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Knowledge investment and search for innovation: evidence from the UK firms

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Abstract

Recent research on innovation management and knowledge transfer has demonstrated that industry knowledge collaboration and knowledge spillovers matter for innovation, but so does a firm's Research and Development (R&D). Conditional to a firm's R&D investment, this study makes a theoretical investigation into the role of two knowledge transfer strategies—industry coopetition and industry knowledge spillovers for a firm's innovation. Based on an analysis of a sample of 17,859 UK firms from 2002 to 2014, we demonstrated why and under what conditions firms will (a) invest in internal R&D, (b) engage in coopetition, and (c) access knowledge spillovers to introduce new to firm (incremental innovation) and new to market products (radical innovation). The results of this study demonstrate that firm managers who choose knowledge spillovers versus coopetition are likely to achieve radical vis-à-vis incremental innovation. Benefits from the coopetition can be achieved with low investment in R&D, while R&D is essential in recognizing the knowledge spillover for radical innovation. By deciding whether to deploy its costly R&D and access external knowledge via industry coopetition or spillovers, the firm is also making a concomitant decision about the type of innovative activity it will generate. Thus, a firm strategy for knowledge transfer and investing in knowledge internally is inextricably linked to a firm strategy involving the type of innovative output.

Keywords Coopetition · Innovation strategy · Knowledge spillover · Research and development · Knowledge transfer

JEL Classification 03 · 032 · 015 · 052

1 Introduction

Governments in developed and developing countries see innovators as a source of regional growth and employment, technological change, and research commercialization, with multiple examples of support for innovation in the US economy (Andersen et al., 2017; Link & Scott, 2010). To innovate, firms invest in research and development (R&D) (Goel et al., 2023) so that they can secure a competitive advantage (D'aveni & Ravenscraft, 1994) and facilitate innovation activity (Laursen & Salter, 2014). Increasingly, firms rely on internal

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knowledge inputs such as investment in Research and Development (R&D) and external knowledge in the form of direct collaboration with incumbent firms (Ketchen et al., 2004; Khanna et al., 1998) and industrial knowledge spillovers (Grilliches, 1992; Audretsch & Feldman, 1996; Audretsch & Belitski, 2020a). We build on Link (1978: 370) in defining "research as the primary search for technical or scientific advancement, and development refers to translating these advancements into product or process innovations." Theoretically and empirically, research and development activities are challenging to separate from the resulting technology. We define coopetition, drawing on Ritala (2018) and Brandenburger and Nalebuff (1996), as the simultaneous pursuit of cooperation and competition. Coopetition is likely to enhance firm innovation performance (Gnyawali et al., 2006; Bengtsson et al., 2010; Huang & Yu, 2011), while innovation performance could also suffer due to the intensified tension from coopetition resulting from the intense contradictions inherent in such relationships (Gnyawali et al., 2011; Park et al., 2014).

Finally, firms aim to access knowledge spillovers as an alternative source of knowledge related to co-location in a city or region with a high investment in R&D by incumbent firms and other entrepreneurs (Audretsch & Belitski, 2013). Marshall (2009) established the concept of knowledge spillovers, further developed by Grilliches (1992).

A vast body of literature has been produced at the intersection of knowledge transfer from competitors and innovation (Bouncken et al., 2018; Ritala & Hurmelinna-Laukkanen, 2013) suppliers, customers and universities and innovation (Belitski et al., 2023) and knowledge spillovers and innovation (Audretsch & Belitski, 2022) with little to no evidence on companies using the combination of open knowledge sources from competitors directly and via knowledge spillovers for innovation (Roper et al., 2013, 2017).

Thus, prior research in knowledge transfer literature has overlooked the two distinct knowledge transfer strategies—knowledge spillovers and knowledge collaboration with competitors leading to a firm's decision on the type of innovation a firm can undertake radical vis-a-vis incremental innovation. The relationship between the source of knowledge transfer and innovation type is often moderated by R&D (Link, 1978; Leyden & Link, 2015). The assumption of homogeneity in innovation outcomes independent of knowledge inputs is surprising because a very different strand of literature in innovation has explicitly analyzed the heterogeneity of innovation and why not all innovative activities are equally dependent on knowledge spillovers, coopetition, or internal investment in R&D (Link & Scott, 2010; Tomlinson & Fai, 2013; Park et al., 2014; Czakon et al., 2020; Link et al., 2022). We suggest that the missing condition can be the firm's investment in R&D, and knowledge sourced via localized spillovers can be an essential factor facilitating and limiting innovation type. Furthermore, we argue that along with investment in human capital that contributes to a firm's absorptive capacity, R&D investment is highly beneficial and can increase innovation output directly (Audretsch & Belitski, 2020b; Bronzini & Piselli, 2016) and indirectly by increasing firm's absorptive capacity (Cohen & Levinthal, 1989). Estimating the impact of R&D on innovation output is challenging as no unique measure of the output from R&D exists (Leonard, 1971; Link, 1978; Kobarg et al., 2019).

Thus, this paper aims to examine how various sources of knowledge, such as investment in internal R&D, knowledge collaboration with competitors, and industry knowledge spillovers, shape two types of innovation.

In pursuing this aim, we first contribute to the knowledge transfer literature by suggesting that knowledge transfer via spillovers or coopetition and internal investment in R&D have a distinct impact on the choice of innovation output—incremental or radical. Our main finding is that coopetition increases incremental innovation, with the effect is more significant for firms who invest in R&D. In contrast, knowledge spillovers in the industry increase radical innovation for firms who invest in R&D. Coopetition is unlikely to increase radical innovation in firms that do not invest in R&D. In contrast, those who invest in R&D will have on an average higher level of radical innovation at any strength of coopetition. We found that R&D intensity matters for both types of knowledge transfer—industry spillovers and coopetition leading to higher radical innovation.

Second, by exploring both the firm's R&D investment and external knowledge transfer via coopetition or spillovers, we can identify and gain in-depth knowledge regarding *how* certain types of resource acquisition activity influence firms resource endowment (Helfat & Peteraf, 2003; Spithoven et al., 2010) and *why* a firm decides to engage in a specific type of innovation (Audretsch et al., 2023; Hsieh et al., 2018).

This study extends the mixed empirical findings originating from the fact that the large body of literature has explicitly ignored the combined effect of R&D investment and coopetition as means of accelerating radical and incremental innovation (Bouncken et al., 2018; Nemeh, 2018; Nemeh & Yami, 2019).

The remainder is as follows—Sect. 2 reviews coopetition and knowledge spillover literature streams. Section 3 illustrates the methodology adopted. Section 4 presents the results, and Sect. 5 discusses these findings with theoretical and managerial implications. Section 6 concludes.

