foreign	−0.05	−0.03	−0.03	−0.03	−0.03	0.01
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)
Greater London	−0.05	−0.05	−0.05	−0.85	1.05	1.35
	(0.16)	(0.16)	(0.16)	(1.20)	(1.40)	(1.01)
Wales	0.02	0.02	0.02	0.18**	0.19**	0.25***
	(0.04)	(0.04)	(0.04)	(0.09)	(0.09)	(0.08)
Scotland	−0.06	−0.08	−0.07	0.45	0.43	0.55
	(0.07)	(0.07)	(0.07)	(0.34)	(0.34)	(0.30)
Northern Ireland	−0.06	−0.07	−0.07	−0.18	−0.16	−0.11
	(0.04)	(0.04)	(0.04)	(0.13)	(0.13)	(0.10)
Regional collaboration (H1)	**0.03****	**0.02****	**0.06****	**0.03****	**0.44****	**0.55****
	(0.01)	**(0.01)**	**(0.03)**	**(0.01)**	**(0.19)**	**(0.15)**
National collaboration	0.06	0.05	0.05	0.04	−0.07	−0.05
	(0.05)	(0.03)	(0.13)	(0.03)	(0.03)	(0.04)
European collaboration	0.09	0.07	0.21	−0.07	−0.29	−0.23
	(0.06)	(0.05)	(0.23)	(0.05)	(0.34)	(0.30)
World collaboration	0.07	0.06	0.36	0.08	0.08	0.12
	(0.06)	(0.06)	(0.22)	(0.06)	(0.35)	(0.30)
Supplier collaboration (H2)		**0.05*****	**0.05*****	**0.06*****	**0.07*****	**0.11*****
		(0.01)	**(0.01)**	**(0.01)**	**(0.01)**	**(0.02)**
Customer collaboration (H2)		**0.09*****	**0.08*****	**0.08*****	**0.08*****	**0.14*****
		(0.01)	**(0.01)**	**(0.01)**	**(0.01)**	**(0.03)**
Competitor collaboration (H2)		**−0.03***	**−0.03***	**−0.04***	**−0.04***	**−0.03****
		(0.01)	**(0.01)**	**(0.02)**	**(0.02)**	**(0.01)**
University collaboration (H2)		**0.02**	**0.02**	**0.03**	**0.03**	**0.04**
		(0.02)	**(0.02)**	**(0.02)**	**(0.02)**	**(0.04)**
Small firm (1–49 FTEs)		0.07	0.05	0.06	0.02	0.03
		(0.05)	(0.06)	(0.05)	(0.05)	(0.01)

(*Continued*)

Table 5. Continued.

Specification	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Sample weighting	**No**	**No**	**No**	**No**	**No**	**Yes**
Medium firm (50–249 FTEs)		0.03	0.02	0.03	0.01	0.02
		(0.05)	(0.06)	(0.05)	(0.06)	(0.05)
Wales × Supplier collaboration						
	0.05	0.01	0.02			
	(0.15)	(0.14)	(0.10)			
Wales × Customer collaboration				0.09	0.11	0.13
				(0.14)	(0.14)	(0.11)
Wales × Competitor collaboration				−0.36	−0.32	−0.28
				(0.24)	(0.25)	(0.22)
Wales × University collaboration				0.35	0.37	0.40
				(0.23)	(0.23)	(0.25)
Northern Ireland × Supplier collaboration				0.07	0.11	0.13
				(0.17)	(0.17)	(0.11)
Northern Ireland × Customer collaboration				0.02	0.04	0.07
				(0.15)	(0.15)	(0.10)
Northern Ireland × Competitor collaboration				0.56**	0.43**	0.49***
				(0.25)	(0.18)	(0.15)
Northern Ireland × University collaboration				0.19	0.21	0.25
				(0.29)	(0.28)	(0.20)
Scotland × Supplier collaboration				0.89	0.78	0.93
				(0.61)	(0.55)	(0.60)
Scotland × Customer collaboration				0.28***	0.27***	0.35***
				(0.11)	(0.10)	(0.12)
Scotland × Competitor collaboration				−0.32	−0.33	−0.26
				(0.31)	(0.39)	(0.30)
Scotland × University collaboration				0.01	0.04	0.03
				(0.03)	(0.05)	(0.02)
Greater London × Supplier collaboration				0.11	0.09	0.08
				(0.30)	(0.33)	(0.13)
Greater London × Customer collaboration				0.15*	0.13*	0.19**
				(0.07)	(0.05)	(0.07)
Greater London × Competitor collaboration				0.07	0.07	0.11
				(0.31)	(0.39)	(0.30)
Greater London × University collaboration				0.17	0.04	0.05
				(0.32)	(0.33)	(0.20)
Regional collaboration × Supplier collaboration (H3)					**0.04****	**0.06*****
					(0.02)	**(0.03)**
Regional collaboration × Customer collaboration (H3)					**−0.10****	**−0.11****
					(0.05)	**(0.04)**
Regional collaboration × Competitor collaboration (H3)					**−0.01**	**−0.001**
					(0.04)	**(0.02)**
Regional collaboration × University collaboration (H3)					**0.04**	**0.06**
					(0.03)	**(0.05)**
National collaboration × Supplier collaboration					0.02	0.04
					(0.04)	(0.05)

