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Exploratory and exploitative linkages and innovative activity in the offshore renewable energy sector

Shane Barrett, Frank Crowley, Justin Doran and Mari O'Connor
Department of Economics, Spatial and Regional Economics Research Centre, Cork University Business School, University College Cork, Cork, Ireland

Abstract

Purpose – This paper examines the relationship between open innovation (measured by exploratory and exploitative linkages) and firm-level innovative activity in the offshore renewable energy (ORE) sector.

Design/methodology/approach – A unique, purpose-built survey that targeted firms operating in the ORE sector and its supply chain was used. The data provides novel insights into the research activities and networking capabilities of an industry in its infant stages of development. Regression models are used to estimate the relationship between firm-level external linkages and innovative activity.

Findings – Exploratory linkages are positively related to more innovative activity. This relationship is subject to diminishing returns, distinguishing the ORE sector from other sectors. Collaborating with suppliers and accessing scientific journals are conducive to research and development (R&D) activity and process innovation, whilst collaborating with customers is associated with the decision to introduce new products and processes.

Originality/value – This study provides evidence of a positive, but curvilinear, relationship between external knowledge linkages and innovative activity, adding novel insights into the relationship between open innovation (OI) strategies, research and innovation outcomes for firms predominantly in the introductory stages of the technological life cycle with limited commercialisation experience. The nuanced finding that specific linkages matter for certain research and innovation (R&I) outcomes adds deeper complexity to March's (1991) framework, where tailoring certain exploratory or exploitative linkages to specific innovation activities is important.

Keywords Research, Open innovation, Knowledge source, Exploratory linkages, Exploitative linkages

Paper type Research paper

1. Introduction

Open innovation (OI), a paradigm developed by Chesbrough (2003), emphasises the need for firms to integrate external and internal ideas and collaborations to advance technological development and innovation. Scholars have placed increasing importance on OI strategies, with external collaboration contributing to research and development (R&D) performance (Asakawa *et al.*, 2010) and the introduction of new and improved products and processes (Köhler *et al.*, 2012). However, diverse knowledge distribution among potential collaborators (Haus-Reve *et al.*, 2019) implies that certain collaborations may be more fruitful than others for distinct innovation outcomes. Indeed, as highlighted by Roper *et al.* (2022), a firm faces

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several choices related to its knowledge acquisition strategy, including whether to use exploratory (interactive) linkages or exploitative (non-interactive) linkages and who to collaborate with. This view of a firm's knowledge search strategy builds on the exploration–exploitation framework of organisational learning proposed by March (1991), whereby firms face a trade-off in their decision about allocating resources between exploring new possibilities and exploiting existing competencies. Drawing upon March's (1991) exploration–exploitation paradigm, this paper examines OI, distinguished by exploratory and exploitative linkages and their relationship to firm-level research and innovation activity within the offshore renewable energy (ORE) sector.

In recent years, despite limited commercialisation success, the ORE sector has attracted large power companies and increased investment (Jay and Jeffrey, 2010; Roesch *et al.*, 2020). The unstandardized nature of products, the diversity of firms and the number of revisions to existing policy initiatives show high levels of learning, experimentation, investment and innovation in the sector (Jeffrey *et al.*, 2013; Richter, 2013). ORE technologies have, to date, performed below initial energy power expectations; however, they are still considered an emerging field capable of becoming an integral part of the future energy mix (Corsatea and Magagna, 2013; MacGillivray *et al.*, 2015). To fully capitalise on this, there is a need to boost research and innovation as an important precondition for the large-scale deployment of ORE (European Commission, 2020). Firms' OI strategies could hold the key to achieving greater success in ORE commercialisation.

This study makes four distinct contributions to the existing OI and organisational learning literature. Firstly, since March's (1991) foundational work, the existing literature has underexamined the importance of exploitative linkages (see, for example, Christensen *et al.*, 2019; Wang *et al.*, 2020). This is despite the literature highlighting that exploitative linkages are a critical source of knowledge for research and innovation (R&I) (Roper *et al.*, 2017), with a limited number of papers discussing both exploratory and exploitative linkages within the same study (Cassiman and Valentini, 2016; Roper *et al.*, 2017, 2022). As a result, there is an acknowledged lack of clarity on which type of links (exploratory versus exploitative) are more important for firm R&I. This paper addresses this dearth of clarity by considering both exploratory and exploitative linkages and their comparative impacts on R&I outcomes in the ORE sector.

