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RESEARCH ARTICLE OPEN ACCESS

Entrepreneurial activity as a conduit of knowledge spillovers

How Entrepreneurs Absorb Knowledge Spillovers During Innovative Product Development: Evidence From UK Start-Ups

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Received: 31 October 2023 | **Revised:** 5 December 2024 | **Accepted:** 2 February 2025

Funding: The authors received no specific funding for this work.

Keywords: absorptive capacity | entrepreneurship | knowledge spillovers | medium to high-tech firms | product innovation | start-ups

ABSTRACT

This study examines the impact of knowledge spillovers on product innovation performance within UK medium to high-tech start-ups. We propose a conceptual model that explains the relationship between incoming and network knowledge spillovers, potential and realized absorptive capacity, and exploratory and exploitative innovation performance, considering technological turbulence. Based on a PLS-SEM analysis of 556 UK-based medium to high-tech start-ups, our results show that during the potential absorptive capacity phase, start-ups focus on acquiring incoming and networked knowledge spillovers. However, the exploitation of network knowledge spillovers occurs during the realized absorptive capacity phase. These findings contribute to the current understanding of the role of knowledge spillovers in absorptive capacity, while from a practical perspective they provide start-ups with guidance on optimizing and exploiting knowledge spillover based on their firms' characteristics.

1 | Introduction

Previous research on knowledge spillovers has focused on defining their types and mechanisms (Audretsch and Lehmann 2005). The Knowledge Spillover Theory of Entrepreneurship (KSTE) posits that entrepreneurial opportunities arise from regional knowledge spillovers, improving firms' capabilities and benefiting other regional players. It also suggests that proximity to knowledge sources facilitates uncommercialized knowledge use (Audretsch et al. 2010). In such a scenario, firms benefit from access to local resources, including government support and human capital, while knowledge exchanges or unintended spillovers from established firms are considered critical (Audretsch et al. 2015; Yi et al. 2021). A key challenge, however, is how start-ups effectively use knowledge spillovers to achieve competitive advantage (Mathias et al. 2021). Recent research on the KSTE highlights that economic agents often exploit knowledge spillovers more effectively than their original creators within entrepreneurial ecosystems (Audretsch and Fiedler 2024; Morris et al. 2023). This perspective has helped researchers to evaluate the roles of actors and the impact of knowledge spillovers in diverse contexts, such as the circular economy and economic growth driven by new ventures (Audretsch and Fiedler 2024).

Knowledge spillovers occur when firms unintentionally distribute knowledge within or outside of their organizational boundaries (Acs and Sanders 2013; Kaiser 2002). Knowledge spillovers are influenced by geographical or virtual proximity to knowledge sources and can be captured at minimal cost (Huggins and Thompson 2015). However, measuring knowledge spillovers is difficult due to their unintentional nature. Therefore, further research is needed to quantify them as a construct in knowledge-intensive environments (Audretsch and Lehmann 2005). Such insights will help researchers determine how start-ups not only capture but also use knowledge spillovers for improving innovation performance (Frederiksen et al. 2016; Ganotakis et al. 2021). In addition, knowledge spillovers influence the evolution of sectors, supporting new ventures in innovation ecosystems driven by foreign investment (Sears and Muhammad 2024; Tryggvason and Giones 2024).

Extant research has examined the development of potential and realized absorptive capacity in firms, influenced by system formalization and socialization capabilities (Jansen et al. 2005). Previous studies have also highlighted how knowledge acquisition, assimilation, transformation, and exploitation drive innovation in high-tech firms (Tseng et al. 2011), while others have explored intentional and unintentional knowledge acquisition from external sources among collaborating firms, which is crucial for recognizing opportunities (Ritala et al. 2015; Foss et al. 2013).

This study contributes to current discourse on the KSTE by providing insights into the impact of knowledge spillovers on start-ups' product innovation performance. It explains how founders' backgrounds, industry type, and firm size influence absorptive capacity and the use of exploratory or exploitative innovation. The findings offer managerial implications for identifying effective knowledge sources, resources, and innovation strategies. In addition, they guide policymakers in supporting high and medium-tech start-ups with strategies to capture knowledge spillovers for product development in emerging or existing markets.

The remainder of this paper is organized as follows: Section 2 presents the theoretical background of this study and its proposed hypotheses. Section 3 describes the methodology adopted, including data collection, sample characteristics, and the measurement instruments used. Section 4 reports the empirical results, focusing on the analysis of the relationships between knowledge spillovers, absorptive capacity, and firms' product innovation performance. Section 5 presents the study's findings, highlighting managerial and policy implications. Finally, Section 6 concludes by summarizing key contributions, limitations, and potential directions for future research.

2 | Theory and Hypotheses

2.1 | Knowledge Spillovers

Knowledge spillovers are often unintentional, acquired without deliberate transmission (Agarwal et al. 2010). Recent research, however, has redefined them as a form of knowledge exchange, where formal measures classify information as transferable or protected (Ritala et al. 2015; Laursen and Salter 2014). At the same time, spillovers typically involve passive collaboration or exposure to public knowledge sources, such as at conferences, with their effects amplified by regional industry concentration (Audretsch and Belitski 2021).

Knowledge spillovers consider the impact of value chain actors on innovation (Kaiser 2002), classified as vertical (e.g., clients, customers, suppliers) or horizontal (e.g., competitors) (Amoroso et al. 2018). Institutional sources of knowledge, such as research centers and universities, and governments (Montoro-Sánchez et al. 2011; Belderbos, Carree, Diederen, et al. 2004), and public knowledge sources, such as conferences, patents, and publications, further contribute to start-ups access to knowledge spillovers (Belderbos, Carree, Diederen, et al. 2004; Chun and Mun 2012). Recent studies suggest that medium-tech firms exploit horizontal spillovers during product development, while high-tech start-ups focus on innovations leading to patents (Becker et al. 2023).

Knowledge spillovers are linked with start-ups' ability to create networks and collaborate with knowledge sources (Ehls et al. 2020). Extant research has highlighted how knowledge absorption impacts product innovation and how collaboration influences start-up performance (Ruiz et al. 2020; Chang et al. 2024). Moreover, the effective exploitation of knowledge spillovers requires investment in ICT to support product development partnerships with incumbents or other firms (Audretsch and Belitski 2023). Moreover, knowledge spillovers have been shown to potentially negatively impact start-up performance. For example, sharing knowledge with external firms can lead to the unwanted appropriation of technology (Bouncken and Kraus 2013; Ritala et al. 2015, 2018; Veer et al. 2016; Gong et al. 2022). Therefore, firms must be careful in what they share, but also appreciate that it is crucial to engage in constant innovation.

2.1.1 | Incoming Knowledge Spillovers

Incoming knowledge spillovers are important for assessing informal collaborations established between start-ups (Blind and Mangelsdorf 2013; Ding et al. 2013). They support start-ups by enhancing their absorptive capacity (i.e., the ability to identify and use new knowledge for growth) (Flatten et al. 2011; Jansen et al. 2005). This capacity is assessed by examining R&D investment and employee exposure to external knowledge sources contributing to innovation performance (Nieto and Quevedo 2005). For start-ups and SMEs, their effectiveness in absorbing knowledge relies on R&D capital and integrated knowledge management policies (Ritala et al. 2022). Such knowledge spillovers include interactions at conferences and collaboration on scientific publications, which can lead to homogeneous, standardized knowledge that limits broader R&D exploration (Cao et al. 2024). Moreover, some firms exploit knowledge spillovers for reverse engineering and patent development to create market prototypes (Becker et al. 2023), which require evaluation beyond traditional R&D investment (Audretsch and Belitski 2023). In addition, seed-stage firms often secure initial funding through investors and networks within entrepreneurial ecosystems, enabling access to diverse external knowledge sources (Malecki 2018; Brinckmann et al. 2011; Alvi and Ulrich 2023).

