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Routledge
Taylor & Francis Group

Economics of Innovation and New Technology

ISSN: 1043-8599 (Print) 1476-8364 (Online) Journal homepage: www.tandfonline.com/journals/gein20

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To cite this article: David B. Audretsch, Maksim Belitski, Rosa Caiazza & Donald Siegel (10 Mar 2026): Assessing the impact of homophily on knowledge collaboration and innovative outcomes, Economics of Innovation and New Technology, DOI: 10.1080/10438599.2026.2641458

To link to this article: https://doi.org/10.1080/10438599.2026.2641458

Published online: 10 Mar 2026.

ECONOMICS OF INNOVATION AND NEW TECHNOLOGY
https://doi.org/10.1080/10438599.2026.2641458

Assessing the impact of homophily on knowledge collaboration and innovative outcomes

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ABSTRACT

Knowledge collaboration is recognized as a major source of innovation and competitive advantage for firms, especially for mall-and medium-sized enterprises (SMEs). Drawing on the open innovation and management literatures and using micro-level data from the U.K. most innovative firms, we demonstrate that innovation output is conditional on knowledge homophily collaboration and partner location. We also find that SMEs benefit to a greater extent from knowledge collaboration with external partners than large firms. Collaboration with customers and suppliers is more beneficial than collaborations with universities or government for SMEs. We develop implications for scholars, entrepreneurs and managers in innovative firms.

ARTICLE HISTORY
Received 7 April 2025
Accepted 12 February 2026

KEYWORDS
Knowledge collaboration; knowledge transfer; open innovation; SMEs; international; regional

1. Introduction

The global economy and innovation are driven increasingly by the intensive production, transfer, adoption and use of knowledge (Powell and Snellman 2004). While a firm may grow for several reasons that may or may not be related to innovative activity (Coad and Rao 2008), successful innovators will always invest in knowledge internally (Cassiman and Valentini 2016) and collaborate on knowledge with external partners (Majchrzak, Jarvenpaa, and & Bagherzadeh 2015; Veugelers 1997). Knowledge collaboration plays an important role in the coordination of R&D activities (Chesbrough 2003, 2006; Knockaert and Spithoven 2014).

While the link between knowledge collaboration and innovation performance has been explored (Fey and Birkinshaw 2005; Gesing et al. 2015; Phelps, Heidl, and Wadhwa 2012), there have been few studies that seek to explore how and why firms collaborate for innovation. The reason why firms actively collaborate on R&D is to share the burden of the resource-intensive innovation process, to find new and commercially exploitable combinations of knowledge (Laursen and Salter 2006), cross-fertilization of

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new ideas, cost reduction (Audretsch and Belitski 2020) as well as access to knowledge spillovers (Acs et al. 2009; Audretsch and Feldman 1996; Brunswicker and Vanhaverbeke 2015).

Although external knowledge collaboration is recognized as a motivation and resource for new technology and products, the geographical dimension of this activity remains a black box (Amoroso, Coad, and Grassano 2018; Boschma 2005; Katz and Martin 1997). The first attempts in this regard suffer from three major shortcomings. First, Faems, Van Looy, and Debackere (2005) investigate knowledge collaborations and their relationship with innovative outputs through a portfolio lens and thus on an aggregate level, which neither differentiates between the effects of the different types of partners nor along the different geographic dimensions. Second, the valuable insights of this study cannot (easily) be transferred to 99% of all businesses and major drivers of innovation across the globe, i.e. to small and medium-sized companies (SMEs) (Muller et al., 2015). Third, SMEs require specific attention, since they represent a unique context with respect to resourced, skills, and the involvement of the owner/entrepreneur in the company's strategy (Decker and Günther 2017). Prior research on innovators has shown that knowledge collaborations are not established in a random fashion (Roper, Love, and Bonner 2017). This is especially true for small firms, who typically engage in new product developments in collaboration with different types of external partners and mainly within close geographical proximities (De Massis et al. 2018). However, it remains unclear, whether this deliberate choice to collaborate with nearby customers and suppliers also leads to the highest innovative output. This obvious source of endogeneity when investigating the relationship of different types and locations of collaborations partners thus calls for an adequate methodological treatment, which is so far lacking.

It is also important to note that our study follows research by Link (2025) and Farè and Vismara (2025) in analyzing the role of homophily in innovation and entrepreneurial finance. We are studying homophily in the context of knowledge collaborations. Homophily is the tendency of individuals or entities to associate with similar others. Link (2025) examines innovation and entrepreneurial behavior among minority entrepreneurs, adding a layer of ethnic and demographic homophily to the literature on innovation. Farè and Vismara (2025) analyze homophily involving founding teams and AI ventures and their propensity to innovate. This extends prior research on homophily within family firms and venture capital partnerships.