Secondly, this paper acknowledges that exploratory and exploitative links are broad dichotomies of individual linkages and that there is considerable within-category heterogeneity. Previous literature has examined the effects of external search breadth as a whole (Asimakopoulos *et al.*, 2020; Laursen and Salter, 2014; Love *et al.*, 2014), with less focus on the effect each individual type of linkage has on innovative activity (O' Connor *et al.*, 2021). This is a limitation of existing literature, and Ardito and Petruzzelli (2017, p. 270) call for more work to be undertaken to examine the "relative significance of each search channel" in stimulating innovation. Additionally, according to Subtil Lacerda and van den Bergh (2020), the question of how best to coordinate a knowledge sourcing strategy remains unanswered in the case of renewable energy. This paper directly addresses these calls for further research by explicitly disaggregating exploratory and exploitative linkages into their individual parts to analyse the heterogeneity of their impact on firms' R&I outcomes.

Thirdly, the ORE sector predominantly consists of SMEs operating in the introductory stages of the technological life cycle, with limited commercialisation experienced to date (Corsatea and Magagna, 2013). Consequently, the ORE sector presents a unique case in which to explore the links between OI and firm R&I. For instance, most studies find a curvilinear relationship between knowledge linkages and firm-level R&I activities. However, Asimakopoulos *et al.* (2020) argue that high-tech firms can better mitigate the costs associated with excessive knowledge sourcing, leading to a flattened, inverted U-shaped curve. This paper considers whether a young high-tech sector like ORE (i.e. data suggests high levels of R&D activity across firm operators) exhibits a positive but diminishing relationship between the diversity of exploratory and exploitative linkages and R&I outcomes. This is an important contribution as it allows for insights into whether a *nascent and emerging* sector like ORE, characterised by its high level of R&D activity, exhibits similar curvilinear external linkages–R&I patterns, as other high-tech industries.

Finally, many of the existing studies on the ORE sector adopt an innovation systems approach at the national level (Corsatea, 2014; van der Loos *et al.*, 2021). This study adopts a firm-level approach using a unique, purpose-built survey that targeted firms operating in the ORE sector and its supply chain. The survey provides novel insights into the R&I activities of firms within the sector. It does so in two ways. First, the inclusion of five distinct R&I activities provides a comprehensive insight into firm innovation in ORE, including measures on: (1) internal research and development, (2) external research and development, (3) new-to-firm product innovation, (4) new-to-market product innovation and (5) process innovation. The consideration of these diverse types of R&I activity is increasingly considered essential in innovation research (Perez-Alaniz *et al.*, 2023). Second, through the inclusion of the vast networking capabilities and linkages of each surveyed firm, novel insights are gleaned into an industry that is at the infant stages of development and consists of many diverse actors.

2. Literature review

2.1 Open innovation

Since Chesbrough's (2003) first book, OI has garnered significant popularity as a research topic and an innovation strategy (West and Bogers, 2014). OI is defined as "a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, 2006, p. 2). A company's openness to outside agents and knowledge flows is often necessary for the development and commercialisation of breakthrough technology (Chesbrough, 2006; West and Bogers, 2014). Whilst new knowledge can arise from inside the firm, it is most likely to originate outside of it (Roper and Love, 2018). Thus, OI is a comprehensive approach for analysing the nature of knowledge flows across organisational boundaries (Carmona-Lavado *et al.*, 2021).

Within the OI framework, Laursen and Salter (2006) introduced the concepts of search breadth and depth. Search breadth encompasses the number of external search channels that a firm draws upon for innovation purposes, whilst depth is the degree of intensity with which they engage with those external sources. The original perspective regarding search breadth is that having more linkages with external actors increases a firm's likelihood of gaining useful external knowledge that, combined with their firm's internal knowledge, leads to product innovation (Leiponen and Helfat, 2010). Thus, interactive learning and knowledge acquisition are positively affected simply by a firm's number of relationships (Roper and Love, 2018).

2.2 Open innovation, exploratory and exploitative linkages

March (1991) developed the concepts of exploration and exploitation to explain organisational learning. According to March (1991), exploration involves experimentation with new alternatives, creating uncertainty and the possibility of both positive and negative returns. It is characterised by seeking and creating new knowledge (Levinthal and March, 1993; Zhang *et al.*, 2023). Exploitation is the refinement of existing technologies and paradigms, leading to predictable and positive returns (March, 1991). Exploitation activities involve improving and refining existing knowledge (Zhang *et al.*, 2023) as it is the "use and development of things already known" (Levinthal and March, 1993, p. 105). Lee and Hemmert (2023) assert that, as exploration and exploitation involve different types of learning, they will have different effects on firm performance. Thus, firms are faced with a nuanced organisational learning tension (Ardito *et al.*, 2020), as exploratory and exploitative knowledge links require different organisational learning models, and they compete for the same resources (March, 1991).