Research within the context of SMEs has examined knowledge spillovers through the constructs of breadth and depth (Ferreras-Méndez et al. 2016; Laursen and Salter 2006; Chen et al. 2011), with findings showing that knowledge spillovers enable start-ups to access external information, potentially leading to improvements in absorptive capacity and collaboration with other firms (Bernal et al. 2022; Audretsch and Belitski 2023). Access and management of incoming spillovers have also been shown to enhance or limit partnerships with incumbents, start-ups, and other firms, depending on technology and geographical proximity, which influence their impact on innovation (Obschonka et al. 2023). These findings raise the question of whether exposure to knowledge spillovers directly improves start-up collaborations and absorptive capacity. Consequently, the following hypotheses are proposed:

Hypothesis 1a. *Incoming knowledge spillovers have a positive effect on the potential absorptive capacity of high-tech start-ups.*

Hypothesis 1b. *Incoming knowledge spillovers have a positive effect on the realized absorptive capacity of high-tech start-ups.*

2.1.2 | Network Knowledge Spillovers

Network knowledge spillovers arise from interactions between start-ups and external entities, such as incubator or accelerator programs, universities, consultants, or government bodies (Sisodiya et al. 2013; Cantù 2017). These spillovers involve integrating processes and technologies across value chains, leading start-ups to focus on technological development and collaboration with aligned firms (Srivastava et al. 2015; Lau and Lo 2015). Hence, it is important to assess how knowledge spillovers from formal institutions, networks, and other firms support innovation within entrepreneurial ecosystems (Fotopoulos 2023). Previous research argues that start-ups' absorptive capacity is influenced by their access to technological knowledge and the openness of external entities (Obschonka et al. 2023), while digital development in urban areas further enhances absorptive capacity through direct interactions and collaboration (Massa et al. 2023; Yu and Meng 2023).

Network knowledge spillovers reflect a start-up'autghors ability to share and capitalize on knowledge from partners (e.g., customers, suppliers, competitors), and government entities. This influences performance indicators, such as access to IT systems, production costs, and new product development (Nwafor et al. 2023). Start-ups may work with value chain partners or collaborate with government bodies when common technologies align (Zhang et al. 2022). As a result, this study proposes the following hypotheses:

Hypothesis 2a. *Network knowledge spillovers have a positive effect on the potential absorptive capacity of high-tech start-ups.*

Hypothesis 2b. *Network knowledge spillovers have a positive effect on the realized absorptive capacity of high-tech start-ups.*

2.2 | Absorptive Capacity

Absorptive capacity is defined as a multidimensional construct consisting of Potential Absorptive Capacity (PAC) and Realized Absorptive Capacity (RAC) (Zahra and George 2002; Limaj and Bernroider 2017). PAC comprises a firm's acquisition and assimilation capabilities and processes to gather knowledge from external sources (Camisón and Forés 2010; Flatten et al. 2011; Senaratne et al. 2021). This process requires continued market assessment, evaluation of new technologies, and integration of knowledge from external sources and partners to align with venture goals (Ozdemir et al. 2024; Pittz and Adler 2023; Riquelme-Medina et al. 2023).

RAC refers to a firm's ability to integrate and renew its stock of knowledge towards a product, process, or managerial innovation (Jiménez-Barrionuevo et al. 2011; Ali et al. 2016; Camisón and Forés 2010). The transformation and assimilation of new technology are crucial for maintaining competitiveness, though overemphasis can reduce firms' capabilities to react to changes in the market quickly and compete through product innovation (Pittz and Adler 2023). The goal of RAC is to effectively channel marketing knowledge into productive processes to enhance product performance (Ozdemir et al. 2024).

Previous studies on absorptive capacity suggest that connectedness in knowledge exchange and formalizing specific processes can improve start-ups' ability to capture and apply knowledge for product innovation purposes (Jansen et al. 2005). Hence, researchers have argued that absorptive capacity in start-ups depends on the CEO or founder's ability to capture and transfer knowledge to the firm to enhance processes and product innovation performance (García-Sánchez et al. 2018; Debrulle et al. 2014). The start-up's founder(s) usually act as an economic agent with the capability to identify and implement knowledge spillovers from incumbents and to share them within the start-up. This leads to the generation of value for the region (Jiménez-Barrionuevo et al. 2011).

Recent research has extended the work of Jansen et al. (2005) by highlighting the importance of formalizing knowledge processes, improving leadership, and using agile methods for product development (Mota et al. 2025). Investment in R&D has been proven to boost firms' absorptive capacity by mitigating knowledge heterogeneity and fostering international partnerships, enhancing socialization tactics (Zhang et al. 2022; Ferreira et al. 2023; Xu et al. 2023). In other words, absorptive capacity, evaluated through knowledge transformation and sharing, drives product and process innovation, while identifying opportunities from knowledge spillovers ensures competitiveness and survival for firms (Shu et al. 2014; Debrulle et al. 2014).

Absorptive capacity is linked to firm performance, particularly in product innovation (Maldonado et al. 2018; Limaj and Bernroider 2017; Ying and Liang 2008). It shapes firms' innovative practices and organizational structures, suggesting that mediating realized absorptive capacity is crucial for effective innovation in high and medium-tech start-ups (Balau et al. 2020; Zhang et al. 2019). Furthermore, it supports firms' learning processes for integrating knowledge spillovers in R&D (Melnychuk et al. 2021). Accordingly, this study proposes the following hypothesis:

Hypothesis 3. *Potential absorptive capacity has a positive effect on realized absorptive capacity.*

2.3 | Explorative and Exploitative Product Innovation in the Context of Technological Turbulence

Firm innovation is often evaluated through their ability to absorb external knowledge spillovers (Belderbos, Carree, Diederen, et al. 2004) and their effective use of these is key to maintaining their competitiveness (Da Rin and Penas 2017). A start-up's ability to innovate and mitigate market risks depends on absorptive capacity, involving R&D intensity and collaborative efforts (Tsvetkova et al. 2014). However, early innovation should not be solely measured by patent counts due to seed-stage limitations (Cantù 2017; Tsvetkova et al. 2014). Instead, start-ups' product innovation capability supports technological growth and effective knowledge management (Ferreira et al. 2023).