We introduce the concept of 'knowledge homophily collaboration' (henceforth, KHC). KHC is defined as the tendency of people to work with others who share similar knowledge, expertise, or other characteristics. KHC could have a strong influence on network structure and the flow of information. For collaborative efforts, KHC could be beneficial if it leads to a shared understanding, but it could also be detrimental if it hinders diverse perspectives and the introduction of new ideas. KHC may also be beneficial for examining some issues within a group, given that it can slow down the spread of ideas, which may allow for an in-depth examination of specific areas. On the other hand, it can also restrict new ideas and perspectives, creating 'echo chambers' that are detrimental for innovation. Still another possible benefit of KHC concerns the enhancement of efficiency and trust: KHC can reduce coordination challenges that arise from differing research standards or methodologies. It is also important to note under KHC, information from within the group is likely to be more easily trusted and evaluated

critically. We will keep these benefits and drawbacks of KHC in mind as we develop our theoretical analysis and concomitant hypothesis development.

Our empirical analysis is based on detailed longitudinal data on 17,517 innovative U.K. firms, over a 13-year time period, to assess the role that geographical proximity and type of collaboration partnership play in innovation performance. 92% of these firms are SMEs. We report three key findings. The first is that collaboration on innovation increases innovation output for SMEs, but not so much for large firms. Second, we demonstrated that SMEs are likely to exploit knowledge collaborations with a variety of partners and that the highest returns from collaboration are from customers and suppliers, as compared to universities and government. Third, knowledge collaborations within regional and national boundaries are most efficient for SMEs and, in particular, with local universities and international customers. We thus confirm prior research which found that the specific type of knowledge (tacit knowledge) is likely to be diffused most effectively and appropriated between SMEs and external partners in close proximity within localized networks (Provan, Fish and Sydow, 2007; Rogers 2004).

2. Theoretical framework

2.1. Knowledge collaboration and firm innovation

External knowledge serves as a complement to in-house knowledge creation (Ketchen, Ireland, and Snow 2007; Schamberger, Cleven, and Brettel 2013) and further facilitates a firm's absorptive capacity. Knowledge collaborations help firms to increase their economic value added and increase competitiveness within the following channels. First, establishing interorganizational relationships increases knowledge transfer that facilitates a firm's innovativeness (Hervas-Oliver et al. 2020; Miotti and Sachwald 2003). Secondly, collaborating for knowledge allows to divide the charges for innovation between partners and synchronize market entry strategy where market entry costs are high (Veugelers 1997) and markets are uncertain (West and Gallagher, 2006).

Given these general benefits from knowledge collaboration, we formulate our baseline hypothesis:

H1: Knowledge collaboration with external partners facilitates innovation.

2.3. Knowledge collaboration and partner choice

When SMEs choose their collaboration partners, two baseline dynamics are at work. First, prior research has shown that SMEs are more likely to cooperate with partners in their own region/country than with partners in other nations (De Massis et al. 2018). Second, SMEs are more likely to cooperate with customers and suppliers, who can directly support product development, compared to other institutional partners such as local government or a university. Various arguments can be brought forward to explain this.

2.3.1. Choosing collaboration partner location

Co-location with local partners is an important factor for SMEs to reduce transaction, organizational and other variable costs (Cassiman and Valentini 2016; Nooteboom et al. 2007). However, the benefits are not limited to access to key resources within a specific

industry and local boundaries. They appear to accrue to, rather than a co-location within a region and a country is important to capitalize on various proximities. In the case of SMEs, we argue that despite the importance of knowledge from international collaboration partners (Brouthers and Hennart 2007), SMEs are more likely to rely on local and national cooperation partners for five reasons.

First, local institutions (Audretsch, Belitski, and Desai 2019) are more understandable for small businesses, as compared to large firms, SMEs tend to be more embedded into local formal and informal institutions (Balland, Boschma, and Frenken 2015). Second, customers and suppliers within regional and national boundaries often target local and national markets, which are most relevant for SMEs, and family-owned small firms (Guenther, Belitski, and Rejeb 2023). Third, SMEs use local markets as springboards for new product development before going internationally (Audretsch and Belitski 2023). Fourth to sustain collaboration with international partners while reducing the transaction costs of collaboration, a greater investment in collaboration is required, which may not be associated with appropriability on the results of the collaboration (Capaldo, Lavie, and Messeni Petruzzelli 2017; Cassiman and Veugelers 2002). Finally, for SMEs facing significant resource constraints, choosing regionally close partners may push them into building localized networks (Provan et al., 2007) with them as these partners are closely located and may exhibit similar business culture (Nooteboom et al. 2007).