In studies that intertwine OI and organisational learning, OI is commonly tied to March's (1991) exploration and exploitation framework. Sources of open external engagement have been described as exploratory (or interactive) linkages or exploitative (non-interactive) linkages (Hewitt-Dundas and Roper, 2011; Roper *et al.*, 2017, 2022; Zhang *et al.*, 2023). According to Roper and Love (2018), both interactive and non-interactive knowledge searches can be considered types of inbound OI. Exploratory linkages are considered linkages to customers, suppliers, consultants, competitors, research institutes and universities (Hewitt-Dundas and Roper, 2011; Wang *et al.*, 2020). Firms pursue exploratory knowledge acquisition strategies to source external knowledge from outside the firm to improve their competitive advantage (Ferreras-Méndez *et al.*, 2015; Leiponen and Helfat, 2010) and to uncover new knowledge, technologies and opportunities (March, 1991; Xia and Roper, 2016). Due to their investigative nature, exploratory linkages are more conducive to breakthrough innovations (Mention, 2011). Thus, exploratory knowledge search strategies are likely to be more important for radical innovation (Roper and Love, 2018).

In contrast, exploitative knowledge search strategies (i.e. non-interactive relationships) are employed by firms that wish to exploit *existing* knowledge, technologies and opportunities (He and Wong, 2004; Zerjav *et al.*, 2018). They include activities such as attendance at conferences, trade fairs or exhibitions; reading scientific journals, trade or technical publications; involvement with industry or trade associations and any other data source (Roper *et al.*, 2017). Exploitative relationships are the deliberate acquisition of knowledge without the direct participation of the other party (Roper *et al.*, 2017), where organisations exploit knowledge previously implemented by others (Glückler, 2013).

2.3 Diminishing returns to openness?

Leiponen and Helfat (2010) note the uncertain nature of the innovation process and that the anticipated returns from innovation are unpredictable and variable. Firms benefit from external search strategies until their absorptive capacity is exhausted (Chen *et al.*, 2011), and the marginal benefits of innovative activities diminish as the number of external connections increases (Duysters and Lokshin, 2011). Consequently, the number of external knowledge linkages and the innovation performance of the firm have been argued to follow an inverted U-shape (Leiponen and Helfat, 2010; Marullo *et al.*, 2022), previously referred to as the *paradox of openness* (Triguero and Fernández, 2018). Additionally, the attention allocation problem (Ocasio, 1997) occurs where firms have difficulty exploring new knowledge once they exceed the number of external linkages that they can effectively dedicate time and resources to (Ferreras-Méndez *et al.*, 2015; Radicic, 2021; Roper and Love, 2018).

However, technological intensity varies by sector, creating different contexts for knowledge exploration and exploitation (Sáenz *et al.*, 2009). Asimakopoulos *et al.* (2020) argue that high-tech firms (like those of ORE) are more likely to extend the benefits of external knowledge sourcing as they have a need to continuously update their internal R&D resources and capabilities, and they routinely rely on engagement with external actors to solve problems. For this reason, Asimakopoulos *et al.* (2020) argue that high-tech firms are likely to develop internal routines to better absorb and assimilate external knowledge for research returns and consequently have a greater capacity to increase external knowledge sourcing without reaching a tipping point of decreasing returns.

Based on the theoretical discussion above and the high-tech nature and early technological life cycle focus of ORE firms, the following hypotheses are proposed:

H1a. Exploratory linkages have a positive relationship with research and innovation in ORE firms, but at a diminishing rate.

H1b. Exploitative linkages have a positive relationship with research and innovation in ORE firms, but at a diminishing rate.

2.4 Individual level linkages and firm research and innovation activities

Whilst existing literature typically focuses on the importance of external knowledge search breadth at an aggregate level (Asimakopoulos *et al.*, 2020; Laursen and Salter, 2014; Love *et al.*, 2014), less is understood about the relative significance of each search channel in stimulating innovation (Ardito and Petruzzelli, 2017). According to Haus-Reve *et al.* (2019), each collaborative partner has access to different sources of knowledge and information, leading to diversity in the role they may play in a firm's knowledge network and ultimately their impact on a firm's R&I outcomes. The same logic can be applied to exploitative linkages, with some external linkages being more important than others (O' Connor *et al.*, 2021; Tomlinson, 2010).