Previous research has examined the effects of absorptive capacity on product innovation in SMEs and start-ups (Jansen et al. 2005; Enkel et al. 2017; Limaj and Bernroider 2017). Exploitative and exploratory innovation influence whether start-ups aim to improve efficiency or explore new processes to cope with disruption (Krishnakumar et al. 2022; Melnychuk et al. 2021). Exploratory innovation is driven by factors such as founders' previous experience and technological changes that occur (Chen et al. 2022). This requires absorbing knowledge spillovers and adapting to existing processes. Similarly, industry engagement affects R&D investment, directly impacting innovation performance (Chen et al. 2022; Lee et al. 2023; Radziwon et al. 2022). Exploratory innovation often leverages diverse knowledge and ties to private funding, emphasizing product quality and R&D budgeting (Li and Deng 2024; Xu et al. 2023). Consequently, this study proposes the following hypotheses:

Hypothesis 4a. *Potential absorptive capacity has a positive relationship with exploratory innovation in high-tech start-ups.*

Hypothesis 4b. *Realized absorptive capacity has a positive relationship with exploratory innovation in high-tech start-ups.*

Exploitative innovation improves existing products and processes in both emerging and established markets (Roth et al. 2024). Recent studies demonstrate that a firm's technology culture significantly affects its commitment to exploitative innovation (Lee et al. 2023). This approach maintains founder continuity, deepens stakeholder engagement, and supports sustainability (Balau et al. 2020; Chen et al. 2022; Khan et al. 2019). Start-ups' R&D activities often involve collaboration with other firms, showing that patents are not always necessary for new product development (Li and Deng 2024). Therefore, it is important to assess whether start-ups across industries should integrate existing knowledge spillovers to improve exploitative innovation. Thus, this study proposes the following hypotheses:

Hypothesis 4c. *Potential absorptive capacity has a positive relationship with exploitative innovation in high-tech start-ups.*

Hypothesis 4d. *Realized absorptive capacity has a positive relationship with exploitative innovation in high-tech start-ups.*

Moreover, previous research has demonstrated that absorptive capacity depends on industry practices, technological intensity, and organizational structure. These factors influence firms' ability to leverage knowledge spillovers, form value chain collaborations, and integrate new technologies (Balau et al. 2020; Messeni Petruzzelli et al. 2022).

Start-ups and SMEs often benefit from technological turbulence due to their size and flexibility to adapt their business models and exploit technological opportunities (Malik et al. 2023; Molina-Castillo et al. 2022). Technological turbulence refers to a start-up's ability to manage uncertainties from technological advancements (Mota et al. 2025; Ozdemir et al. 2024). The moderating effect of technological turbulence may also suggest the potential for implementing agile practices (Meier and Kock 2024). Therefore, this study proposes the following hypotheses, which are summarized in our conceptual model in Figure 1.

Hypothesis 5a. *Technological turbulence has a positive effect on start-ups exploratory innovation.*

Hypothesis 5b. *The effect of realized absorptive capacity on exploratory innovation is moderated by technological turbulence.*

3 | Methodology

3.1 | Sample and Data Collection

Our sample consisted of high and medium-tech start-ups and KIBS registered in the United Kingdom. We used Beauhurst, an online data platform with over 30,000 registered users in the UK, widely used by scholars (Spigel 2022; Owen 2021; Vulkan et al. 2016). In total, we identified a sample frame of 6551 high-tech start-ups in the seed and growth stages and operating within ten years, because during the first 10 years, start-ups generate employment and prove that they are capable of surviving (Fritsch and Changoluisa 2017; Bandera et al. 2016).

The questionnaire was pretested and piloted by three academics, three start-up CEOs, and experts in the high-tech field to assess its content validity. An online survey questionnaire was emailed (widely used by researchers such as Montabon et al. 2018) in January 2019 to key informants such as the Chief Executive Officer, Chief Operating Officer, and Chief Technology Officer, who are likely to be involved in entrepreneurial initiatives and innovation activities (McKelvie et al. 2018). Two reminders were sent to those who did not respond after one to two weeks from the initial email. After eliminating incomplete questionnaires and outliers, 556 responses were obtained; a response rate of 8.49%, similar to that in prior studies (e.g., Muñoz-Leiva et al. 2010; Senaratne et al. 2021; Sisodiya et al. 2013). Table 1 summarizes the descriptive statistics.

3.2 | Measures

Confirmatory Factor Analysis (CFA) was performed to test the measurement model with the reflective constructs of absorptive capacity, and exploratory and exploitative product innovation. Partial Least Squares was conducted to include the formative constructs of incoming and network knowledge spillovers (McIntosh et al. 2014; Hair et al. 2012). Appendix Table A1 summarizes the measurement constructs based on a seven-point Likert scale, ranging from 1, strongly disagree, to 7, strongly agree.

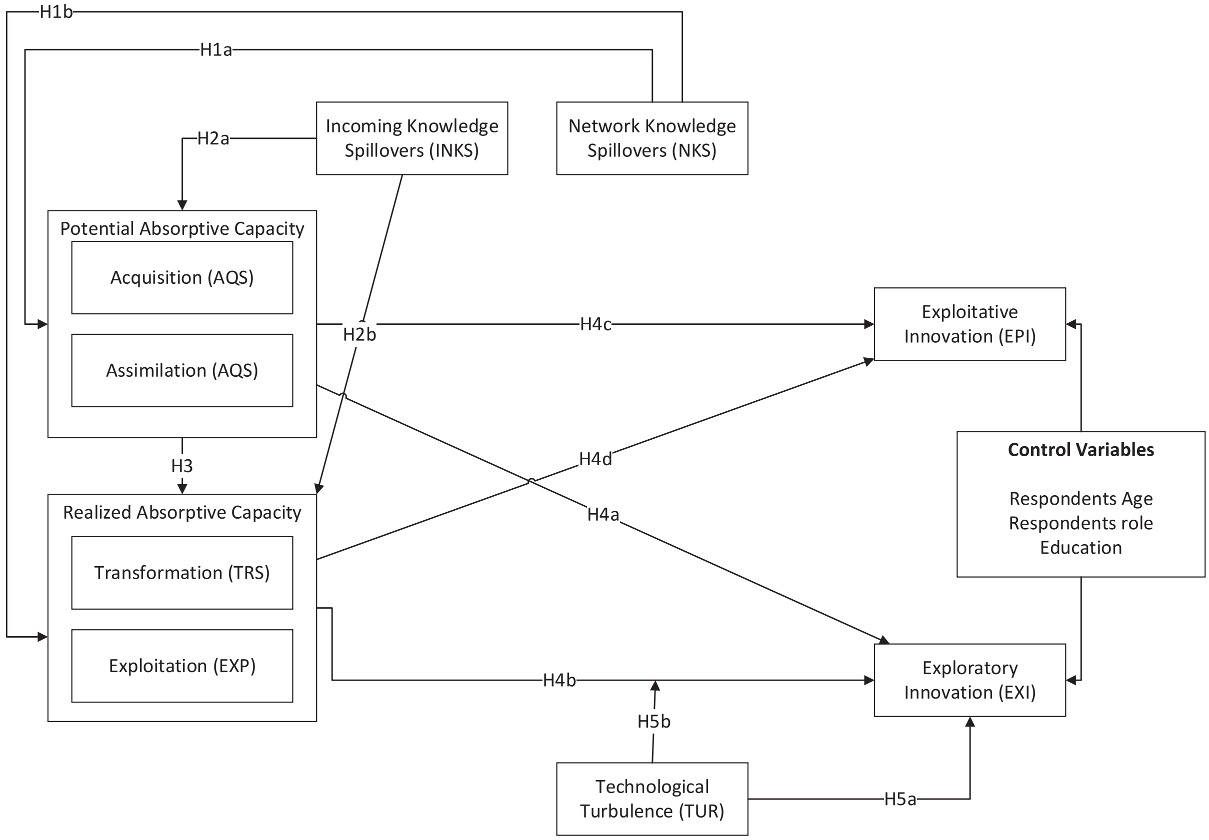

FIGURE 1 | Proposed knowledge spillovers and product innovation model.