Scholars have also debated about the importance of geographical proximity with the development of digital technologies and internet, zoom platforms enabling knowledge transfer internationally. Despite the digitalization process and the impact of COVID-19, SMEs still perceive regional proximity and local markets as 'safe heavens' and as a key pillar of SME's competitive advantage (Belitski, Aginskaja, and Marozau 2019). We propose:

> H2: Knowledge collaboration for innovation in SMEs is positively moderated by regional proximity of collaboration partners, i.e. the closer the partner the higher the positive effects of knowledge collaboration.

2.3.2. Choosing collaboration partner type

The success of product innovation depends on the intensity and efficiency of R&D and other forms of knowledge collaboration (Audretsch and Belitski 2020; Cassiman and Veugelers 2002; Fey and Birkinshaw 2005), as well as access to a broad variety of different collaboration partners (Laursen and Salter 2006, 2014). Depending on the purpose of the collaboration, such as exploitation or exploration-oriented collaboration, different types of partners may offer different complementarities which can be leveraged (Faems, Van Looy, and Debackere 2005). In the case of exploitation-oriented collaboration with partners, the focus is on enhancing existing skills and leveraging the complementarities between existing products and technologies. These partnerships oftentimes involve the customers and suppliers of the focal firm (Hoegl and Wagner 2005). We argue that collaboration with customers can also be effective for new product development and design (Hippel, 2005; Shepherd and Zacharakis 2003). Exploration-oriented collaboration with partners is intended to create new skills and competencies.

Unlike collaborations with customers or suppliers, collaborations with universities do not increase the risk of imitation, which may reduce the uncertainty of new product

commercialization from an investor perspective (Veer, Lorenz, and Blind 2016). Information on university-based innovations can be interpreted by investors as signals of a potential increase in firm value (Bogers 2011). Investors anticipate firms' future innovation performance and could use information about research collaborations with universities as a signal of R&D results and innovation capabilities (Hicks 1995), new products to be launched in the future, which increases revenues. The effectiveness of collaboration with universities depends on the signal fit, costs, credibility, observability of collaboration links, project of collaboration and university quality.

The process of collaboration with universities often includes a lengthy process of research grant applications and the continuous investment of time and resources to experiment and test the results in R&D labs. Collaboration with universities gives rise to newly generated knowledge that must be understood, assimilated, and applied in the firm in order to be valuable, and SMEs may have a limited absorptive capacity to benefit from such collaboration (Veugelers 1997). High-quality universities will also require a firm to have some innovation potential before collaboration may take place (Chang, 2004).

In the context of product innovation, suppliers and customers offer specific advantages over other types of collaboration partners for SMEs compared to large firms with more resources and greater internal capabilities (Zahra and George 2002). First, they offer complimentarily of knowledge being in the same industry allows firms to adapt and apply knowledge faster, making additional investment in R&D obsolete or unnecessary. Complimentary knowledge improves firm productivity and innovation while minimizing search and exploration time, which serves as a substitute for R&D investment. Second, collaboration with customers ensures the co-creation of products, therefore better addressing customer needs and better understanding the market in which a product will be supplied. Following von Hippel (2005), the customer is a creator participating in the input side of the firm's operations, which enables better customization of products and services (Shepherd and Zacharakis 2003). Synchronizing the focal knowledge with the knowledge and needs of the customer, in particular in the product design and development process, will address market needs more efficiently. Learning from customers can also come as a substitute for internal investment in knowledge as part of R&D (Knockaert and Spithoven 2014). A firm is likely to go through multiple iterations of product development with its customers and suppliers, unless it completes a product, resulting in the adaption and adjustment of characteristics of the production system that facilitate new product development. We propose:

> H3: Knowledge collaboration for innovation in SMEs is positively moderated by the type of collaboration partner, so that collaborations with customers and suppliers are more beneficial than collaborations with universities.

3. Methodology

3.1. Sample

Our sample is built upon a combination of three databases, including the Business Registry (BSD), the Business Expenditure in Research and Development (BERD), and the UK Innovation Survey (UKIS). These datasets draw on data from six surveys with 849 firms

during 2006–2018. To consolidate our data set, we first compiled the six surveys conducted by the Office of National Statistics (ONS) at the two-year interval from 2006 to 2018. We then enriched our initial data set with data from BSD and BERD, including the firm age, size, ownership, employment, industry, innovation enables and barriers, R&D, support and training, interorganizational networks, alliances (nature, type and location). We have then checked the data for missing values and added explanatory and control variables in the model (1) providing a final sample of 21,140 observations (see Table 1). Table 2 illustrates the sample distribution by industry, region in the UK, firm size for 2006–2018.

3.2. Variables

3.2.1. Dependent variables

Our dependent variable is innovative output, measures as the share of new to market product sales which were new to a firm over the last 3 years (Nieto and Santamaria 2007; Roper, Love, and Bonner 2017). The new product share varies from 0 to hundred, with a mean of 3.7% (see Table 1). Product innovation is defined as technologically new products or services that are operationalized at a firm level and which are new to the market (Laursen and Salter 2014; Roper, Love, and Bonner 2017).