At an early technological stage, firms are likely to explore relationships with universities and public research institutes to access basic and applied knowledge (Roper *et al.*, 2008). However, it has been cautioned that "academic research rarely produces 'prototypes' of inventions for development and commercialization by industry" (Mowery and Sampat, 2004, p. 118). Indeed, according to Haus-Reve *et al.* (2019), collaborations with universities and research institutions are typically aimed at creating new knowledge with uncertain commercial applications. This echoes Tether (2002), who theorises that universities are particularly useful for basic and long-term strategic research. Thus, the theoretical literature suggests that collaboration with universities and public research institutions is more likely to occur at the earlier stages of the innovation process, namely the R&D phase.

Exploratory linkages to suppliers may benefit firms' innovation performance as suppliers possess expertise and comprehensive knowledge regarding parts and components (Tsai, 2009). Suppliers can drive firm process innovation as their economic objectives are closely aligned (Criscuolo *et al.*, 2018), and they can provide new inputs to the firm's production processes (Un and Asakawa, 2015). Furthermore, Criscuolo *et al.* (2018) say that suppliers themselves can spur process innovation as their new technologies and components enable firms to change their production processes.

Exploratory linkages to suppliers may also positively impact firm R&D and product innovation. Petersen *et al.* (2005) argue the importance of integrating suppliers early in the new product development cycle to unlock R&D gains in supply chain, product and process design. According to Fossas-Olalla *et al.* (2015), firms' suppliers typically have more knowledge and experience about the key components of new products than the firms themselves. Empirically, existing studies highlight the positive impact of linkages to suppliers on firm product innovation (Fossas-Olalla *et al.*, 2015; Köhler *et al.*, 2012; O' Connor *et al.*, 2021), including both incremental (Hsieh *et al.*, 2018) and radical product innovation (Fossas-Olalla *et al.*, 2015; Nieto and Santamaría, 2007).

Sánchez-González and Herrera (2014) believe that cooperation with customers can encourage firms' investments that are targeted at expanding their knowledge base, including R&D. Thomä and Zimmermann (2020) highlight that experience-based knowledge, gained from exploratory learning with customers, can be an important driver of innovation for firms. The involvement of lead customers in the development of novel or complex new products reduces the likelihood of poor product design (Grimpe and Kaiser, 2010) and helps firms identify new ideas regarding products and solutions (Fernandes *et al.*, 2017), therefore reducing the risk associated with the introduction of a new product to the market (Chen *et al.*, 2011; Tödtling *et al.*, 2009). The theoretical argument for the importance of exploratory linkages to customers is reflected in much of the empirical literature, which shows a positive impact on product innovation (Kang and Kang, 2010; Stojčić, 2021) and radical product innovation specifically (Sánchez-González and Herrera, 2014).

Competitors can provide access to resources that help firms reduce costs and complementary technical knowledge that assists technology development (Radicic *et al.*, 2019; Tsai *et al.*, 2011) as well as the development of a bigger market (Ritala and Hurmelinna-Laukkanen, 2013). However, according to Ritala and Hurmelinna-Laukkanen (2013), interactions with competitors are deemed to be high-risk given the potential to lose proprietary knowledge. Un *et al.* (2010) assert that collaborations with competitors are likely to have the smallest impact on product innovation given the similarity in firms' knowledge bases. Indeed, collaboration with competitors appears to be rare in the ORE context, with Wieczorek *et al.* (2013) noting that knowledge sharing is limited by commercial competitiveness as firms do not codify their knowledge for fear of losing their competitive advantage. Given the above discussion, competitor collaborations are unlikely to occur within the ORE sector and thus, a hypothesis is not formulated to reflect this.

Based on the above discussion, the following hypotheses related to individual exploratory linkages and their impact on firm R&I activities are proposed:

H2a. Linkages with universities and research institutes are positively related to R&D activities.

H2b. Linkages with suppliers are positively related to R&D activities and new-to-firm (incremental) and new-to-market (radical) product/service innovations and process innovations.

H2c. Linkages with customers are positively related to R&D and new-to-market (radical) product/service innovations.

Whilst most of the conceptual and empirical findings highlight the significance of exploratory linkages, especially for firms in nascent high-tech industries, there is also a strong theoretical basis for firms to adopt an exploitation linkage strategy (Roper *et al.*, 2022). For example, the exploitation of existing knowledge through observations and monitoring of suppliers and competitors at conferences, trade fairs and industry association events can be a vital source of information for innovations (Bathelt and Schuldt, 2008; Maskell, 2014). Maskell *et al.* (2006) posit that such events represent "temporary clusters", acting as melting pots of knowledge, mixing local and global insights and facilitating the exchange, diffusion and absorption of industry standards and best practices among interested stakeholders. Jones and Craven (2001) proposed that trade fairs are instrumental in amplifying the innovative absorptive capabilities of SMEs by procuring valuable data on competitors' pricing and future initiatives. Fitjar and Huber (2014) highlight the positive impact of trade fairs and conferences on process innovation, which, they say, underlines the importance of more subtle forms of interaction for firm innovation performance.