3.2.1 | Independent Variables

Absorptive capacity is analyzed through multidimensional constructs that evaluate start-ups' knowledge acquisition, assimilation, transformation, and exploitation activities (Ferreras-Méndez et al. 2016; Flatten et al. 2011). Research on high-tech firms has often used two multidimensional reflective constructs (Limaj and Bernroider 2017; Jiménez-Barrionuevo et al. 2011; Flor et al. 2018). *Potential absorptive capacity* measures start-ups' capacity for knowledge acquisition and assimilation (Jiménez-Barrionuevo et al. 2011; Camisón and Forés 2010), while *realized absorptive capacity* evaluates start-ups' ability to adapt new knowledge to their operations (Jansen et al. 2005). Potential and realized absorptive capacity constructs were measured using eight items each (Camisón and Forés 2010; Limaj and Bernroider 2017; Maldonado et al. 2018; Flatten et al. 2011). Using both potential and realized absorptive capacity allows for the assessment of a start-up's ability to identify and apply knowledge spillovers for product innovation (Aliasghar and Haar 2023).

Knowledge spillovers have two constructs. *Incoming Knowledge Spillovers* (INKS) construct measures start-ups' engagement with knowledge sources (e.g., conferences, publications, online communities, and other firms) (Cassiman and Veugelers 2002; Belderbos, Carree, Diederen, et al. 2004; De Faria et al. 2010). Such sources of knowledge unbounded to collaboration are defined as the formative construct of INKS (Foss et al. 2013; Sisodiya et al. 2013), which can lead to the potential capacity of a start-up to organize knowledge spillovers and to open the opportunity for future collaboration (Becker et al. 2023; Cao et al. 2024). *Network Knowledge Spillovers* (NKS) involves start-ups' access to information through informal sources and collaboration (Cassiman and Veugelers 2002; Belderbos, Carree and Lokshin 2004), assessing the knowledge flows between firms, individuals, and institutions (Shu et al. 2014). These sources include individual forms of knowledge spillovers from competitors, customers, suppliers, universities, or research institutes, and the government (Lau and Lo 2015; Belderbos, Carree, Diederen, et al. 2004; Montoro-Sánchez et al. 2011). The construct enables the assessment of the effects of potential partners in the value chain of the entrepreneurial ecosystem (Ferreira et al. 2023). In this study, participants were asked to evaluate the importance of the mentioned sources of NKS and INKS for exploring new business and technological opportunities. Thus, incoming and network knowledge spillovers were considered formative constructs measured with seven and five items, respectively, considering their depth and breadth as a measurement tool for incoming spillovers (Cui et al. 2015; Sisodiya et al. 2013).

Technological Turbulence (TUR) was measured by asking respondents to consider the technological change in their industry and its impact on their start-up development. The variable sought to identify if high-tech start-ups consider technological change as a tool for survival or a restriction that affects their product innovation (Santarelli and Vivarelli 2007; Su and Yang 2018). Technological turbulence was measured using a 7-point Likert scale: (1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree) (Ferreras-Méndez et al. 2016; Zobel 2017).

TABLE 1 | Descriptive data of the participants.

Respondent profile	Responses	Percentage
Respondents' age (years)		
20 to 29	32	5.8
30 to 39	91	16.4
40 to 49	167	30.0
50 and above	266	47.8
Respondents' role		
Chief Executive Officer (CEO)	466	83.8
Chief Operations Officer (COO)	14	2.5
Chief Technology Officer (CTO)	18	3.2
Director	45	8.1
Other	13	2.3
Gender		
Male	491	88.3
Female	65	11.7
Education		
Doctoral degree	106	19.1
Master's degree	177	31.8
Bachelor's degree	177	31.8
No qualifications	14	2.5
Other	82	14.7
Company background		
Type of industry		
Electrics, electronics, communications, and precision	27	4.9
Information technology, computer operation service	157	28.2
Computer programming, consultancy, and related activities	90	16.2
Telecommunications	10	1.8
Aircraft and spacecraft	13	2.3
Medical, precision, and optical instruments	41	7.4
Pharmaceuticals	46	8.3
Scientific research and development	41	7.4
Other	131	23.6
Age (years)		
1 to 3	170	30.6
4 to 6	194	34.9
7 to 9	80	14.4
More than 9	112	20.1
Size (number of employees)		
Less than 1	11	2.0
1 to 9	283	50.9
10 to 49	212	38.1
More than 50	50	9.0
Market type		
International market	389	70.0
European market in a neighboring country	18	3.2
National market	128	23.0
Local market	21	3.8
Ownership		
Headquartered outside of the United Kingdom	8	1.4
Headquartered in the United Kingdom	548	98.6

(Continues)

TABLE 1 | (Continued)

Note: $N = 556$.

3.2.2 | Dependent Variables

Exploratory Innovation (EXI) measures a start-up's intentions to create new products (Su and Yang 2018). The process sets to link new extracted ideas and conduct experiments to test prototypes and expresses the intentions of high-tech start-ups to continue expanding to generate new technologies (Limaj and Bernroider 2017; Enkel et al. 2017). *Exploitative Innovation* (EPI) evaluates the incremental enhancement and refinement of current products, services, or operations (Roberts and Dinger 2016; Bouncken and Kraus 2013; Liao et al. 2007; Cui et al. 2015). The EXI and EPI constructs were measured with five items each to assess start-ups' capability to develop new products or to extend the characteristics of current ones (Enkel et al. 2017; Jansen et al. 2005; Su and Yang 2018).

3.2.3 | Control Variables

Respondents' age and highest qualification were controlled to measure education and available tacit knowledge spillovers (Limaj and Bernroider 2017; Song et al. 2017). The respondent's current managerial position (Shafique and Kalyar 2018; Lau and Lo 2015) and their previous work experience in the same industry before working for the start-up (Song et al. 2017) were also controlled for the same reason. The characteristics of start-ups were controlled, including firm size, firm age (i.e., number of years in operation since its establishment), firm location, and industry type (Lau and Lo 2015; Jin et al. 2019).

Firms were categorized as either operating in high-tech or medium-tech sectors, as technology implementation varies by industry type and affects firms' access to specialized resources (Bengtsson et al. 2020). According to the Statistical Classification of Economic Activities in the European Community (NACE), high-tech sectors comprise industries requiring extensive technical knowledge, such as pharmaceuticals, while medium-tech industries, such as financial services, use technology to improve their operations. Therefore, start-ups were classified using the NACE list codes to distinguish between high-tech (35.3, 30, 32, 24.4, 33), knowledge-intensive high-technology services (60, 72, 73), and others in knowledge-intensive financial services (65, 66, 67).

4 | Results

Exploratory Factor Analysis was initially conducted to identify the shared variance between variables through a correlation matrix that defines constructs (Field 2018), resulting in the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy of 0.893. A reliability test was conducted on every construct by ensuring that each factor had a Cronbach's alpha above 0.7, with at least three variables for all constructs (Field 2018) (see Appendix Table A1). Additionally, *Confirmatory Factor Analysis (CFA)* was completed to cross-validate the findings (Field 2018; Blunch 2012). The model engulfing only the reflective constructs produced a good fit (CMIN = 2.720, CFI = 0.937, SRMR = 0.060, RMSEA = 0.056, PClose = 0.042, and Chi-square = 587.5) (Hu and Bentler 1999; Bentler and Hu 1998).