3.2.2. Explanatory variables

We follow Audretsch and Belitski (2023) and Kobarg, Stumpf-Wollersheim, and Welpe (2019) set of variables for collaboration partner type across local region, national markets, in Europe and other parts of the world (outside Europe). The inclusion of binary variables in a model for each of the four main regions enables us to identify the role that each collaboration partner plays in the innovation performance of a firm, leveraging by the spatial proximity of this effect. For each partner type, we discovered the following patterns of knowledge collaboration across partner type and proximity. The most common partnership is supply-chain with an average of 6% of SMEs collaborating with local suppliers. On average, 7% of SMEs collaborate with local customers, 9% of SMEs collaborate with suppliers nationally, and 11% collaborate with national customers. On average, 3% of firms only collaborate with competitors locally and 5% collaborate with competitors in national market. Collaboration with competitors overseas is limited to only 2% of SMEs. Collaboration with the government is also low; only 2–3% for SMEs. On average, 5–6% of SMEs collaborate with consultants regionally and nationally and only 1% with international consultants. The list of control variables used in this study is provided in Table 1.

3.3. Data analysis

Given that the returns to innovation are highly skewed and that growth rate distributions are heavy-tailed (Coad and Rao 2008), we adopt Tobit model (Amemiya 1984) also used in prior research on knowledge collaboration and innovation performance (Audretsch and Belitski 2020; 2023).

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 z_{it} + \varepsilon_{it} \quad (1)$$

Table 1. Descriptive statistics.

Label		Description	Mean	Std. Dev.
Product innovation (share new product revenue, %)		% of firm's total turnover from goods and services, new to the market (%)	3.706	11.991
Binary variable = 1 if firm co-operates on innovation within a region	Ent group	With any of other businesses within enterprise group, 0 otherwise	0.048	0.214
	Suppliers	With any suppliers of equipment, materials, services, 0 otherwise	0.059	0.235
	Customers	With any clients or customers, 0 otherwise	0.073	0.261
	Competitors	With competitors or businesses in industry, 0 otherwise	0.032	0.175
	Consultants	With consultants, commercial labs or private R&D institutes, 0 otherwise	0.036	0.185
	Universities	With universities or high educational institutions, 0 otherwise	0.038	0.192
	Government	With any of other businesses within enterprise group, 0 otherwise	0.024	0.153
Binary variable = 1 if firm co-operates on innovation within national market	Ent group	With any of other businesses within enterprise group, 0 otherwise	0.055	0.228
	Suppliers	With any suppliers of equipment, materials, services, 0 otherwise	0.099	0.298
	Customers	With any clients or customers, 0 otherwise	0.111	0.314
	Competitors	With competitors or businesses in industry, 0 otherwise	0.050	0.218
	Consultants	With consultants, commercial labs or private R&D institutes, 0 otherwise	0.056	0.230
	Universities	With universities or high educational institutions, 0 otherwise	0.041	0.199
	Government	With any of other businesses within enterprise group, 0 otherwise	0.038	0.192
Binary variable = 1 if firm co-operates on innovation within European countries	Ent group	With any of other businesses within enterprise group, 0 otherwise	0.033	0.179
	Suppliers	With any suppliers of equipment, materials, services, 0 otherwise	0.043	0.203
	Customers	With any clients or customers, 0 otherwise	0.045	0.207
	Competitors	With competitors or businesses in industry, 0 otherwise	0.018	0.133
	Consultants	With consultants, commercial labs or private R&D institutes, 0 otherwise	0.014	0.116
	Universities	With universities or high educational institutions, 0 otherwise	0.009	0.094
	Government	With any of other businesses within enterprise group, 0 otherwise	0.007	0.081
Binary variable = 1 if firm co-operates on innovation within other world countries	Ent group	With any of other businesses within enterprise group, 0 otherwise	0.032	0.176
	Suppliers	With any suppliers of equipment, materials, services, 0 otherwise	0.032	0.177
	Customers	With any clients or customers, 0 otherwise	0.040	0.197
	Competitors	With competitors or businesses in industry, 0 otherwise	0.015	0.121
	Consultants	With consultants, commercial labs or private R&D institutes, 0 otherwise	0.011	0.106
	Universities	With universities or high educational institutions, 0 otherwise	0.008	0.089
	Government	With any of other businesses within enterprise group, 0 otherwise	0.006	0.076
	SMEs	Binary variable = 1 if full time employees <250, zero otherwise	0.725	0.403
Control Variables	Foreign firm	Binary variable = 1 if a firm's headquarter is localized abroad, zero otherwise	0.435	0.496
	Family firm	Binary variable = 1 if a firm is family-owned or co-owned, zero otherwise	0.104	0.305

(*Continued*)

Table 1. Continued.