Roper *et al.* (2022) found exploitative linkages such as industry associations to be more common for incremental product innovations and process innovation, as the knowledge exploited from these sources already exists in the market (Katila and Ahuja, 2002). Tödtling *et al.* (2009) highlight the significance of business connections predominantly in the commercialisation stage of the innovation process, but specifically, they are more important for firms introducing less advanced innovations.

Fleming and Sorenson (2004) postulate that grounding technological efforts in scientific knowledge (as found in publications) provides a robust foundation for firms. This approach not only streamlines their direction but also enhances the potential for radical and innovative technological advancements. Popp (2016) previously identified scientific journals to be positively related to undertaking R&D in the nonrenewable energy sector, whilst Klevorick *et al.* (1995) identified university publications as important for radical innovations in some industries.

The theoretical and empirical literature is limited to the impact of specific exploitative linkages on firm R&I activities within the ORE sector. But from the existing patterns in the general innovation literature, the following hypotheses related to the impact of exploitative linkages on firms' R&I activities are proposed:

H2d. Industry associations are positively related to new-to-firm (incremental) product/service and process innovation.

H2e. Conferences, trade fairs and exhibition attendance are positively related to new-to-firm (incremental) product/service and process innovations.

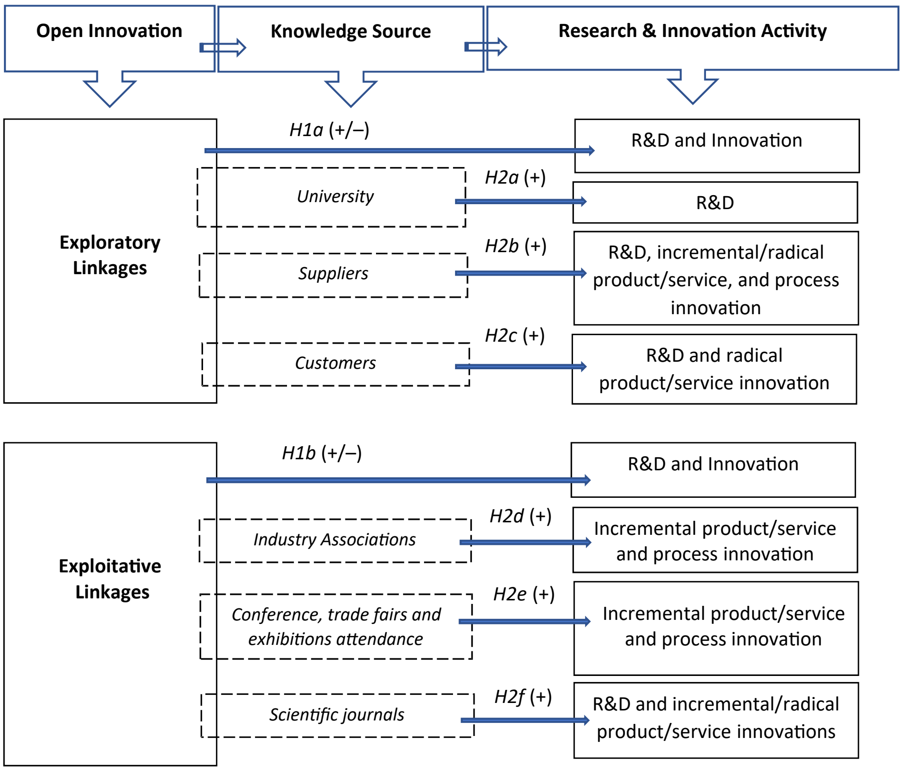
H2f. Accessing scientific journals is positively related to R&D activities and new-to-firm (incremental) and new-to-market (radical) product/service innovations.

To summarise, Figure 1 below provides an overview of the conceptual underpinnings of this study and the predicted hypotheses from Hypothesis 1a through Hypothesis 2f.

3. Research methodology

3.1 Data collection

A purpose-built survey was employed to collect the data used in this paper. The Renewable Energy Innovation Survey (REIS hereafter) is a business enterprise, innovation and



Source(s): Authors' own work

Figure 1.
Knowledge sourcing strategy and research and innovation activity in the ORE sector

environmental survey that is similar in form and content to the Community Innovation Survey (CIS) and was specifically targeted at UK and European firms operating in the ORE sector and its potential supply chain. The sampling frame population is made up of enterprises that have signalled their engagement in the offshore renewable energy sector throughout Europe through registered networks like Ocean Energy Supply Chain, Offshore Renewable Energy Catapult, the Ocean Power Innovation Network and EMEC (the European Marine Energy Centre Limited). In total, 1,368 firms comprised the sampling frame. These firms were contacted by email with follow-up calls, eliciting 231 responses and a response rate of 17.2% [1].