2 Theoretical framework

2.1 Heterogeneity in innovation outcomes

Innovation enhances a firm's competitive advantage through organizational renewal, growth, and profits (Boulding & Christen, 2008; Lieberman & Montgomery, 1988). We define two innovation types—radical and incremental innovation. Radical innovation is an introduction of a new product to the market that is revolutionary and substantially different from the existing products in the market (Bouncken et al., 2018; Pavitt, 1991), what scholars often refer to as Schumpeterian innovation (Audretsch & Belitski, 2023a). Compared to incremental innovation (Koberg et al., 2003), which re-introduces existing products and services, radical innovations transform markets and significantly contribute to society (Leifer et al., 2000; Marvel & Lumpkin, 2007). On the other hand, incremental innovation can allow firms to avoid mistakes made by firms along with costs associated with first-mover innovation; in other words, avoid uncertainties associated with first-mover innovation completely (Arora et al., 2021; Cirik & Makadok, 2021; Krishnan & Ulrich, 2001).

2.2 R&D investment and inter-industry spillover as knowledge transfer

Knowledge resources are essential for creating and sustaining a competitive advantage.

The endowment of organizational knowledge resources is a critical success factor (Spender & Grant, 1996). A firm's resource endowments help it build its 'absorptive capacity' and acquire, assimilate, and transform new knowledge (Cohen & Levinthal, 1990). Firms can acquire knowledge through various external sources (Cassiman & Veugelers, 2002) through coopetition- cooperating with their competitors (Gnyawali et al., 2006) and via industry knowledge spillovers (Audretsch & Belitski, 2020a). Knowledge transfer is unintentionally taking place through knowledge spillovers when firms supply and buy from each other in the industry and invest in R&D; additionally, they can invest in developing and improving internal knowledge sources by investing in developing their R&D (Denicolai et al., 2016). Since some of these resources are difficult to imitate, they can play a critical role in firms' ability to innovate (McEvily & Chakravarthy, 2002). These resources can also act as an 'isolating mechanism' by enabling firms to gain a competitive advantage, as suggested by Lieberman and Montgomery (1988).

Innovation requires various interdependent knowledge inputs (Howard et al., 2017). R&D can serve as an indication of a firm's investment in its internal knowledge generation activity. However, while investment in R&D internally is distributed in creative works, it is also an investment in firm-specific human capital, which creates greater absorptive capacity (Bianchi, 2001). R&D leads to new product creation (innovation) because it facilitates experimentation and improvisation with new knowledge combinations not yet available in the market. It is unlikely that R&D investment will aim to imitate existing products. Such investment brings in new knowledge that helps recognize external (knowledge and market) opportunities and turns them into new market products.

2.3 Coopetition and innovation types

Management scholars argue that firms, despite the risks of coopetition, are increasingly engaging in it, especially in industries with a short product lifecycle (Arranz & Arroyabe, 2008; Gnyawali & Park, 2009; Nieto & Santamaria, 2007). Existing research suggests that coopetition is essential for innovation (Ritala, 2018). This is because the coopetition brings together complementary financial and human capital resources necessary for engaging in innovation-related activities (Bianchi, 2001; Tether, 2002), and by combining their complementary resources and capabilities, firms can enhance their innovation-related activities (Cassiman & Valentini, 2016; Khanna et al., 1998).

Despite the growing popularity of coopetition, it can present challenges for the participating firms. Existing research suggests that not all firms are ready to coopetition because of the potential involuntary knowledge outflow to competitors (Roper et al., 2017). Innovators are less likely to collaborate with competitors when they develop innovation and when considerable investment in R&D and pre-design of the prototype are involved. Innovators are more willing to coopetition during a new product's launch phase. By engaging in the launch phase, firms can reduce the time needed to commercialize new products, access market information (Gnyawali et al., 2006), and reduce entry costs (Laursen & Salter, 2014). Innovators can also use coopetition to strategically reduce innovation-related competition (Aghion & Howitt, 2008).

The positive effects of coopetition relate to learning from competitors (Bouncken & Fredrich, 2016; Simonin, 1999), but the knowledge gained from the joint activity may not directly translate to innovation. The coopetition process also allows all the members involved to discover their partners' activities, thus making it easier to replicate competitors' processes or innovations (Roper et al., 2013) since knowledge transfer occurs through parties involved by information exchange and personal interactions. Employees of both firms within the same industry and markets have diverse educational and work experience, and coopetition brings together a diverse set of knowledge resources and knowledge-sharing opportunities (Nieto & Santamaría, 2007). While voluntary and involuntary knowledge transfer between competitors is a positive effect of coopetition, knowledge hoarding can be a problem. These problems can arise when all partners experience a lack of trust, a lack of incentives, and a risk of high opportunism (Bouncken & Fredrich, 2016; Khanna et al., 1998). Existing research suggests that fear of imitation can also affect motivation to share knowledge within the industry (Cassiman & Veugelers, 2002; Oxley & Sampson, 2004).

Firms will choose incremental vis-a-vis radical innovation, with the relationship depending on the firm's investment in R&D. This is because coopetition creates tacit knowledge between competitors. Still, such knowledge may not always be formalized (Quintana-Garcia & Benavides-Velasco, 2004) if the recipient firms do not have the capability and creativity to understand and interpret the information (De Dreu et al., 2011; Majchrzak et al., 2012).

Coopetition is seen as a cost-cutting activity in industries with a high cost of R&D activities to increase organizational capabilities. It is beneficial for partners to be able to innovate product that has already been introduced in the industry by competitors instead of pursuing innovation. Therefore, we hypothesize that a firm will focus on incremental innovation in the absence of or low internal R&D investment. We hypothesize:

Hypothesis 1 Coopetition will have a more significant positive effect on incremental than radical innovation for firms with no investment in internal R&D.

2.4 Coopetition, R&D, and innovation types

The innovation type may originate from different combinations of external knowledge transfer and investment in internal R&D (Semadeni & Anderson, 2010). So far, the evidence has been inconclusive. For instance, Mention (2011) analyzed 1052 innovative firms and discovered that internal knowledge is most important as external collaboration in service firms does not result in innovation and only initiates new components to firm products. Tomlinson and Fai (2013) analyzed data on 371 UK manufacturing SMEs and found that coopetition has no significant impact on innovation. This argument highlights potential risks of coopetition and possible adverse effects when a firm's R&D investment is high.