Label		Description	Mean	Std. Dev.
	Age of firm	Age of a firm (years since the establishment)	18.666	10.036
	Scientists	The proportion of employees that hold a postgraduate degree	6.313	15.930
	R&D intensity to sales	R&D expenditure to sales ratio	0.010	0.046
Variables used as instruments at the first stage regression				
Suppliers collaboration (UKIS)		Mean of collaboration with regional, national and international suppliers at industry level for each year. Industry level is defined as two-digit SIC 2007.	0.246	0.157
Customers collaboration (UKIS)		Mean of collaboration with regional, national and international customers at industry level for each year. Industry level is defined as two-digit SIC 2007.	0.288	0.227
University collaboration (UKIS)		Mean of collaboration with regional, national and international universities at industry level for each year. Industry level is defined as two-digit SIC 2007.	0.089	0.115
Variables used as dependent variables for testing the likelihood of collaboration				
Collaboration regional		Binary variable = 1 if a firm collaborates at least with one type of partners (or more up to 7 types) in a region, zero otherwise	0.136	0.343
Collaboration national		Binary variable = 1 if a firm collaborates at least with one type of partners (or more up to 7 types) in a country, zero otherwise	0.179	0.383
Collaboration Europe		Binary variable = 1 if a firm collaborates at least with one type of partners (or more up to 7 types) in Europe, zero otherwise	0.083	0.276
Collaboration international		Binary variable = 1 if a firm collaborates at least with one type of partners (or more up to 7 types) internationally, zero otherwise	0.073	0.260
Collaboration suppliers		Binary variable = 1 if a firm collaborates with a supplier at least in one or more geographical regions, zero otherwise	0.166	0.372
Collaboration customers		Binary variable = 1 if a firm collaborates with a customer at least in one or more geographical regions, zero otherwise	0.181	0.385
Collaboration universities		Binary variable = 1 if a firm collaborates with a university at least in one or more geographical regions, zero otherwise	0.074	0.263

Source: Office for National Statistics (2021).
Office for National Statistics (2023a).
Office for National Statistics (2023b).

where *i* is a firm, *t* is time. The dependent variable y_{it} is the share of sales of products that are new to market. The explanatory variables and interaction terms are represented by x_{it}, while other control variables representing firm-specific characteristics exogenous to innovation are z_{it}, ε_{it} is an error term:

$$\varepsilon_{it} = \mu_i + \nu_{it} \tag{2}$$

Where μ_i denotes the random effect controlling for unobserved heterogeneity and ν_{it} is the error term. In addition, we control for other potential biases as multicollinearity and examined the variance inflation factors for all variables, finding each being less than 10 (Wooldridge 2009). We perform random-effects Tobit models for panel data where the outcome variable is censored for the entire sample based on Wooldridge (2009).

Table 2. Industrial / regional and firm size distribution in a sample.

Industry distribution Firms %		
1 – Mining & Quarrying	166	0.79
2 – Manufacturing basic	1282	6.06
3 – High-tech manufacturing	4106	19.42
4 – Electricity, gas and water supply	167	0.79
5 – Construction	2220	10.50
6 – Wholesale, retail trade	3422	16.19
7 – Transport, storage	1151	5.44
8 – Hotels & restaurants	1150	5.44
9 – ICT	1437	6.80
10 – Financial intermediation	692	3.27
11 – Real estate and other business activity	2669	12.63
12 – Public admin, defence	2133	10.09
13 – Education	80	0.38
16 – Other community, social activity	465	2.20
Total	**21,140**	**100.00**′
Regional distribution′		
North East	1147	5.43
North West	1984	9.39
Yorkshire and The Humber	1750	8.28
East Midlands	1704	8.06
West Midlands	1861	8.80
Eastern	1912	9.04
London	1981	9.37
South East	2348	11.11
South West	1796	8.50
Wales	1350	6.39
Scotland	1671	7.90
Northern Ireland	1636	7.74
Total	**21,140**	**100.00**′
Firm size distribution′		
Small firms	11,588	54.82
Medium	5680	26.87
Large	3872	18.32
Total	**21,140**	**100.00**

Number of obs. 21,140. Source: Office of National Statistics (2021, 2023a, 2023b).

4. Results

We begin by testing the link between knowledge collaboration and innovative performance of SMEs across types of partner and geographical location using Tables 3 and 4. Our findings in Table 3 support H1 which states that knowledge collaboration positively affects innovation in SMEs across different types of collaboration partners and proximity.