Table 1 provides definitions and descriptive statistics for each of the variables used in the analysis [2]. This paper employs five different types of innovation activity: internal R&D; external R&D; new-to-market innovation (radical); new-to-firm innovation (incremental) and process innovation. The definitions for these research and innovation indicators are in line with the definitions provided by the Oslo Manual (OECD, 2005).

The REIS asked respondents to indicate the number of innovation partners they collaborated with. The survey gave respondents a choice of 10 innovation partner types: consultants, suppliers, enterprises that are considered competitors, enterprises within the firms' enterprise group, other enterprises, universities or higher education institutes (HEIs), government or public research institutes, clients and customers from the public sector, clients and customers from the private sector and nonprofit organisations. Following the seminal contribution of Laursen and Salter (2006), the measurement of exploratory linkages is the sum of the number of innovation cooperation partners the firm had, a measure consistently used in the literature (Ferreras-Méndez *et al.*, 2015; Subtil Lacerda and van den Bergh, 2020).

Exploitative linkages were measured in a similar way to existing literature (Hewitt-Dundas and Roper, 2011; Roper *et al.*, 2017). Respondents were asked to indicate which non-interactive data sources were considered for their innovations. Respondents were given four options: (1) conferences and trade fairs; (2) scientific journals and/or trade publications; (3) professional and industry associations and (4) other data sources. Firms are assigned a value of 0 where they have zero exploitative linkages and a value of 4 where they have used each exploitative data source for their innovations.

3.2 Data analysis

This paper employs an innovation production function, which is a common empirical strategy in the innovation literature (Crowley, 2017; Lööf *et al.*, 2017). Equation (1) below is estimated using five distinct probit models, each examining a different type of innovative activity.

$$IA_{ih} = \beta_0 + \beta_1 Explor_i + \beta_2 Exploit_i + \beta_3 ExplorSq_i + \beta_4 ExploitSq_i + \beta_3 Z_i + \varepsilon_i \quad (1)$$

IA_{ih} refers to the innovation activities for firm i and h is the type of innovation activity (i.e. the dependent variables in the probit models). β_0 is the constant or intercept term. $Explor_i$ refers to the sum of exploratory linkages for firm i. $Exploit_i$ refers to the sum of exploitative linkages for firm i. $ExplorSq_i$ and $ExploitSq_i$ are the squared terms of exploratory and exploitative linkages, respectively. These are included to test for possible nonlinear effects (Love *et al.*, 2014). Z_i refers to several firm-specific control variables, which include firm size, firm age, percentage of the workforce with a third-level qualification, whether the firm is a recipient of subsidies and whether they are a multi-plant firm. These are standard controls within the innovation literature (Perez-Alaniz *et al.*, 2023; Roper *et al.*, 2008).

Equation (2) includes the disaggregated individual-level exploratory and exploitative linkages and is estimated using five distinct probit models.

Variable name	Definition	Mean	St Dev
In-house R&D	A binary variable which takes the value of 1 where a firm has invested in internal R&D during the years 2017–2019, 0 otherwise	0.653	0.477
External R&D	A binary variable which takes the value of 1 where a firm has invested in external R&D during the years 2017–2019, 0 otherwise	0.472	0.500
New-to-market product innovation	A binary variable which takes the value of 1 if the organisation has introduced a new or significantly improved product innovation (goods or services) to the market before their competitors (it may have already been available in other markets) during the years 2017–2019, 0 otherwise	0.497	0.501
New-to-firm product innovation	A binary variable which takes the value of 1 if the organisation has introduced a new or significantly improved product innovation (goods or services) that was only new to the enterprise during the years 2017–2019, 0 otherwise	0.386	0.488
Process innovation	A binary variable which takes the value of 1 where the firm implemented new or significantly improved methods for producing goods or providing services, logistics, delivery or distribution methods, methods for information processing or communication, methods for accounting or other administrative operations during the years 2017–2019, 0 otherwise	0.628	0.484
Exploratory linkages	Count variable which takes a value of 0–10 depending on the number of co-operation partners the organisation had as part of its innovation activity from 2017–2019. Partners could include consultants, suppliers, enterprises that are competitors, enterprises within the firms' enterprise group, other enterprises, universities or higher education institutions (HEI's), public research institutes, customers from the public sector, customers from the private sector and nonprofit organisations	3.135	3.241
Exploitative linkages	Count variable which takes the value of 0–4 depending on the number of non-interactive linkages the organisation has interacted with as part of its innovation activity. Linkages could include conferences, scientific journals, industry associations and other data sources	1.462	1.274
Customer linkages	A binary variable which takes the value of 1 where respondents had indicated they interacted with customers from the public sector or customers from the private sector, 0 otherwise	0.417	0.494
Supplier or consultant linkages	A binary variable which takes the value of 1 where respondents had indicated they interacted with suppliers or consultants, 0 otherwise	0.532	0.500
Competitor linkages	A binary variable which takes the value of 1 where respondents had indicated they interacted with competitors or enterprises in the organisation's own enterprise group or other enterprises, 0 otherwise	0.396	0.491
Public linkages	A binary variable which takes the value of 1 where respondents had indicated they interacted with universities, research institutes, nonprofit or organisations or government, 0 otherwise	0.349	0.478
Conferences	A binary variable which takes the value of 1 where respondents indicated their attendance at conferences, trade fairs or exhibitions, 0 otherwise	0.508	0.501