Radical innovation depends on a firm's investment in internal R&D, industry knowledge spillovers, and knowledge collaboration (Suarez & Lanzolla, 2007). These knowledge sources can complement each other and create a competitive advantage for a firm by strengthening the internal knowledge capability and speeding up market entry. Complementarities between knowledge inputs change a firm's routines and processes (Hill & Rothaermel, 2003) and generate new knowledge that can lead to transformative innovation. The recombination of competitors' knowledge could be more beneficial as it allows experimenting with new ideas (Katila & Ahuja, 2002) within existing markets and increases the propensity to innovate (Troilo et al., 2014) radically. Even though combined knowledge is essential for innovation, not all firms have the internal capacity to extract knowledge from external sources, in particular via coopetition.

In coopetition, firms manage complementary knowledge to facilitate a collaborative innovation process, with cognitive and technological proximity enhancing knowledge co-creation. Cognitive and technological proximity facilitates the exchange of tacit knowledge between partners (Ritala & Hurmelinna-Laukkanen, 2013), resulting in further knowledge spillovers (Audretsch & Feldman, 1996). This results in a positive side of the coopetition-innovation nexus. Howard et al. (2017), using micro-level data on 717 technology-based firms, demonstrated that knowledge collaboration is more likely between firms with which global trajectories of key technologies are more closely aligned.

Investment in internal knowledge, such as R&D and other investments, bolsters the relationship between external knowledge and innovation (Denicolai et al., 2016), stimulating creativity (De Dreu et al., 2011) but not always leading to new market products. Legal and strategic agreements with competitors may become a roadblock for the first mover, as co-creating new knowledge may imply value co-creation and capture. Howard et al. (2017) also demonstrated that when knowledge partners are more active in defending their intellectual property and forming R&D alliances, it generates the interlock, and the firm is more likely to gain access to the partner's tacit knowledge.

Therefore, enforcement of R&D collaboration agreements and non-disclosure of knowledge when co-creating knowledge with competitors may prevent first-mover advantage. While coopetition increases the risks of unintended knowledge outflows to competitors (Cassiman & Veugelers, 2002), such outflows could be legally binding, and an independent market entry strategy may no longer be an option.

As the intensity of coopetition increases, transaction costs, and risks also increase. At the same time, collaborating with competitors creates a delay in independent first market entry, as all collaborators jointly the IP on the novel innovation, reducing the propensity of each partner to innovate and commercialize new products solely, resulting in a negative effect. Knowledge-sharing opportunities with competitors can facilitate the process of innovation (Li et al., 2008). Still, it will prevent a firm from commercializing new knowledge independently or individually, limiting the introduction of radical innovation. These results demonstrate potential benefits and risks from coopetition to radical innovation. A link between coopetition and innovation will be diminished by the potential costs, risks, and limitations of coopetition, dissipating the benefits from competitors' knowledge, eventually flipping the knowledge spillover of the innovation curve downwards (Audretsch & Belitski, 2022). We hypothesize:

Hypothesis 2a The combined effect of internal R&D and coopetition on radical innovation is inverted U-shaped.

2.5 Knowledge spillovers, R&D, and innovation types

Industry knowledge spillovers are an attractive source of external knowledge for innovation from industry. Their unique phenomenon is based on the "non-excludability" of knowledge (Audretsch & Keilbach, 2007: 1246) created by the third organizations, which is used by pro-active firms who access knowledge spillovers to innovate (Audretsch et al., 2023). While the members of competitor firms share common knowledge and other resources (Gong et al., 2013), knowledge spillovers allow innovators to use knowledge independently of industry competitors as a positive externality. The main criterion for using the industry knowledge spillover is the firm's investment in R&D. Existing literature shows that without internal R&D, firms may be unable to integrate knowledge spillovers (Cohen & Levinthal, 1989). The firm's capacity to recognize and adopt external knowledge will facilitate knowledge spillovers and new product creation independently of active collaboration with partners. It may enable rapid market entry before competitors.

Knowledge spillovers are transmitted with the following two mechanisms. Firstly, the mechanism of knowledge spillover works as a conduit to acquire information about new products and processes from external sources (intermediate inputs) and may enable new offerings when combining knowledge from the local market (Bartelsman et al., 1994; Keller, 2002). Secondly, industry knowledge spillovers result from high investment in R&D in specific sectors, when the number, concentration, and contacts between R&D managers, R&D collaboration, and poaching of employees.

Firms with high investment in R&D will quicker appropriate knowledge spillover and combine knowledge inputs to create radically new products (Audretsch & Belitski, 2020b). To reap the advantages of co-location with firms who invest in R&D locally, a firm may consider an interval investment in knowledge to better access and absorb the knowledge that spills from other firms in a region. Firms with access to knowledge spillovers are unlikely to choose incremental innovation as they bear the cost of R&D and will aim to create new-to-market products. We hypothesize:

Hypothesis 2b The combined effect of internal R&D and knowledge spillovers increases radical innovation and has no effect on incremental innovation.

Our conceptual framework is presented in Fig. 1.

3 Data and method

3.1 Data matching and sample description

To test our hypotheses, we used six pooled cross-sectional datasets—Business Structure Database (BSD), known as the Business Registry, and the Community Innovation Survey (UKIS) (Office for National Statistics, 2017, 2018, 2019). Firstly, we pooled UKIS and BSD data by year and firm ID. Each of these UKIS is conducted every second year by the Office of National Statistics (ONS). Secondly, we used Business Structure Database (BSD) data to match it by year of UKIS. This match was done to minimize the endogeneity issue of a two-way causality. Each wave of the UKIS is selected as a stratified sample of a pool of firms by region, firm size, and industry. The data has a panel element with firms appearing more than once in the survey.

Although we have an unbalanced panel during 2002–2014, our final sample of data available, excluding all missing values, consists of 21,140 observations. For the list of the variables included in this study, please refer to Table 1, while the correlation matrix is presented in Table 4 in the "Appendix". Our sample consists of 90 industries at 2-digit SIC across 12 UK regions, which were used to calculate knowledge spillovers. Sample description by industry, firm size, and the survey wave is illustrated in Table 2A, B.