Next, Partial Least Squares analysis was conducted using SmartPLS 2.0 to test the model for including the formative constructs of network and knowledge spillovers (Chen and Chang 2016; Limaj and Bernroider 2017; Sisodiya et al. 2013; Cui et al. 2015). The PLS-SEM approach enables the evaluation of reflective and formative constructs on composite models (Benitez et al. 2020). Table 2 summarizes the Composite Reliability (CR) and average variance extracted (AVE) for the reflective constructs of absorptive capacity and product innovation. Overall, the results support reliability and convergent validity for the reflective constructs using the criteria proposed.

The Variance Inflation Factors (VIF) analysis for the seven dimensions of the formative INKS and NKS constructs all passed the cut-off criteria of 10, with a maximum value of 2.093. The results prove that the formative constructs did not have collinearity problems. For Network Knowledge Spillovers, the variables related to suppliers (NKS2), clients (NKS3), and universities (NKS5) were significant. In the case of Incoming Knowledge Spillovers, variables linked to scientific publications (NKS3) and access to online communities (NKS5) were significant for start-ups (Table 3).

The different variations of the structure model were analyzed using bootstrapping with five thousand subsamples, a Bias-Correlated and Accelerated (BCa) Bootstrap, and a two-tailed test with a significance level of 0.1 (see Table 4).

Model 1a was further analyzed, assessing the direct effects of constructs with no control variables. Model 1b ran the base model except for testing the moderating effects of incoming knowledge spillovers, network knowledge spillovers, and technological turbulence. The models showed that PAC significantly positively affected RAC ($\beta = 0.609$, $t = 15.511$ $p < 0.001$), and PAC had a direct positive effect on exploratory innovation (EXI) ($\beta = 0.122$, $t = 2.032$ $p < 0.05$) and EPI ($\beta = 0.111$, $t = 1.895$, $p < 0.05$). Hence, Hypotheses 3 and 4a are supported. In addition, the direct relations of RAC and innovation showed a robust positive effect on EXI ($\beta = 0.349$, $t = 6.014$ $p < 0.001$) and EPI ($\beta = 0.231$, $t = 4.017 < 0.0001$), supporting Hypotheses 4b and 4d.

TABLE 2 | Composite reliability, validity, and correlation table.

	CR	AVE	AQS	ASM	EPI	EXI	EXP	INKS	NKS	PAC	RAC	TRM	TUR
AQS	0.809	0.587	0.766										
ASM	0.907	0.765	0.529	0.875									
EPI	0.889	0.667	0.205	0.258	0.817								
EXI	0.899	0.747	0.301	0.326	0.247	0.864							
EXP	0.885	0.72	0.42	0.579	0.274	0.482	0.848						
INKS	na	na	0.418	0.332	0.217	0.263	0.296	na					
NKS	na	na	0.428	0.292	0.042	0.088	0.22	0.435	na				
PAC	0.863	0.519	0.824	0.916	0.269	0.36	0.586	0.419	0.397	0.72			
RAC	0.912	0.598	0.428	0.625	0.318	0.448	0.918	0.308	0.224	0.621	0.773		
TRM	0.888	0.665	0.381	0.585	0.315	0.362	0.734	0.279	0.2	0.571	0.943	0.816	
TUR	0.848	0.657	0.159	0.227	0.168	0.249	0.29	0.212	0.217	0.227	0.277	0.23	0.81

TABLE 3 | Quality criteria of formative measurement.

Formative constructs	Dimensions	Weights	VIF	*p*
Network Knowledge Spillovers (NKS)	1. Organizations or start-ups	0.095	1.416	0.42
	2. Suppliers	0.199*	1.275	0.045
	3. Clients or customers	0.735***	1.253	0
	4. Competitors	0.05	1.515	0.663
	5. Universities or research institutions	0.497***	1.771	0
	6. Consultants	−0.187	1.604	0.086
	7. Government	−0.058	2.093	0.625
Incoming Knowledge Spillovers (NKS)	1. Reading white papers	0.222	1.402	0.091
	2. Attending conferences or exhibitions	−0.066	1.637	0.637
	3. Scientific journals or publications	0.356*	1.628	0.039
	4. Companies or associations	0.609***	1.461	0
	5. Online communities	0.207	1.231	0.083

***$p < 0.001$.
*$p < 0.05$.

TABLE 4 | Initial models analyzed and description.

Name	Description	Rationale
Model 1a	Not including control variables and TUR construct	Analysis run to develop an adequate model
Model 1b	Assessing moderation effects of knowledge spillovers between RAC and EXI, EPI and TUR	
Model 1c	Assessing moderation effects of knowledge spillovers between RAC and TUR with EXI and EPI	
Model 2	Moderating effects of Incoming Knowledge Spillovers (INKs) and TUR on RAC, EXI, and EPI	Focused on the evaluation of the types of companies and background of entrepreneurs
Models 2 a and b	Extension by evaluating the types of high-tech start-ups, KIBS, and other companies	
Models 3 a, b, c and d	Evaluation of entrepreneurs that hold a BA, MSc, PhD, and other titles	

In evaluating the effects of knowledge spillover sources, INKS presented a positive level of significance with PAC ($\beta = 0.304$, $t = 6.97$, $p < 0.001$). However, the INKS *t*-values with the construct of RAC generated a *t*-statistic below 1.96 with a *p*-value of 0.107. Thus, it can be stated that Hypothesis 1a is supported, while hypothesis 1b is not supported.

Likewise, NKS had a strong positive and significant effect with PAC ($\beta = 0.265$, $t = 6.078$, $p < 0.001$), supporting Hypothesis 2a. NKS had a negative effect on RAC that was not statistically significant ($\beta = -0.05$, $t = 1.188$, $p < 0.1$), rejecting Hypotheses 2b. These results suggest that knowledge spillovers positively affect high-tech start-ups during the acquisition and assimilation processes. However, incoming knowledge spillovers can be detrimental to the innovation process in product development and innovation stages. The hypotheses are summarized in Table 5.

Next, we evaluated the direct moderated effect of technological turbulence and the knowledge spillover constructs on innovation (Model 1b). In this case, incoming and network knowledge spillovers (INKS and NKS) lost statistical significance. There was statistical evidence of a negative moderating effect from incoming knowledge spillovers between RAC and exploratory innovation (EXI) ($\beta = -0.178$, $t = 2.638$, $p < 0.01$). Therefore, it can be stated that the perception of constant technological changes affected high-tech start-up's capability to generate new products.

We also evaluated the moderating effect of knowledge spillovers between PAC and RAC (Model 1c) and found that INKS negatively moderated PAC and EXI ($\beta = -0.155$, $t = 3.265$, $p < 0.001$). The evidence suggests that the influence of other firms and institutions could be detrimental during the development of prototypes and minimum viable products. In addition,

TABLE 5 | Summary of the hypothesis test.