(continued)

Table 1.
Variable definitions and descriptive statistics

Variable name	Definition	Mean	St Dev
Scientific journals	A binary variable which takes the value of 1 where respondents had consulted scientific journals or trade/technical publications, 0 otherwise	0.422	0.495
Industry associations	A binary variable which takes the value of 1 where respondents are involved in professional associations or industry associations, 0 otherwise	0.517	0.500
Other data sources	A binary variable which takes the value of 1 where other any other data source not previously mentioned (such as internet searches) are considered for the enterprise's innovation, 0 otherwise	0.015	0.122
Employment (log)	The natural log of the number employees reported in 2019	2.346	1.953
Firm age	The natural log of a continuous variable which is calculated by subtracting the year the firm was established from the current year (2021)	2.618	1.103
% University education	The percentage of the organisation's employees who have obtained a third level qualification (i.e. university, college, HEI)	68.387	34.297
Multi-plant	A binary variable which takes the value of 1 if the organisation has more than one plant, 0 otherwise	0.442	0.497
Received subsidy	A binary variable which takes the value of 1 where an organisation has received public financial support for acquiring knowledge or innovation activities from one of or a combination of local government, regional government, national government and European-level government during the years 2017–2019, 0 otherwise	0.467	0.501
Asset owner/Operator and other type firm	This variable is a binary variable coded 1 if the company is classed as an asset owner/operator, 0 otherwise	0.101	0.301
Project developer	This variable is a binary variable coded 1 if the company is classed as a project developer, 0 otherwise	0.105	0.308
Technology supplier	This variable is a binary variable coded 1 if the company is classed as a technology supplier, 0 otherwise	0.351	0.478
Service or consultancy	This variable is a binary variable coded 1 if the company is classed as a service or consultancy provider, 0 otherwise	0.442	0.497
UK	This variable is a binary variable coded 1 if the company is based in the UK, 0 otherwise	0.512	0.501
Ireland	This variable is a binary variable coded 1 if the company is based in the Republic of Ireland, 0 otherwise	0.306	0.462
Europe	This variable is a binary variable coded 1 if the company is based in another European country other than Ireland or the UK, 0 otherwise	0.181	0.385

Source(s): Authors' own work

Table 1.

$$IA_{ih} = \beta_0 + \beta_1 Public\,Links_i + \beta_2 Suppliers_i + \beta_3 Competitors_i + \beta_4 Customers_i + \beta_5 Conferences_i + \beta_6 ScientificJournals_i + \beta_7 IndustryAssociations_i + \beta_8 OtherDataSources_i + \beta_9 Z_i + \varepsilon_i \quad (2)$$

where $Public\,Links_i$, $Suppliers_i$, $Competitors_i$ and $Customers_i$ are binary variables taking a value of 1 if a firm reported linkages with universities or public research institutions, suppliers, competitors and customers, respectively, and 0 otherwise. Likewise, $Conferences_i$, $ScientificJournals_i$, $IndustryAssociations_i$ and $OtherDataSources_i$ are a series of binary variables for the disaggregated exploitative linkages variable, which take a value of 1 if the firm engaged with conferences, scientific journals, industry associations and other data sources, respectively. They take a value of 0 otherwise.

4. Results

Table 2 displays the results from Eq. (1) for each of the five innovation activities. Table 3 indicates the results from Eq. (2). Each probit model is statistically significant [3]. Exploratory linkages are significant, as indicated in equation (1), but exploitative links are insignificant. A comparison of the results from equation (1) in Table 2 with those of equation (2) in Table 3 reveals a mix of significant outcomes for individual linkages, when contrasted with the synergistic effects of exploratory linkages (Table 2). This highlights the importance of combining numerous interactions, rather than relying on a few individual links. This is especially true for exploratory interactions.