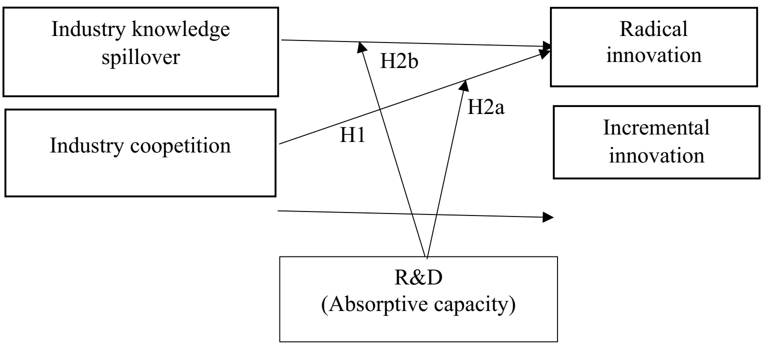

Fig. 1 Conceptual framework

Table 1 Variables description. *Source*: Office for National Statistics (2018). Department for Business, Innovation and Skills, Office for National Statistics, Northern Ireland. Department of Enterprise, Trade and Investment. 2018. *UK Innovation Survey, 1994–2016: Secure Access*. [data collection]. *6th Edition*. UK Data Service. SN: 6699, https://doi.org/10.5255/UKDA-SN-6699-6. Office for National Statistics (2017). *Business Structure Database, 1997–2017: Secure Access*. [data collection]. *9th Edition*. UK Data Service. SN: 6697, https://doi.org/10.5255/UKDA-SN-6697-9. Office for National Statistics (2019), '*Business Expenditure on Research and Development, 1995–2017: Secure Access* [data collection]'. 8th Edition. UK Data Service. SN: 6690, https://doi.org/10.5255/UKDA-SN-6690-8

Variable (source)	Definition	Obs	No-zero obs	Mean	SD
Radical innovation (UKIS)	Equals one, if over the last 3 years a firm has created new service and (or product, which was also new to the market, zero otherwise	21,140	6821	0.50	0.51
Incremental innovation (UKIS)	Equals one, if over the last 3 years a firm has created new service and (or product, which was similar to already existing product in the market or competitors, zero otherwise	21,140	8785	0.63	0.48
Age (BSD)	Years since the establishment of a firm	21,140	21,140	17.85	9.71
Employment (BSD)	Number of full-time employees, in logarithms	21,140	21,140	4.00	1.48
Exporter (UKIS)	Equals one, if a firm over the last 3 years exported products and services, zero otherwise	21,140	11,059	0.35	0.48
Survival (BSD)	Equals one, if a firm survived until 2017, zero otherwise	21,140	14,994	0.58	0.49
Foreign (BSD)	Equals one, if a firm has a main company (headquarters overseas, zero otherwise	21,140	10,699	0.45	0.50
Process Innovation (UKIS)	Equals one, if a firm over the last 3 years has created new or (and significantly improved processes to manufacture new products and services, zero otherwise	21,140	5286	0.25	0.43
Subsidiaries (BSD)	Subsidiaries, in logarithms	21,140	20,748	1.00	0.92
Regional collaboration (UKIS)	Equals one, if a firm over the last 3 years has collaborated on knowledge with regional partners (suppliers; clients or customers; competitors; consultants, private R&D institutes; universities; government, zero otherwise	21,140	4420	0.14	0.34
National collaboration (UKIS)	Equals one, if a firm over the last 3 years has collaborated on knowledge with partners in the UK (suppliers; clients or customers; competitors; consultants, private R&D institutes; universities; government, zero otherwise	21,140	6130	0.17	0.38
Global collaboration (UKIS)	Equals one, if a firm over the last 3 years has collaborated on knowledge with partners in Europe or other world (suppliers; clients or customers; competitors; consultants, private R&D institutes; universities; government, zero otherwise	21,140	3902	0.11	0.31
Software intensity (UKIS)	Ratio of machinery, of firm's own equipment and software expenses over the last 3 years (000s pound sterling to turnover (000s pound sterling	21,140	11,214	0.01	0.04
R&D intensity (UKIS)	Ratio of firm's own R&D investment over the last 3 years (000s pound sterling to turnover (000s pound sterling	21,140	9814	0.01	0.05

Table 1 (continued)

Variable (source)	Definition	Obs	No-zero obs	Mean	SD
Industry knowledge spillover (BERD)	Industry knowledge spillover by 2 digits SIC and 120 UK boroughs calculated using R&D expenditure in £000s within firm sector at 2 digit SIC (excluding firm's expenditure in the borough where a firm is located. Data is taken from the external BERD survey	21,140	15.338	0.16	0.22
Industry coopetition (UKIS)	How important over the last 3 years for a firm was knowledge collaboration and product (service co-creation with direct competitors in the industry (from zero—not important to 3—highly important	21,140	17,276	1.23	1.05

Table 2 (A) Geographical, (B) firm size and wave split of the sample. *Source*: Office for National Statistics (2017, 2018, 2019)

Description	Waves						
	2005	2007	2009	2011	2013	2015	Total
(A)							
North East	830	93	85	61	< 20	74	
North West	1341	129	117	174	32	223	
Yorkshire and The Humber	1179	110	133	126	< 20	217	
East Midlands	1178	145	121	121	< 20	233	
West Midlands	1285	146	122	143	21	290	
Eastern	1252	143	128	159	25	103	
London	1401	104	111	170	36	132	
South East	1543	162	157	203	48	145	
South West	1196	127	141	128	27	118	
Wales	975	106	97	74	< 20	119	
Scotland	1115	116	122	104	< 20	138	
Northern Ireland	1215	84	90	73	< 20	145	
Total							21,140
(B)							
Micro and small 1–49	6380	513	558	912	184	1150	
Medium 50–249	4098	362	389	404	61	428	
Large > 249	4032	590	477	220	23	359	
Total							21,140

3.2 Measures

Our first dependent variable is radical *innovation*, which equals one if a firm develops and introduces a new product or service to the market and zero otherwise (Roper et al., 2017; Un et al., 2010). Our second dependent variable is incremental innovation, which equals one if a firm has developed a product or service that existed in the market before a firm and is new to the firm, zero otherwise (Kobarg et al., 2019). Firms report zero in cases where no innovation project was undertaken, or the project was not completed over the 3-year period the questionnaire referred to. Innovation plans may not have been completed within the 3 years preceding the survey.

We use three explanatory variables related to knowledge transfer from the industry—industry knowledge spillovers and direct collaboration with competitors (coopetition) and knowledge creation in-house—internal R&D. All explanatory variables are lagged one period to address potential lag between knowledge investment and transfer to a firm and innovation outputs (Hall et al., 1984) Following Grilliches (1992) and Keller (2002), we operationalized *industry spillovers* using the flow of knowledge from the internal R&D expenditure in the industry. These knowledge spillovers are industry-specific and calculated using 2-digit SIC classification and 2-letter postcode for boroughs. Knowledge spillovers include the "spillover pool" (in-house R&D expenditure by firms within the 2-digit SIC and 2-letter postcode). While calculating industry knowledge spillovers we used BERD data and excluded the firm's R&D. The industry spillover is calculated as:

$$S_{ir} = \frac{w_{ii}\left(R_{ir} - R_f\right)}{R_{i_{country}}} \tag{1}$$

where subscript *i* indicates a firm; *R* is a measure of internal R&D within the 2 digit SIC (Bloom et al. 2007); and w_{ii} is an industry weight, $w_{ii} = 1$ R_f—is the firm's internal R&D; R_{ir}—R&D in industry i and region r (by 2 letter postcodes in the UK); $R_{i\_country}$—R&D expenditure at a country ion the industry r. Knowledge spillover demonstrates the degree of regional specialization of the industry if S_{ir} ratio increases.