Hypotheses		Empirical evidence
Hypothesis 1a	Network knowledge spillovers have a positive effect on the potential absorptive capacity of High-Tech start-ups	Supported
Hypothesis 1b	Network knowledge spillovers positively affect the realized absorptive capacity of High-Tech start-ups	Not supported
Hypothesis 2a	Incoming knowledge spillovers have a positive effect on the potential absorptive capacity of high-tech start-ups	Supported
Hypothesis 2b	Incoming knowledge spillovers positively affect the realized absorptive capacity of high-tech start-ups	Not supported
Hypothesis 3	Potential absorptive capacity has a positive effect on realized absorptive capacity	Supported
Hypothesis 4a	Potential absorptive capacity has a positive relationship with exploratory innovation in high-tech start-ups	Supported
Hypothesis 4b	Realized absorptive capacity has a positive relationship with exploratory innovation in high-tech start-ups	Supported
Hypothesis 4c	Potential absorptive capacity has a positive relationship with exploitative innovation in high-tech start-ups	Supported
Hypothesis 4d	Realized absorptive capacity has a positive relationship with exploitative innovation in high-tech start-ups	Supported
Hypothesis 5a	Technological turbulence has a positive effect on start-ups exploratory innovation	Supported
Hypothesis 5b	The effect of realized absorptive capacity on exploratory innovation is moderated by technological turbulence	Supported

technological turbulence (TUR) had a direct positive effect on exploratory innovation (EXI), indicating that start-ups that developed new products took advantage of the development of current technology ($\beta = 0.094$, $t = 2.248$, $p < 0.05$). The summary of the bootstrapping results is illustrated in Table 6.

From the three models, we can state that the two first-order formative dimensions of knowledge spillovers only directly affected PAC. In addition, NKS positively affected the product innovation dimensions. However, NKS could cause a negative moderating effect between potential and realized absorptive capacity (PAC and RAC), confirming that the positive results of knowledge were obtained during the firm's acquisition and assimilation stages of information. Moreover, technological turbulence (TUR) directly affected absorptive capacity and exploratory innovation; however, if the change in technology moderated or restricted how the firm operated to generate new products, firms reduced their capability to engage in exploratory innovation.

Model 2 showed that the founders' individual experience involving either CEO, COO, or CTO, which was represented by the age of the entrepreneur, was only negatively significant for high-tech firms towards exploratory innovation (EXI) ($\beta = -0.121$, $t = 2.644$, $p < 0.01$). Interestingly, firm size had only a significant effect on relevance for medium high-tech start-ups and KIBS towards the engagement of EPI ($\beta = 0.176$, $t = 3.785$, $p < 0.001$). Regarding TUR, technological turbulence changes directly affected EPI on KIBS and medium high-tech firms ($\beta = 0.826$, $t = 2.573$, $p < 0.05$). On the other hand, high-tech start-ups could be affected positively by rapid technological environments on exploitative innovation of existing products (EXI) ($\beta = 0.131$, $t = 2.371$, $p < 0.05$). Moreover, TUR presented a small negative moderating effect between realized absorptive capacity and exploratory innovation.

Regarding knowledge spillovers, KIBS and medium high-tech start-ups were the only industries that could absorb NKS during start-up activities involving RAC ($\beta = 0.243$, $t = 2.046$, $p < 0.05$). The empirical results suggest that firms in this category only focused on engaging in innovation that involved implementing new technologies.

Next, we assessed if the level of academic qualifications illustrated differences among entrepreneurs in Model 3. The firm size indicated a positive statistical significance towards exploratory innovation (EXI) for entrepreneurs that held a bachelor's degree ($\beta = 0.143$, $t = 2.517$, $p < 0.05$) and Master's in Arts or Science (MBA/MSc) ($\beta = 0.143$, $t = 2.492$, $p < 0.05$). Hence, entrepreneurs with a higher or no academic background believed hiring human capital was not required to access tacit knowledge spillovers to engage in product innovation.

Entrepreneurs that held doctoral degrees preferred to develop new forms of products and expand on knowledge. The statement was proven by the strong statistical significance between RAC and exploratory innovation (EXI) ($\beta = 0.334$, $t = 3.105$, $p < 0.001$). Furthermore, the same statistical effect on EXI was evidenced for those with a Master's degree ($\beta = 0.243$, $t = 2.87$, $p < 0.01$). Therefore, we can state that academic qualifications raised awareness that rapid technological change influenced new products' development. Finally, evidence suggests that by comparing all the groups by qualification, only entrepreneurs with a PhD sensed that technological turbulence could negatively affect

TABLE 6 | Results of the PLS path model analysis for Model 1.

Path	Model 1a		Model 1b		Model 1c	
	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value
NKS → EPI	0.153	1.813	0.217	1.83	0.173	1.842
NKS → EXI	0.15**	2.727	0.065	1.101	0.093	1.7
NKS → PAC	0.304***	6.97	na	na	na	na
NKS → RAC	0.074	1.598	na	na	0.052	1.321
INKS → EPI	−0.12	1.793	0.129	1.053	na	na
INKS → EXI	−0.104*	2.241	−0.056	0.99	na	na
INKS → PAC	0.265***	6.078	na	na	na	na
INKS → RAC	−0.05	1.188	na	na	−0.016	0.693
PAC → AQS	0.825***	44.786	0.818***	41.657	0.818***	41.789
PAC → ASM	0.916***	117.763	0.92***	131.504	0.92***	132.99
PAC → EPI	0.111	1.895	0.046	0.827	0.042	0.781
PAC → EXI	0.122*	2.032	0.078	1.475	0.077	1.431
PAC → RAC	0.609***	15.511	0.622***	17.645	0.555***	13.142
RAC → EPI	0.231***	4.017	0.174**	3.084	0.165**	2.904
RAC → EXI	0.349***	6.014	0.238***	4.661	0.255	5.217
RAC → EXP	0.917***	105.708	0.917***	104.476	0.917	105.144
RAC → TRM	0.944***	165.279	0.944***	163.474	0.944	162.364
NKS × PAC → EXI			−0.178**	2.638	−0.155**	3.265
TUR → EPI					0.052	1.238
TUR → EXI					0.094*	2.248
TUR × RAC → EXI					−0.225**	3.469

***Significant at the 0.001-level ($p < 0.001$).
**Significant at the 0.01-level ($p < 0.01$).
*Significant at the 0.05-level ($p < 0.05$).

exploratory innovation ($\beta = -0.41$, $t = 6.13$, $p < 0.001$). The statistics of models 2 and 3 are shown in Table 7.

5 | Discussion

5.1 | Influence of Knowledge Spillovers on Product Innovation

Previous research indicates that high-tech start-ups primarily utilize knowledge spillovers during the potential absorptive capacity phase, with a focus on exploratory innovation driven by R&D investments and skilled human capital (Audretsch et al. 2020). While our findings confirm this general pattern, we caution that continued reliance on additional knowledge spillovers during the research phase may hinder exploratory innovation by introducing redundant or misaligned inputs. This highlights the importance of strategically managing spillovers to maximize their utility during the early stages of innovation. Technological change can spur significant breakthroughs, particularly when entrepreneurs actively experiment and engage in market testing. Similarly, to Ferreira et al. (2023), we have identified that start-ups purposefully seek knowledge spillovers as part of their open innovation strategies. However, we further prove that openness to knowledge and implementation depends on whether the new venture is a medium or high-tech start-up. Companies seeking exploitative innovation tend to leverage knowledge spillovers throughout all innovation processes by utilizing technological tools. In contrast, high-tech start-ups often begin with open innovation but eventually transition to using in-house resources to pursue exploratory innovation. This aligns with Li and Deng (2024), who highlight that entrepreneurs are motivated to enhance product quality and secure private funding.