Although the benefits from external collaboration differ across the seven types of collaboration partners, the coefficients of collaboration within the enterprise group ($\beta =$ 3.52–7.16, $p < 0.01$), suppliers ($\beta = 5.10$–10.28, $p < 0.01$) and customers ($\beta = 6.40$–11.81, $p < 0.01$) are consistently positive and significant. Collaboration with regional ($\beta = 5.57$, $p < 0.01$) and national universities ($\beta = 2.40$, $p < 0.01$) positively affects innovation, while collaboration with universities in other countries is negatively associated with product innovation. These findings enrich prior research on the role universities in exploratory and basic forms of knowledge (Audretsch and Belitski 2021), while the role of customers and suppliers was found to facilitate exploitation-oriented innovation of firms (Faems, Van Looy, and Debackere 2005). This provides the first evidence of the role of customers and

Table 3. Random-effects Tobit estimation of product innovation.

Dependent variable:	Product innovation											
Geographical Diversity:	UK – Regional			UK National			European Countries			Other Countries		
Model:	Random-effects Tobit			Random-effects Tobit			Random-effects Tobit			Random-effects Tobit		
Variables	Coef.	S.E.	*P*>|z|	Coef.	S.E.	*P*>|z|	Coef.	S.E.	*P*>|z|	Coef.	S.E.	*P*>|z|
Enterprise group	7.16	1.23	0.00	3.52	1.11	0.00	4.90	1.38	0.00	6.81	1.42	0.00
Suppliers	5.10	1.20	0.00	7.84	0.97	0.00	10.28	1.24	0.00	9.10	1.40	0.00
Customers	6.40	1.11	0.00	11.81	0.93	0.00	8.92	1.24	0.00	8.00	1.32	0.00
Competitors	−1.73	1.62	0.29	0.03	1.18	0.98	1.61	1.76	0.36	3.73	1.95	0.06
Consultants	5.30	1.43	0.00	0.65	1.17	0.58	2.68	2.06	0.19	−1.53	2.39	0.52
University	5.57	1.35	0.00	2.40	1.33	0.07	−1.72	2.54	0.50	−10.39	3.13	0.00
Government	1.33	1.75	0.45	1.48	1.37	0.28	2.19	2.83	0.44	4.54	3.40	0.18
Foreign	1.86	0.61	0.00	0.33	0.68	0.63	0.37	0.68	0.58	0.51	0.69	0.46
Age	−7.03	2.03	0.00	−7.29	2.40	0.00	−7.49	2.45	0.00	−7.98	2.15	0.00
Age squared	0.31	0.12	0.00	0.38	0.13	0.00	0.34	0.09	0.00	0.28	0.09	0.00
SMEs	3.47	1.46	0.02	2.85	1.45	0.05	2.26	1.45	0.12	2.17	1.45	0.14
Family firms	2.74	1.55	0.26	2.01	2.54	0.40	2.33	2.53	0.46	2.32	1.54	0.28
Scientists	0.35	0.02	0.00	0.32	0.02	0.00	0.33	0.02	0.00	0.33	0.02	0.00
R&D intensity	92.58	4.90	0.00	88.40	4.89	0.00	90.05	4.92	0.00	89.88	4.95	0.00
constant	−37.22	3.75	0.00	−36.94	3.78	0.00	−36.39	3.77	0.00	−36.63	3.78	0.00
Year, region controls	YES			YES			YES			YES		
Sigma e	24.26	0.47	0.00	24.35	0.47	0.00	24.51	0.48	0.00	24.44	0.48	0.00
rho	0.333	0.023		0.316	0.023		0.317	0.024		0.325	0.024	
Industry control	YES			YES			YES			YES		
Number of obs	21,140			21,140			21,140			21,140		
Number of groups	19,510			19,510			19,510			19,510		
Log likelihood	−31,342			−31,177			−31,368			−31,409		
Wald chi2	3577			3790			3595			3529		
Prob > chi2	0.00			0.00			0.00			0.00		
Left-censored	16,780			16,780			16,780			16,780		
Uncensored	5323			5323			5323			5323		

Note. Standard errors are robust for heteroscedasticity in parentheses. Reference category for firm size = large firm (250+ FTEs); Reference category for firm ownership status: public corporation. Reference category for sector: mining. Reference category for wave: 2005. Reference category for region: Northern Ireland. Industry (2 digit SIC) and year fixed effects are suppressed to save space. Estimation method: Tobit. Significance level: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001''$ unless other stated.

Source: Office of National Statistics (2021, 2023a, 2023b). *Number of observations 21,140.*

Table 4. Random-effects Tobit estimation of product innovation.