Coopetition is measured by the importance of collaboration with competitors for innovation activities (zero—not important to 3—highly important). Unlike knowledge spillovers, coopetition is not limited to the same region.

Our last explanatory variable is internal R&D as a proxy for technical capital, and we treat these expenditures drawing on Link (1978) as a direct input into the innovation production process. We operationalized internal R&D over the last 3 years (000s pound sterling) to total sales (000s pound sterling) (Kobarg et al., 2019). R&D intensity can measure a firm's absorptive capacity as it facilitates acquiring, assimilating, and transforming new knowledge (Cohen & Levinthal, 1989, 1990; Eisenhardt & Martin, 2000).

To demonstrate the effect of knowledge spillover and coopetition on two types of innovation outcomes, we created a variable absorptive capacity low (associated with zero R&D intensity and the first quartile of R&D intensity) and absorptive capacity high, which means that R&D intensity is greater than zero and it's within second, third or fourth quartile). This measure was used in Fig. 2 to calculate the predictive margins of knowledge spillover of innovation and coopetition on innovation at different levels of R&D.

Firm size and age may directly affect a firm's innovation capabilities (Haltiwanger et al., 2013). The log of the number of full-time employees is used as a proxy for firm size and

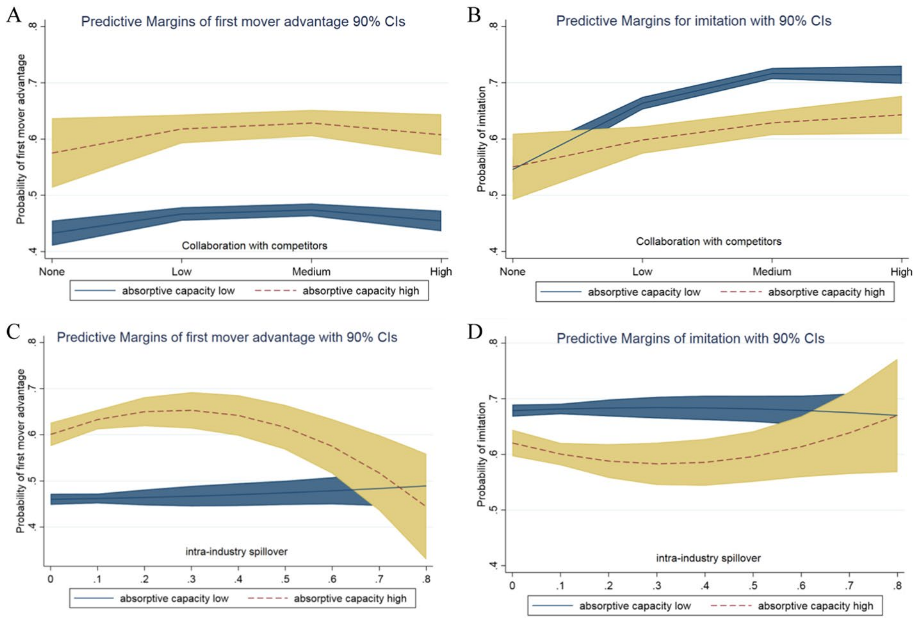

Fig. 2 Predictive margins for radical and incremental innovation for industry knowledge spillovers, coopetition, and R&D. *Source*: Office for National Statistics (2017, 2018, 2019)

years since the establishment as a proxy for a firm age (Rogers, 2004); collaboration is an important channel of knowledge transfer. To control for knowledge collaboration intensity (van Beers & Zand, 2014), we use binary variables of regional, national and global knowledge collaboration. Prior research has demonstrated that knowledge is interdependent and that a firm's performance can exhibit a form of external dependency when a firm pursues the development or/and adoption of new technologies (Howard et al., 2017).

We control foreign ownership by including the variable 'foreign' (Fitza & Tihanyi, 2017). It is coded as one if the company headquarters is located overseas and zero if not. Due to high competition in foreign markets, exporters are more likely to introduce innovation. The variable "exporter" equals one if a firm sells its products in foreign markets and zero otherwise. We add the variable "survival," which indicates whether or not a firm continues its operations in 2017 following the argument that innovators survive longer (Colombelli et al., 2013). We control for the legal status of newly established firms (publicly listed company, buyout, spin-off, partnership, not-for-profit), as prior research found that newly emerging organizations are more likely to introduce new products and services and experiments (Bradley et al., 2011). Firms that belong to a larger enterprise group could be less likely to innovate (Okhmatovskiy et al., 2020).

3.3 Model specification

Using multivariate logistic regression, we estimate two models for radical and incremental innovation (Koberg et al., 2003). The following equation represents the logistic (logit) models we used to estimate the likelihood of radical and incremental innovation:

$$y_{(i,t)} = \beta_0 + \sum_{i=1}^{n} \beta_{11} x_{i,t-1} + \sum_{j=1}^{n} \beta_{12} z_{i,t} + \rho_{1i} + \lambda_{1t} + u_{1(i,t)} \tag{2}$$

where $Y_{i,t}$ is a types of innovation (radical or incremental) in the firm i at time t; $x_{i,t-1}$ is a vector of our explanatory variables such as R&D intensity, industry spillover, and coopetition and their interaction for a firm i in time $t-1$ (Hall et al., 1984); $z_{i,t}$—is a vector of control exogeneous variables for a firm i in time t. We control for unobserved heterogeneity of a firm i by adding industry and region fixed effects ρ_i, and time fixed effects λ_t. The error term is denoted by $u_{i,t}$ for firm i, at time t. Our reference year is 2002–2004, our reference region is North-East of England, and our reference industry is mining and agriculture. As part of a robustness check, we applied the weighting of the sample and estimated logistic regression with survey weights by firm size, industry, and region.

We calculated VIF from a Pooled OLS version of the model, and individual and a group value of VIF were less than five (Wooldridge, 2009).