In contrast, medium-tech start-ups exhibit a distinct pattern of leveraging knowledge spillovers throughout the product development lifecycle. Unlike high-tech firms, they continue to rely on spillovers even after initial product implementation. These spillovers help sustain R&D budgets and drive iterative innovation, enabling medium-tech firms to compete effectively with established market players (Audretsch et al. 2021). This cyclical

TABLE 7 | Results of the PLS path model analysis for Model 2 and Model 3.

Path	Model 2a (High-tech companies)		Model 2b (KIBS and other companies)		Model 3a (Bachelor's degree)		Model 3b (MA/MSc)		Model 3c (Other qualifications or none)		Model 3d (PhD)	
	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value
Age company → EPI	0.067	1.442	0.011	0.151	0.051	0.803	0.051	0.8	−0.04	0.43	0.233*	2.488
Age company → EXI	−0.046	0.83	0.016	0.302	−0.059	0.768	−0.059	0.762	−0.111	1.128	0.087	1.299
Age entrepreneur → EPI	−0.121**	2.644	−0.066	0.859	−0.032	0.495	−0.032	0.5	−0.049	0.381	−0.217**	2.651
Age entrepreneur → EXI	−0.022	0.455	0.008	0.109	0.063	0.894	0.063	0.903	−0.081	0.967	−0.043	0.639
Firm size → EPI	0.011	0.2	0.176***	3.785	0.04	0.541	0.04	0.541	0.163	1.343	0.067	0.721
Firm size → EXI	0.047	1.025	0.058	1.09	0.143*	2.517	0.143*	2.492	0.014	0.189	−0.103	0.987
NKS → EPI	0.255	1.794	0.032	0.289	0.169	1.406	0.169	1.421	−0.24	0.914	0.173	1.042
NKS → EXI	0.088	1.114	0.1	0.962	0.316	2.9	0.316**	2.864	0.114	0.61	0.036	0.367
NKS → PAC	0.267***	4.028	0.384***	5.528	0.228	2.59	0.228*	2.594	0.28*	2.346	0.478***	5.439
NKS → RAC	0.096	1.293	0.243*	2.046	0.019	0.181	0.019	0.181	−0.091	0.495	0.209	1.601
NKS × PAC → RAC	−0.017*	2.023	−0.009	0.774	0.008	0.742	0.008	0.736	0.017	0.849	−0.026	1.858
INKS → EPI	−0.22*	2.497	0.005	0.048	−0.056	0.493	−0.056	0.498	0.093	0.386	0.156	1.129
INKS → EXI	−0.093	1.514	−0.133	1.659	−0.188	1.682	−0.188	1.702	−0.131	1.012	0.019	0.212
INKS → PAC	0.282***	4.867	0.264***	3.847	0.312	3.548	0.312**	3.701	0.304**	2.87	0.271**	3.079
INKS → RAC	0.013	0.242	−0.034	0.415	−0.065	0.796	−0.065	0.81	−0.129	0.764	0.087	0.924
PAC → AQS	0.833***	41.949	0.803***	18.746	0.822	21.925	0.822***	22.396	0.763***	9.832	0.896***	38.295
PAC → ASM	0.916***	100.291	0.916***	67.895	0.926	75.327	0.926***	75.597	0.91***	46.478	0.938***	61.47
PAC → EPI	0.076	1.133	0.077	0.676	0.163	1.744	0.163	1.71	0.068	0.468	−0.084	0.512
PAC → EXI	0.101	1.343	0.114	1.118	0.011	0.107	0.011	0.104	0.159	1.069	0.009	0.085
PAC → RAC	0.74***	10.219	0.587***	5.836	0.583	5.944	0.583***	7.491	0.402*	2.115	0.854***	8.356
RAC → EPI	0.224	1.662	0.687**	2.456	0.555	2.287	0.555*	2.305	0.561*	2.065	0.107	0.363
RAC → EXI	0.221***	3.638	0.296***	3.549	0.243	2.856	0.243**	2.87	0.141	1.327	0.334**	3.105
RAC → EXP	0.903***	78.4	0.94***	77.781	0.918	59.135	0.918***	59.038	0.898***	40.871	0.937***	54.959

(Continues)

approach to leveraging both exploratory and exploitative innovation suggests that medium-tech start-ups utilize open innovation practices to enhance performance and innovation outcomes, thereby positioning themselves competitively in both local and international markets (Ferreira et al. 2023). Our findings reveal that realized absorptive capacity is pivotal for both high- and medium-tech start-ups but is utilized differently across these contexts. For high-tech firms, realized absorptive capacity is crucial for focused new product development, as its impact diminishes when start-ups diversify excessively into similar products. This extends prior studies highlighting its role in enhancing project performance, particularly in sectors such as auto parts manufacturing (Khan et al. 2019) and imitation strategies. For medium-tech firms, realized absorptive capacity drives iterative product improvement by enabling the extensive use of delayed spillover effects to enhance existing processes within entrepreneurial ecosystems (Sears and Muhammad 2024).

5.2 | Influence of Start-Up Characteristics by Sector

Our findings reveal that the background and expertise of entrepreneurs play a crucial role in shaping the innovation strategies of start-ups, particularly by sector. High-tech firms significantly benefit from founders with deep domain expertise, enabling them to enhance existing products effectively. Conversely, medium-tech start-ups can overcome a lack of founder experience by hiring skilled human capital to access external knowledge spillovers. Importantly, neither the age of the entrepreneur nor the size of the firm directly influences exploratory innovation. This finding suggests that it is the established processes and technological capability, instead of firm demographics, that drive unique product development.

These results confirm previous research indicating that high-tech firms depend heavily on technological expertise and their stock of knowledge. This knowledge is enhanced through R&D employee training and the establishment of knowledge-sharing processes. In contrast, medium-tech start-ups strategically rely on external resources to address capability gaps. This aligns with Ozdemir et al. (2024), who found that companies use digital technologies to extract knowledge spillovers, enhancing not only innovation but also operational efficiency.

Firm size presents a more nuanced dynamic. While smaller firms are often recognized for their flexibility in adapting to technological changes, larger firms may use their resources to amplify innovation performance (Molina-Castillo et al. 2022). Our study further demonstrates that increases in the number of employees specifically enhance exploratory innovation in firms led by entrepreneurs with bachelor's or master's degrees. Founders in these categories strategically hire talent to access external knowledge spillovers, thereby augmenting their firms' absorptive capacity. These findings contribute to a refined understanding of how sectoral differences shape start-up innovation dynamics. High-tech start-ups rely on their founders' expertise as a pivotal driver of innovation, while medium-tech firms compensate by strategically utilizing external talent to access and exploit knowledge spillovers. This demonstrates that the relationship between firm size and innovation performance

TABLE 7 | (Continued)

Path	Model 2a (High-tech companies)		Model 2b (KIBS and other companies)		Model 3a (Bachelor's degree)		Model 3b (MA/MSc)		Model 3c (Other qualifications or none)		Model 3d (PhD)	
	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value	Std coeff.	*t*-value
RAC → TRM	0.931***	112.815	0.961***	138.485	0.954	124.791	0.954***	123.399	0.924***	50.521	0.953***	75.213
TUR → EPI	0.072	0.412	0.826*	2.573	0.553	2.007	0.553*	2.009	0.772	1.69	0.155	0.456
TUR → EXI	0.131*	2.371	0.04	0.643	0.1	1.209	0.1	1.245	0.285*	2.527	−0.01	0.16
TUR × RAC → EXI	−0.158*	2.17	−0.3*	4.743	−0.16	1.309	−0.16	1.314	−0.286	0.953	−0.41***	6.13
TUR × RAC → EPI	−0.005	0.253	−0.077	1.987	−0.052	1.509	−0.052	1.521	−0.093	1.612	0.002	0.041

***Significant at the 0.001-level ($p < 0.001$).
**Significant at the 0.01-level ($p < 0.01$).
*Significant at the 0.05-level ($p < 0.05$).

is mediated by the founder's educational background and the firm's ability to deploy external resources effectively. Moreover, our findings expand on existing research, such as studies on universities, where firm size is linked to innovation targeting specific market technologies (Schenkenhofer et al. 2024).