Dependent variable:	Product innovation											
Geographical Diversity:	UK – Regional			UK National			European Countries			Other Countries		
Model:	Tobit regression			Tobit regression			Tobit regression			Tobit regression		
Variables	Coef.	S.E.	P>|z|	Coef.	S.E.	P>|z|	Coef.	S.E.	P>|z|	Coef.	S.E.	P>|z|
Enterprise group	7.03	1.55	0.00	2.60	1.26	0.04	4.15	1.48	0.01	6.37	1.60	0.00
Suppliers	2.22	1.40	0.11	6.63	1.20	0.00	8.21	1.38	0.00	4.81	1.66	0.00
Customers	4.24	1.35	0.00	9.86	1.13	0.00	7.64	1.47	0.00	7.62	1.49	0.00
Competitors	2.25	1.96	0.25	−1.75	1.41	0.21	2.32	2.02	0.25	5.35	2.25	0.02
Consultants	4.78	1.73	0.01	0.60	1.44	0.67	1.64	2.46	0.50	−4.84	2.75	0.08
University	4.29	1.63	0.01	2.92	1.67	0.08	−1.95	3.14	0.53	−8.50	3.77	0.02
Government	1.69	2.06	0.41	1.22	1.70	0.47	0.36	3.07	0.91	2.47	4.07	0.54
Foreign	1.82	0.73	0.01	0.89	0.73	0.22	0.90	0.73	0.22	1.25	0.74	0.09
Age	−6.68	2.22	0.00	−6.29	2.01	0.00	−6.90	2.02	0.00	−6.54	1.67	0.00
Age squared	0.23	0.05	0.00	0.28	0.03	0.00	0.33	0.03	0.00	0.22	0.03	0.00
SMEs	3.36	1.73	0.05	2.35	0.73	0.01	2.24	1.69	0.19	2.15	1.71	0.31
SMEs x Suppliers	3.26	1.63	0.04	2.76	0.63	0.04	2.08	0.61	0.04	1.96	0.62	0.01
SMEs x Customers	4.75	1.66	0.00	3.86	1.69	0.02	4.30	1.63	0.01	4.09	1.66	0.01
SMEs x University	2.66	0.65	0.01	1.52	0.66	0.04	2.24	1.63	0.17	2.05	1.65	0.21
Family firms	1.23	1.18	0.34	0.98	1.19	0.34	1.35	1.18	0.32	1.41	1.18	0.30
Scientists	0.31	0.02	0.00	0.28	0.02	0.00	0.29	0.02	0.00	0.29	0.02	0.00
R&D intensity	74.46	8.51	0.00	69.91	8.66	0.00	71.05	8.55	0.00	71.73	8.86	0.00
Constant	−33.05	3.61	0.00	−32.06	3.61	0.00	−31.18	3.58	0.00	−31.20	3.59	0.00
Year and region controls	YES			YES			YES			YES		
Sigma_e	26.79	0.66		26.67	0.66		26.74	0.65		26.90	0.66	
Industry control	YES			YES			YES			YES		
Number of obs	21,140			21,140			21,140			21,140		
Number of groups	19,510			19,510			19,510			19,510		
Log likelihood	−7871			−7836			−7872			−7888		
Wald chi2												
Prob > chi2	0.00			0.00			0.00			0.00		
Left-censored	16,780			16,780			16,780			16,780		

Note: standard errors are robust for heteroscedasticity in parentheses. Reference category for firm size = large firm (250+ FTEs); Reference category for firm ownership status: public corporation. Reference category for sector: mining. Reference category for wave: 2006–2008. Reference category for region: Northern Ireland. Industry (2-digit SIC) and year fixed effects are suppressed to save space. Estimation method: Tobit. Significance level: $*p < 0.05$; $**p < 0.01$; $***p < 0.001''$ unless other stated.
Source ONS: Office of National Statistics (2021, 2023a, 2023b). Number of observations 21,140.

suppliers as main sources of exploitation-type innovation, rather than the long-term basic research, supporting H3 Our findings demonstrate that customers, suppliers and local universities facilitate new product innovation and commercialization (Audretsch 2014) with the effects differing if firm and external partners are collocated with each other or not. This provides the first early evidence on testing H2. Finally, it appears that the return to knowledge collaboration is partner specific and location specific. There is no direct relationship between collaboration with consultants, competitors and government on innovation output, while the coefficients of investment in R&D ($\beta = 89–92$, $p < 0.01$) and the share of workers with university degree ($\beta = 0.32–0.35$, $p < 0.01$) are positive and significant. Age has a U-shaped relationship with innovation output. SMEs will have higher innovation outputs than large firms with positive and significant coefficients ($\beta = 2.17–3.47$, $p < 0.01$) (Table 3, specifications 1–4). We then move to estimating (1) with interaction between SMES and type of collaboration partner and report the results in Table 4. Our first evidence confirms results in Table 3 on the importance of external collaboration for innovation performance and across different partner types and geographical proximities (Chesbrough 2003; 2006).