(*Continued*)

Table 5. Continued.

Specification	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Sample weighting	**No**	**No**	**No**	**No**	**No**	**Yes**
National collaboration × Customer collaboration					0.04	0.08
					(0.13)	(0.08)
National collaboration × Competitor collaboration					0.09	0.19
					(0.07)	(0.08)
National collaboration × University collaboration					0.03	0.07
					(0.08)	(0.05)
European collaboration × Supplier collaboration					0.09	0.13
					(0.07)	(0.09)
European collaboration × Customer collaboration					0.04	0.15
					(0.09)	(0.11)
European collaboration × Competitor collaboration					−0.16**	−0.11
					(0.07)	(0.06)
European collaboration × University collaboration					−0.05	−0.07
					(0.04)	(0.06)
World collaboration × Supplier collaboration					0.12	0.16
					(0.07)	(0.10)
World collaboration × Customer collaboration					0.16	0.21
					(0.12)	(0.14)
World collaboration × Competitor collaboration					0.05	0.15
					(0.07)	(0.09)
World collaboration × University collaboration					0.03	0.05
					(0.06)	(0.03)
Inverse Mills ratio	0.01	0.13**	0.14**	0.13**	0.13**	0.14**
	(0.04)	(0.05)	(0.05)	(0.05)	(0.04)	(0.05)
Constant	−0.33**	−0.40**	−0.38**	−0.36**	−0.35**	−0.30***
	(0.15)	(0.16)	(0.16)	(0.16)	(0.15)	(0.10)
Year, industry and region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Left-censored observations	1831	1831	1831	1831	1831	1831
LR chi^2	508.12	517.0	536.97	525.69	563.12	4610.91
Pseudo-R^2	0.27	0.28	0.29	0.29	0.30	0.43
Log-likelihood	−673.43	−668.72	−659.87	−664.81	−645.77	−5612.25
T-test Regional collaborationβ_R = National collaboration β_N	*p*-values	0.01	0.01	0.01		
T-test Regional collaborationβ_R = European collaboration β_E	*p*-values	0.02	0.01	0.01		

(*Continued*)

UK region. The number 23 means there are 23 firms in the sample with the same employment in the same industry and same UK region. We estimate equation (1) using the Tobit model and apply the stratified sample weights in the regression. The results of this weighted estimation are reported in specification 6 in Table 5. We include the same variables and use the same method as applied to calculate specification 5 in Table 5.

Hypothesis 1, which states that firms benefit more from regional collaboration, is supported, followed by the role of suppliers and customers and the negative effect of competitors on firm innovation, supporting Hypotheses 2a–c. We find support for Hypothesis 3 which stated that knowledge collaboration with various partner types in regional proximity has a greater effect on Schumpeterian firm innovation than outside the region. Collaboration

with customers in close proximity is supported for Scotland and London, as in the main results.

We performed further robustness checks to test Hypothesis 1 by calculating two additional models in Appendix A in the Supplemental data online. We are interested whether Hypothesis 1 holds when controlling for other dimensions of knowledge collaboration following the stepwise approach (see specifications 1–4 in Appendix A online). Furthermore we added knowledge collaboration intensity regionally, nationally, in Europe and worldwide individually one at a time to test their individual effect of each geographical dimension on innovation (specifications 5–8 in Appendix A online). Both models provide statistical support to Hypothesis 1.