4 Results

Table 3 illustrates the results of the logistic estimation. The results related to the relationship between industry knowledge spillovers and types of innovation outcomes conditional on investment in R&D are presented in columns 3–4 (Table 3), and coopetition and innovation outcomes conditional on investment in R&D in columns 1–2 (Table 3). Columns 1 and 3 in Table 3 predict the level of radical innovation, and columns 2 and 4 predict the level of incremental innovation; coefficients are reported in odd ratios. The value of the coefficient

Table 3 Results for logistic regression (odds ratios reported). *Source*: Office for National Statistics (2017, 2018, 2019)

Specification	(1)	(2)	(3)	(4)
Dependent variable	Radical innovation	Incremental	Radical innovation	Incremental
Age	0.906* (.03)	1.067 (.04)	0.907* (.03)	1.068 (.04)
Employment	0.972 (.02)	0.956 (.02)	0.972 (.02)	0.957 (.02)
Exporter	1.699*** (.11)	0.990 (.07)	1.698*** (.11)	0.990 (.07)
Survival	1.059 (.06)	0.911 (.06)	1.060 (.06)	0.908 (.06)
Foreign	1.080 (.07)	0.937 (.07)	1.081 (.07)	0.935 (.07)
Process innovation	1.61*** (.15)	1.11** (.09)	1.58*** (.19)	1.121** (.10)
Subsidiaries	1.052 (.04)	0.999 (.04)	1.050 (.04)	0.999 (.04)
Regional collaboration	1.162* (.09)	0.973 (.07)	1.165* (.09)	0.974 (.07)
National collaboration	1.451*** (.10)	1.136 (.08)	1.454*** (.10)	1.134 (.08)
Global collaboration	1.531*** (.12)	0.893 (.078)	1.529*** (.12)	0.896 (.078)
Software intensity	2.108* (1.1)	2.255* (1.3)	2.218* (1.2)	2.192* (1.3)
Industry coopetition	1.241* (.13)	2.144*** (.24)	1.245** (.12)	2.022*** (.21)
Industry coopetition squared	0.941** (.03)	0.857*** (.03	0.940* (.02)	0.868*** (.02)
Industry spillover	1.502 (.74)	0.904 (.48)	1.100 (.60)	1.213 (.72)
Industry spillover squared	0.593 (.42)	1.105 (.84)	1.088 (.85)	0.699 (.59)
R&D intensity	1.882** (.44)	1.032 (.25)	1.864*** (.19)	0.733** (.07)
R&D intensity × industry coopetition	1.041 (0.30)	0.621* (0.16		
R&D intensity × industry coopetition sqrd	0.993 (.08)	1.11 (.09)		
R&D intensity × industry spillover			6.111** (3.3)	0.242 (.30)
R&D intensity × industry spillover sqrd			0.028* (.01)	9.807 (19)
Legal status, regions, year and industry controls	Yes	Yes	Yes	Yes
chi2	902.34	1165.84	906.93	1164.10

Number of observations: 21,140

Reference industry = mining and agriculture, reference region = North East of England; legal status = listed company; reference wave = 2002–2004. Robust standard errors are in parenthesis

Significance level: *$p<0.05$; **$p<0.01$, ***$p<0.001$

above unity (1), means an increase in the likelihood, while the value below unity (1) means a decrease in the likelihood. The models' goodness of fit is evaluated by comparing the likelihood ratios across different models.

In Table 3 and our model, we included coopetition in levels and a squared term. Our H1, which states that coopetition has a greater effect on incremental than radical innovation, is supported (columns 1–4, Table 3). Interestingly, we found that the relationship between coopetition and radical innovation is not significant for the linear relationship but significant for the non-linear relationship. This finding extends prior research on coopetition and innovation ($\beta = 1.241$, $p < 0.01$ and $\beta = 0.941$, $p < 0.01$) (column 1 Table 3) (Bouncken et al., 2018; Lind & Mehlum, 2010) by demonstrating that both innovation types could suffer due to the intensified tension from coopetition (Bengtsson & Kock, 2014).

We also find that the relationship between coopetition and incremental innovation is non-linear, expanding the prior research on why companies engage in coopetition ($\beta = 2.144$, $p < 0.01$ and $\beta = 0.857$, $p < 0.01$) (column 2 Table 3). This finding is important as it demonstrates that knowledge-sharing opportunity with competitors facilitates incremental innovation to a greater extent than radical innovation (Gong et al., 2013). More importantly, as the intensity of coopetition increases, the risks and costs related to coopetition grow, leading to a decrease in radical innovation. Our finding is important as we show that coopetition may only work until a certain threshold for radical innovation.

Our hypothesis H2a stated that a combination of investment in R&D and coopetition for radical innovation is inverted U-shaped. We found that the direct effect of investment in R&D is insignificant, so our hypothesis is not supported. Related to our H2a, the odds ratio of the interaction coefficient between R&D investment and coopetition (in levels) is significant and positive ($\beta = 0.621$, $p < 0.05$) (column 2, Table 3). However, the squared term of interaction is insignificant, not supporting H2a. Our estimation demonstrated that R&D investment facilitates the effect of coopetition on incremental innovation, but this does not lead to a negative effect. These findings extend prior research on knowledge transfer from competitors (Ritala & Hurmelinna-Laukkanen, 2013), demonstrating the existence of the inflicting point in the relationship between coopetition and radical innovation.

With regards to our hypothesis H2b, we found a positive effect of a firm's R&D on a firm's innovation ($\beta = 1.88$, $p < 0.01$) (column 1, Table 3). Economically, we interpret this effect as a one percent increase in internal R&D intensity associated with an increase in the propensity of radical innovation in 1.88 times. The direct effect of knowledge spillovers on two innovation types is insignificant (columns 1–4, Table 3).

Our H2b, which states that the combined effect of investment in R&D and knowledge spillover will increase radical innovation, is supported. Additionally, the results suggest that the relationship is more complex than we expected. An increase in industry knowledge spillovers in a region and greater firm's R&D will at some point lead to a negative effect on radical innovation ($\beta = 6.111$, $p < 0.01$) and squared term ($\beta = 0.028$, $p < 0.05$) (column 3, Table 3). This demonstrates that the relationship is non-linear.

In order to test non-linearity in the relationship illustrated in Fig. 1, we draw on Lind and Mehlum's (2010) technique for non-linearity testing. We use predictive margins to test our hypothesis (Fig. 2A–D) using the results of estimation in Table 3 for each specification.

Predictive margins in Fig. 2B clearly demonstrated an inverted U-shape relationship with diminishing returns of coopetition for incremental innovation. Figure 2B supports our H1, which states that coopetition will have a greater positive effect on on incremental than radical innovation for firms with lack of internal R&D. However, firms that do not invest in R&D and have a high level of coopetition are likely to outperform their counterparts who also invest in R&D and collaborate in the industry with competitors. Additionally, there is a diminishing return for incremental innovation ($\beta = 0.621$, $p < 0.01$). Figure 2A also demonstrates the positive effect of coopetition for radical innovation when the level of coopetition is low, and firm invests in R&D. We do not find support for H2a. As expected, we find that firms collaborating with competitors and not investing in R&D will be less likely to introduce new products to the market (Fig. 2A).