The interaction coefficients of SMEs and knowledge collaboration with suppliers and customers are consistent and positive across all four specifications, which mean both local, national and international collaboration with suppliers and customers adds to innovation performance. However, the interaction coefficient between SMEs and knowledge collaboration with universities is positive and significant only regionally ($\beta = 2.66$, $p < 0.05$) and nationally ($\beta = 1.52$, $p < 0.05$) (Table 4, specifications 1 and 2). The benefit of collaboration with universities internationally (Europe and the world) dissipates for SMEs internationally, supporting the resource constraints of SMEs in establishing international collaborations (Audretsch and Belitski 2023; De Massis et al. 2018).

Our H2, on the higher benefits of collaboration with external partners within a close proximity, holds for exploration-oriented innovation and the exchange of tacit knowledge (Audretsch and Feldman 1996). H2 does not hold for exploitation-oriented innovation, where regional and international suppliers and customers continue to have an equal and positive impact on product innovation.

The results overwhelmingly support H3 as external collaborations of SMEs with customers and suppliers are more beneficial and add more to the innovation outcomes compared to collaborations with other partners, such as universities or government, contrasting prior research (Audretsch, Coad, and Segarra 2014; Belitski, Aginskaja, and Marozau 2019). The positive effect of collaboration with suppliers and customers remains strong across regional, national, European and international geographical dimensions. The cumulative benefits of SMEs collaborating with suppliers regionally, nationally, in Europe and the world are positive and all increase innovation sales by at least 5 percentage points (Table 4, spec. 1–4). The cumulative benefits of SMEs collaborating with customers regionally are above 7 percent, nationally above 6 percent, in European and global markets above 4 percent (Table 4, spec. 1–4). Interestingly, collaboration with international customers adds more to innovation of SMEs than collaboration with international suppliers, while this difference disappears when they are in close proximity.

Collaboration with regional and national universities adds on average 2.66% ($\beta = 2.66$, $p < 0.01$) and 1.52% ($\beta = 1.52$, $p < 0.05$) to innovation outputs. It serves as a valuable

source of complementary competences and innovative ideas, but the effect is clearly lower than collaboration with suppliers and customers.

5. Discussion and conclusion

In the previous decade, scholars have paid increasing attention to knowledge collaboration in the context of open innovation (Cassiman and Veugelers 2002; Chesbrough 2006; Coad and Rao 2011; Hervas-Oliver et al. 2020; Katz and Martin 1997). While several studies have investigated drivers of innovation performance (Coad, Segarra, and Teruel 2016), only a few have investigated whether geographic proximity and partner type moderate this effect (Capaldo and Messeni Petruzzelli 2011; Capaldo, Lavie, and Messeni Petruzzelli 2017). This study advances the theory and practice of knowledge collaboration in entrepreneurship and small business literature regarding how best to manage SME openness across the partner type and geographical dimensions in order to enhance innovation output.

Our findings contribute to the scholarly discourse on entrepreneurship, small business and open innovation in several ways. Firs, we advance research by reveal the effects of knowledge collaboration on firms' innovation by different groups of partners. Additionally, we extend knowledge on the effects of geography on external collaborations and innovation. Therefore, we reveal that knowledge collaboration facilitates product innovation, with SMEs likely to benefit more from collaboration with partners in close geographical proximity, although this effect is conditional on the partner type. Moreover, we found collaboration with universities and research institutes positively affected innovation outputs for SMEs within regional/national proximity, while collaboration with customers and suppliers facilitated innovation across all four geographical dimensions.

The study raises questions regarding the optimal geographical proximity of collaboration partners for SMEs and whether an optimal proximity exists. Further research should expand our findings to evaluate whether an optimal proximity of collaboration exists, and whether SMEs should bear this in mind when establishing local, national and international collaboration agreements as well as when choosing from different collaboration partner types. For example, our findings may help policymakers and research institutions to decide whether research institutions and industry across Europe should further promote of research consortia between firms? (Amoroso, Coad, and Grassano 2018). Subsequent literature will also focus on demonstrating the role of SMEs as well as sole proprietors, family firms and not-for-profit organizations in exploring open innovation opportunities across different geographical and functional dimensions. It is important to further research the selection bias for these companies and the factors which determine the choice of collaboration partner. The major limitation of this study includes the small panel element, which can be leveraged with further data releases.

Our findings have several important policy implications, especially for promoting international collaborations. We found that international collaboration with customers and suppliers brings benefits equal to collaboration nationally and more benefits that collaboration regionally. The implications for innovation policy may include multi-level support for SME agreements (Coad, Amoroso, and Grassano 2017) with international collaborators and the need to establish secure relationships across national boundaries. This may embrace IP protection along with R&D agreements and consultancy, as well as access

to entrepreneurial finance. Finally, we believe that our study contributes to a growing literature on SMEs and innovation (e.g. Audretsch and Belitski 2023; Farè 2022; Farè, Dejardin, and Toulemonde 2024).

Disclosure statement

No potential conflict of interest was reported by the authors.

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