5.3 | Influence of the Entrepreneur's Characteristics

Entrepreneurs' backgrounds and prior experience play a critical role in shaping how start-ups leverage knowledge spillovers for innovation. Our findings reveal that founders' educational qualifications and strategic decisions significantly influence innovation pathways. For instance, older entrepreneurs with doctoral degrees may struggle with exploitative innovation, possibly due to a bias against improving existing products rooted in their market familiarity. In contrast, entrepreneurs with master's degrees actively invest in human capital to explore new technologies and foster growth through collaboration (Jiang et al. 2023). Our analysis further indicates distinct differences in how entrepreneurs with varying educational backgrounds engage with innovation. Founders with doctoral degrees tend to prioritize exploitative innovation, focusing on incremental improvements to existing technologies. They often leverage their academic status to secure funding and participate in government projects, collaborating with universities to develop new products (Jiang et al. 2023).

High-tech firms rely heavily on skilled human capital to boost performance and secure resources, a dynamic consistent with previous findings on R&D-focused organizations (Nielsen 2015; Korber et al. 2022). However, our research shows that this strategy is even more effective for medium-tech start-ups, where hiring human capital enhances the knowledge base of both the company and its founders. While openness to knowledge sharing can lead to positive spillovers, it may also cause negative effects—particularly for high-tech firms, where R&D processes are highly sensitive to external influences (Ritala et al. 2018).

We extend prior research by demonstrating that knowledge spillovers in medium-tech companies significantly enhance realized absorptive capacity (RAC) processes, which, in turn, boost exploitative product innovation. Collaboration with external partners—including universities, customers, and suppliers—is another key driver of innovation. Literature emphasizes that R&D partnerships can improve product quality, reduce costs, and enable entry into new markets (Kim and Kim 2022). Furthermore, we demonstrate that start-up firms can absorb diverse types of incoming and network knowledge spillovers during the potential absorptive capacity (PAC) phase. These spillovers include contributions from companies within the value chain, universities, consultants, and government institutions during the RAC phase (Kim and Kim 2022). However, uncontrolled network spillovers can hinder effective implementation, as evidenced in collaborative projects that lack clear structures for information sharing (Le Roy et al. 2024). Finally, Recent studies support our findings, showing that medium-tech start-ups effectively use alliances and technological tools to manage spillovers. We further contribute to the literature by identifying that these effects are also likely to occur in high-tech start-ups focused on exploratory innovation.

6 | Conclusion

The foundations of knowledge spillovers are intrinsically tied to entrepreneurs' backgrounds and prior experiences, shaping the initial operations and strategic directions of start-ups (Schmidt 2015). Traditional metrics, such as employee count and years of operation, have been widely used to evaluate new ventures (Jin et al. 2019; Zobel 2017). However, this study demonstrates that these metrics alone are insufficient to capture the complex dynamics of innovation. A critical contribution of this study is the application of knowledge spillover dimensions as formative constructs (Laursen and Salter 2006; Belderbos et al. 2018; Sisodiya et al. 2013). Our findings confirm that start-ups effectively gather network and incoming knowledge spillovers during the PAC phase. Furthermore, RAC is indispensable for the development of new products, demonstrating that absorptive capacity processes are not uniform but rather contingent upon the specific characteristics of the start-up and the sector in which it operates.

This study also validates the use of formative constructs for knowledge spillovers in structural equation modeling. While previous research often treated these variables as reflective, our findings support their use as formative dimensions, particularly the depth and breadth construct commonly employed in innovation research (Bengtsson et al. 2015; Lazzarotti et al. 2017; Cui et al. 2015; Gölgeci et al. 2019; Jia et al. 2018). These insights provide strong evidence for policymakers to design regulations that facilitate entrepreneurial access to knowledge spillovers.

Finally, while this research establishes a robust foundation for understanding network and incoming knowledge spillovers, it also highlights areas for future exploration. Future studies could incorporate external factors such as geographical location, firm openness, and the adoption of technological tools to overcome proximity-related challenges. Longitudinal studies are particularly valuable for examining how absorptive capacity evolves over time, providing deeper insights into the mechanisms that sustain innovation. By addressing these dimensions, scholars and practitioners can refine both the theoretical and practical understanding of knowledge spillovers within entrepreneurial ecosystems.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Appendix A

TABLE A1 | Factor analysis results.

Names and items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Exploratory innovation (alpha = 0.823; CR = 0.831)						
We invent and develop new products and services			0.839			
We experiment with new products and prototypes that challenge existing ideas in our industry			0.91			
We develop new products and prototypes that are entirely new to our company			0.864			
Exploitative innovation (alpha = 0.840; CR = 0.839)						
We continuously extend the offerings of existing products and services		0.77				
We implement minor adaptations or features to existing products and services		0.895				
We continuously launch improved characteristics of existing products and services to the market		0.891				
We improve our efficiency in the delivery of products and services		0.676				
Potential absorptive capacity (acquisition) (alpha = 0.639; CR = 0.651)						
Our employees regularly visit other branches or companies				0.925		
We encourage our employees to identify and use external information sources				0.534		
We collect business and technological knowledge through informal means (Example: lunch with industry friends, talks with trade partners)				0.708		
Potential absorptive capacity (assimilation) (alpha = 0.836; CR = 0.845)						
We regularly organize and conduct internal meetings in the company to discuss new findings						0.925
We work together across the company to interpret and understand external information						0.534
External information is shared between employees						0.708
Realized absorptive capacity (transformation) (Alpha = 0.738; CR = 0.746)						
We are proficient at recording and storing relevant information for future reference	0.76					
We quickly analyze and interpret the changing demands of our product development	0.881					
New opportunities to serve our customers are quickly understood	0.901					
We quickly recognize the usefulness of new external knowledge to existing knowledge	0.803					
Realized absorptive capacity (exploiting) (Alpha = 0.774; CR = 0.776)						
We can use new technologies in new product prototypes and ideas	0.726					
We constantly consider how to exploit knowledge better	0.678					
We combine external and internal resources into novel configurations (Example: Research and Development, results, products)	0.55					

(Continues)

TABLE A1 | (Continued)

Names and items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Technological turbulence (alpha = 0.752; CR = 0.759)						
The technology in our industry is changing rapidly					0.848	
It isn't easy to forecast where our markets' technologies will be in the next five years					0.832	
A large number of new product ideas have been made possible through technological breakthroughs in our industry					0.786	