Figure 2C demonstrates an inverted U-shaped relationship between knowledge spillovers and radical innovation for firms that invest in R&D. This finding partly supports H2b, which predicted the positive effect of knowledge spillover for innovation when the firm's own R&D increases ($\beta = 6.111$, $p < 0.01$) (Roper et al., 2013, 2017). Our results demonstrate limits to the open innovation strategy of firms (Audretsch & Belitski, 2023b). It also shows that the knowledge spillover may have limits as a positive externality and may reduce radical innovation when industry knowledge spillovers are high. We explain this by excessive and uncontrolled industry spillovers, which may threaten a firm's incentive to invest in R&D and innovate, as the knowledge is easily dissipated. An increase in knowledge spillover consequently decreases the propensity to innovation (Bloom et al., 2013). When knowledge of competitors can be easily observed (high knowledge spillovers), free-riding may occur, increasing the cases of reverse engineering, copying, espionage, and poaching of workers (Audretsch & Belitski, 2020a, 2023b). Figure 2D shows that changes in knowledge spillovers will not result in subsequent changes in the propensity to achieve incremental innovation independently of R&D investment.

Other interesting findings include the role that firm R&D intensity, firm age, firm employment (size), investment in software, export orientation, and knowledge collaboration play in radical innovation (columns 1 and 3) and incremental innovation (columns 2 and 4, Table 3). The firm's software intensity increases the firm's propensity to incremental innovation (column 2, Table 3). Firm size (Rogers, 2004) and firm age (Haltiwanger et al., 2013) reduce radical innovation propensity without effect on incremental innovation. Firm size does not explain the propensity of either innovation type, while younger firms are more likely to innovate radically. An increase in software spending doubles the likelihood of radical innovation.

5 Robustness checks

We performed several robustness checks. We estimated the logistic regression with knowledge spillovers (column 3, 4 Table 3) and coopetition (column 1, 2 Table 3). Our models also included other controls and time, regional, and industrial fixed effects. By including firm characteristics and interaction terms of R&D and external knowledge, we can observe the change in the significance of the predicted coefficients and decide on the bias size when knowledge spillovers, coopetition, and the other firm's controls are estimated.

Secondly, we calculated knowledge spillovers at the 3-digit SIC level and estimated Eq. (3) with a lower significance of the results. This means that learning from very close competitors (3-digit SIC) vs. distant competitors (2-digit SIC) may reduce innovation and the ability to recombine relevant knowledge (Kobarg et al., 2019).

Thirdly, we performed logistic estimations with and without bootstrap and clustered our standard errors by 2-digit industry SIC, correcting for heteroskedasticity across industries. This allows us to check for potential bias in estimation due to autocorrelation in errors between firms when spillovers are calculated at 2-digit SIC 2007. Both estimations provided the same results on the direction of the relationship and the significance levels.

Fourthly, we used weights of the stratified sample provided by the ONS and calculated by the industry and the firm's size using the original UKIS sample. We compared the estimation results with the predicted coefficients between weighted and unweighted models. The results were consistent for the signs, significance, and confidence intervals.

Fifthly, to address the variance structure of the model by standardizing all explanatory and control variables around the mean and performing the estimation. This could decrease the multicollinearity in interactions. All coefficient signs, significance levels, and confidence intervals remained unchanged, supporting H1 and H2b and partly supporting H2a.

6 Discussion

The knowledge transfer and open innovation literature has long focused on challenges confronting a firm's knowledge search and transfer choices and how internal knowledge creation and collaboration with competitors on knowledge influence a firm innovative output. A key finding of this paper is that it is not just the quantity of innovative input that matters, independently, be this a spillover or coopetition, but rather the quality or nature of that innovative input that shapes innovation type.

Extending the innovation literature engages with the depth and breadth of knowledge collaboration (Kobarg et al., 2019). Unlike prior research, which pointed out the inverted U-shaped relationship between knowledge collaboration with external partners and innovation performance (Kobarg et al., 2019; Audrestch & Belitski, 2022), this study argues that it is the type of external knowledge collaboration that matters for the type of innovation and that both knowledge collaboration with competitors (coopetition) and knowledge spillovers are subjected to diminishing marginal returns.

Therefore, we contend that both the coopetition and knowledge spillovers are linked to the type of innovation, and the extent of the knowledge spillover/coopetition should be taken into account under different levels of the firm's own R&D investment as it may generate a very nuanced relationship with innovation types. This is a more nuanced and detailed study compared to the most recent works on limitations to innovation (Saura et al., 2023) and the role of coopetition for innovation (Ritala, 2018; Belitski et al., 2023). Our theoretical argument also complements Denicolai et al. (2016), Audretsch and Belitski (2022), and Roper et al. (2017) prior research, which argued that excessive knowledge transfer reduces innovation across industries. In doing so, this study raises new concerns about how managers and policymakers should approach the "tipping point" of coopetition and knowledge spillover but not go over it, which results in diminishing marginal returns from coopetition (Ritala & Hurmelinna-Laukkanen, 2013).

Interestingly, the results of this study burst the myth that coopetition does not influence innovation at all (Tomlinson & Fai, 2013) and further the works of Czakon et al. (2020) and Ritala (2018), who complement the argument on the positive effect of coopetition on innovation and more complex relationship of an optimal level of coopetition to improve innovation performance (Bouncken et al., 2018; Park et al., 2014). It extends its works beyond innovation, comparing various mechanisms of industry knowledge sourcing and how it shapes innovation types.

Thus, this study contributes to knowledge transfer and open innovation literature that calls for exploring the extent to which firms engage in different types of collaboration strategies for innovation, which subsequently lead to different types of innovation (Audretsch & Belitski, 2023b). In doing so, we offer a framework that helps to explain what types of investments in knowledge and knowledge collaborations are likely to yield innovation and when they lead to incremental innovation. Unlike prior work on the limits to open innovation (Saura et al., 2023), where the collaboration intensity is observed, this study examined various combinations between R&D and innovation inputs—R&D coopetition with external partners and knowledge spillovers to unpack its joint effect on manager's choice of innovation type.

The results of the study offer several insights. Firstly, we learned why knowledge collaborations sometimes have different outcomes. Besides, we learned that collaborative relationships and innovative outcomes are not linear. Secondly, at the core of our investigation is the possibility that not all R&D investment and collaboration lead to innovation (Semadini & Anderson, 2010; Suarez & Lanzolla, 2007), and there is an optimum level of R&D investment and coopetition where firms get the maximum return from these investments. Thirdly, we demonstrated that this issue is important but needs to be explored related to types of innovation and firms' investment decisions. We call for subsequent studies to examine how spillovers and knowledge collaboration with different external partners occur in industrial clusters and across different locations within the same industry.