5. DISCUSSION AND CONCLUSIONS

This study examines the role that geographical proximity plays in the relationship between knowledge collaboration with different types of external partners (e.g., suppliers, customers, universities, consultants) and innovation output in Schumpeterian firms, furthering prior research on the role of localisation of knowledge spillovers (Audretsch & Feldman, 1996; Colombelli et al., 2016) and heterogeneity of external partners (Audretsch & Belitski, 2020a; Beers & Zand, 2014; Kobarg et al., 2019). Drawing on prior research in regional economics (Balland et al., 2015; Boschma, 2005; Fritsch et al., 2019), this study argues that firms benefit from having partners with close geographical proximity; however, return to knowledge collaboration in close spatial proximity depends on the type of knowledge partner. While firms generally benefit from regional collaboration in the form of geographical co-location in an industrial cluster or ecosystem (Uzzi, 1996), there might be a risk of lock-in effects, particularly with local customers in regions that are neither internationalised nor specifically closed (Balland et al., 2015). Collaboration with customers at arm's length may lock innovators into creating products that are demanded by local markets, but may have limited demand and applicability to foreign markets. Schumpeterian firms that aim to introduce new products to new markets need to consider this and work with customers regionally and internationally, in particular in markets with high competition where complex knowledge inputs are required (Katila & Ahuja, 2002). This is why maintaining both close and distant knowledge collaboration with external partners for innovation is an efficient ambidextrous strategy. Depending on its location – Scotland, Wales, Northern Ireland, England or Greater London – a Schumpeterian firm can benefit to a greater extent if it chooses to collaborate with a specific partner type within the regional proximity. This study's results have demonstrated that location in a specific macro-region in the UK is likely to affect the innovation strategy of a Schumpeterian start-up, whether to engage with horizontal (competitors) or vertical (suppliers and customers) knowledge collaborators. Firms located in London may leverage their international collaboration by collaborating with international partners within the proximity of Greater London.

Our study also extends the prior research on localised knowledge spillovers (Audretsch & Feldman, 1996; Audretsch & Belitski, 2022) and ecosystems of innovation by arguing that not all collaboration partners matter in close geographical proximity for innovation in Schumpeterian firms. The benefits of co-location with a specific type of collaboration partner for a Schumpeterian firms are region-specific, and may be conditional on the availability of local knowledge, as well as the local culture of innovation which will either enhance or limit knowledge spillovers.

5.1. Policy and entrepreneurial implications

First, our findings confirm the importance of using both geographical and type of knowledge collaborator perspectives when studying Schumpeterian firms' innovation. For example, we found that collaboration with the same partner, for example, customers in Scotland or London, may not have an equivalent effect on innovation outputs in Northern Ireland or Wales. The decision to relocate Schumpeterian firms in a region or prioritise collaboration with a specific partner type across the UK could be considered a conducive regional policy.

Second, collaboration with European competitors was found to hamper innovation outcomes in Schumpeterian firms, which may be through reverse knowledge sourcing or weak protection of knowledge in start-ups, so that collaboration either reduces the first-mover advantage (Belitski & Mariani, 2023) or switches R&D investment and innovation efforts to competitors. Policymakers may consider using various tools to minimise the negative effects of collaboration with competitors, for example through competition laws. For the UK, this may mean retaining common market access in a post-Brexit period, and introducing design policies that would enable Schumpeterian firms in the UK to benefit to a greater extent from their open innovation strategies with European partners.

Finally, we hypothesised that the returns to collaboration would be higher for customers and suppliers within closer geographical proximities. The empirical evidence has proved that collaboration with customers and suppliers in close proximity has many benefits, and that this is a future avenue for research.

The first limitation of this study is a significant cross-sectional component, as the sample is rotated and not repeated. This means that the firms observed in one year may opt out of answering the innovation survey in the next stage, which generates discontinuity. We are therefore very careful with imposing the causality of the relationship while there is a small panel element of Schumpeterian firms observed throughout 2002–14. Creating a longitudinal study that could be matched by region or industry may also allow for multilevel research and for innovation knowledge spillover effects to be incorporated over time.

The second limitation of this study is that it does not measure the amount of research and development

undertaken jointly with collaboration partners. Subsequent research will address both the depth and breadth of knowledge collaboration for Schumpeterian firms and the type of collaboration partner. Doing so would advance Kobarg et al.'s (2019) study for general innovators.

Future research will also distinguish the breadth and depth as well as the intensity of knowledge collaboration for firms at different stages of the growth continuum and for different firm types (e.g., Brittelstand, Mittelstand) (Pahnke et al., 2023). Knowledge collaboration is a heterogeneous phenomenon, and it is likely to be nonlinear in its effect on innovation. We call for more research to explain these nonlinearities across different partner types of geographies and types of entrepreneurs. Different types of firms (large versus small; start-ups versus established firms, etc.) may rely on a specific partner type and location as the knowledge that is sourced from this partner and addresses a specific functionality of a firm at a specific stage of the growth continuum.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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