6.1 Managerial implications

First, managers need to be aware that co-location with their competitors in the industry facilitates innovation if firms invest in R&D (Brandenburger & Nalebuff, 1996; Raza-Ullah & Kostis, 2020). High knowledge spillovers may increase unintended knowledge outflows, decreasing this propensity to innovate for both knowledge recipient and knowledge provider in the market if the level of industry spillovers is greater than 0.4 (a tipping point for spillover).

Second, investment in R&D is important when a firm is co-located with competitors and the level of knowledge spillovers is less than 0.4. In contrast, reducing R&D expenditure can be a desirable strategy when the intensity (depth) of coopetition increases significantly. Firms will be worse off if they slightly modify new products and continue R&D.

Third, to increase returns to coopetition, firm managers need to figure out how to secure first-mover advantage and form an R&D alliance when interlocked partners co-create knowledge together and, exchange tacit knowledge and protect intellectual property (Howard et al., 2017). Prior research considered the interlocks as a mechanism to decrease competitive uncertainties or means of improving resource dependences by minimizing patent litigations and R&D alliances (Howard et al., 2017); this, however, may have an important implication for the first-mover advantage and be able to develop and commercialize new to market products before competitors.

6.2 Policy implications

Policymakers must regulate the breadth and depth of coopetition using legal means, as excessive coopetition limits innovation. The same is true with knowledge spillovers; however, the degree of spillover regulation may be limited as passive collaboration is more challenging to track and measure. That said, the government may have more powers to enhance knowledge spillovers but fewer powers to limit them, preventing unintended knowledge outflows. On the contrary, the government has less power to initiate coopetition while more control over cartels and how this coopetition develops. The role of legal and strategic protection mechanisms needs to be further discussed when studying coopetition. Joint patents could be a good option. At the same time, it is unlikely to facilitate a first-mover advantage for every single firm in the partnership; it is likely to control intellectual property rights and prevent free-riding between competitors. Managing knowledge spillovers for innovation is challenging as part of the localized knowledge created by incumbent firms may be transferred to competitors involuntarily (Audretsch & Keilbach, 2007) and, while the government may still want competitors to continue collaborating and recombining ideas (Bouncken et al., 2018; Simonin, 1999).

7 Conclusion

An implication of Cohen and Levinthal (1989) and the ensuing mountain of research is that while the sources of knowledge accessed externally and by internal investment in R&D are very different, the resulting innovation is different. Just as all paths may lead to Rome, an implicit implication from our study is that the two very different paths to knowledge—coopetition or industry spillovers may have different effects on each innovation type, with R&D moderating this relationship.

The point of this paper is to suggest that when it comes to knowledge, not all roads lead to the same place. Knowledge transferred via industry knowledge spillovers is more conducive to both innovation types. By contrast, knowledge generated by the firm itself is more conducive to radical innovation. Thus, while Cohen and Levinthal (1989) identified that R&D has two faces, this paper suggests that those two faces of R&D tend to generate very different types of innovative output and differently moderate the relationship between two sources of knowledge—spillovers and collaboration. By deciding whether to deploy its costly R&D and access external knowledge, the firm is, therefore, also making a concomitant decision about the type of innovative activity. In addition, this study contributes to the knowledge spillover of innovation literature in explaining the returns from knowledge collaboration and industry spillovers.

Firm managers deciding on incremental innovation and consequently investing in R&D would waste resources. Our results also demonstrate that benefits from coopetition can be achieved when internal R&D is in place but is moderate, as an increase in R&D may revert knowledge spillover of innovation (Audretsch & Belitski, 2022).

This study has several limitations. Our first limitation is that the panel element is small, meaning seventy percent of firms only appear twice in the data. At the same time, this limits the research design, specifically the ability to get close to causal inferences, pooling the two distinct data sources together and including all firms that have ever reported their innovation activity.

Our second limitation is that fitting controls and region/time/industry fixed effects may not fully handle a model's 'endogeneity' issue. While we performed various sensitivity checks on the specification and estimator in this repeated cross-sectional firm-level setting, future research should address several outstanding endogeneity problems. First, simultaneity (some technological/policy shock affecting both R&D activity and innovative activity); reverse causation (innovative activity is likely associated with the firm's R&D and vice versa, which varies by the firm over time; firm-level unobserved factors (e.g., management strategy, workforce quality outside qualifications, firm ownership and legal status and other firm characteristics also vary with time). Future researchers may restrict the analysis to the panel component, allowing them to run regressions with firm fixed effects.

Appendix

See Table 4.

Table 4 Correlation matrix. *Source ONS*: matched Business Register (2002–2014) and UK Innovation Survey (2002–2014)

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Innovation	1														
2	Imitation	0.14*	1													
3	Age	−0.22*	0.39*	1												
4	Employment	0.21*	0.44*	0.57*	1											
5	Exporter	0.20*	0.36*	0.43*	0.58*	1										
6	Survival	0.24*	0.05*	0.24*	0.18*	0.16*	1									
7	Foreign	0.15*	0.20*	0.11*	0.08*	0.06*	0.20*	1								
8	Process Innovation	0.33*	0.19*	0.17*	0.12*	0.11*	0.22*	0.12*	1							
9	Subsidiaries	0.09*	0.09*	0.11*	0.06*	0.06*	0.15*	0.07*	0.32*	1						
10	Regional collaboration	0.07*	0.08*	0.10*	0.07*	0.06*	0.14*	0.07*	0.36*	0.36*	1					
11	National collaboration	0.36*	0.08*	0.21*	0.22*	0.26*	0.16*	−0.01*	0.12*	0.08*	0.07*	1				
12	Global collaboration	0.16*	0.07*	0.06*	0.09*	0.07*	0.01	0.01	−0.07*	0.28*	−0.04*	−0.03*	1			
13	Software	0.28*	0.09*	0.22*	0.23*	0.26*	0.15*	0.00	0.12*	0.28*	0.08*	0.42*	0.02*	1		
14	R&D intensity	0.20*	0.02*	0.21*	0.28*	0.25*	0.23*	0.03*	0.10*	0.04*	0.08*	0.18*	0.18*	0.25*	1	
15	Industry knowledge spillover	0.19*	0.50*	0.63*	0.47*	0.45*	0.20*	0.10*	0.14*	0.09*	0.08*	0.14*	0.07*	0.16*	0.16*	1
16	Industry coopetition	−0.11*	0.13*	0.01*	0.03*	0.00	0.05*	0.03*	0.08*	−0.14*	−0.01*	−0.11*	0.23*	−0.10*	0.09*	0.15*

Number of observations 21,140

*Significant at 5% significance level

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