Variables	In-house R&D	External R&D	New-to-market	New-to-firm	Process innovation
Exploratory linkages	0.251***	0.199***	0.121***	0.123***	0.279***
	(0.041)	(0.044)	(0.043)	(0.040)	(0.041)
Exploitative linkages	−0.046	−0.127	−0.005	−0.109	−0.078
	(0.124)	(0.134)	(0.121)	(0.115)	(0.131)
Exploratory linkages^2	−0.023***	−0.016***	−0.006	−0.007*	−0.023***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Exploitative linkages^2	0.039	0.074*	0.010	0.042	0.051
	(0.040)	(0.043)	(0.039)	(0.036)	(0.044)
Firm size (log)	0.001	0.025	0.036	−0.009	0.099***
	(0.024)	(0.028)	(0.025)	(0.024)	(0.023)
Firm age (log)	0.061	−0.032	−0.038	0.016	−0.074*
	(0.047)	(0.051)	(0.044)	(0.042)	(0.039)
% University education	0.003**	−0.000	−0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Multi plant	0.165**	0.085	0.163**	−0.020	−0.100
	(0.071)	(0.087)	(0.082)	(0.077)	(0.084)
Received subsidy	0.212**	0.176*	0.036	0.046	0.114
	(0.083)	(0.091)	(0.093)	(0.084)	(0.088)
Project developer	0.264***	0.157	0.350***	−0.106	0.265***
	(0.047)	(0.193)	(0.131)	(0.155)	(0.086)
Technology supplier	0.376***	0.325**	0.187	−0.022	0.216*
	(0.080)	(0.144)	(0.120)	(0.130)	(0.113)
Service or consultancy	0.015	0.090	0.085	−0.106	0.209*
	(0.104)	(0.157)	(0.118)	(0.129)	(0.119)
European	0.038	0.124	−0.048	−0.299***	−0.111
	(0.105)	(0.121)	(0.124)	(0.077)	(0.132)
Irish	−0.259**	−0.073	−0.102	−0.172**	0.030
	(0.110)	(0.102)	(0.097)	(0.082)	(0.091)
Observations	199	199	199	199	199
Wald Chi-square	98.51	65.85	56.13	40.61	92.90
(prob)	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)
Pseudo R^2	0.504	0.317	0.233	0.169	0.418

Note(s): Robust standard errors in parentheses
***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$
Reference categories: Asset operators, asset owner/operator and other-type firm and UK
Source(s): Authors' own work

Table 2. Output from Eq. (1) reporting marginal effects

Variables	In house R&D	External R&D	New-to-market	New-to-firm	Process innovation
Public linkages	0.336***	0.266***	0.002	0.002	0.259***
	(0.095)	(0.102)	(0.110)	(0.101)	(0.092)
Supplier/Consultant linkages	0.423***	0.311***	0.111	0.080	0.282***
	(0.099)	(0.105)	(0.103)	(0.104)	(0.093)
Competitor linkages	−0.113	−0.046	0.230**	0.218**	0.026
	(0.118)	(0.123)	(0.105)	(0.102)	(0.102)
Customer linkages	−0.163	−0.014	0.226**	0.180*	0.205**
	(0.107)	(0.116)	(0.099)	(0.101)	(0.097)
Scientific journals	0.312***	0.288***	−0.034	0.059	0.248***
	(0.083)	(0.109)	(0.112)	(0.104)	(0.085)
Conferences	−0.053	0.011	−0.083	−0.092	0.052
	(0.094)	(0.116)	(0.107)	(0.101)	(0.097)
Industry associations	−0.075	−0.035	0.208**	0.098	−0.111
	(0.094)	(0.120)	(0.097)	(0.090)	(0.095)
Other data sources	−0.119	0.233	0.311	0.347	0.080
	(0.184)	(0.257)	(0.248)	(0.293)	(0.256)
Employment (Log)	0.023	0.040	0.029	−0.015	0.106***
	(0.023)	(0.027)	(0.026)	(0.025)	(0.024)
Firm age (Log)	0.023	−0.036	−0.039	0.021	−0.099**
	(0.042)	(0.049)	(0.044)	(0.042)	(0.041)
% University education	0.002**	−0.001	−0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Multi plant	0.133*	0.100	0.176**	0.003	−0.075
	(0.069)	(0.089)	(0.084)	(0.076)	(0.085)
Received subsidy	0.167**	0.142	0.057	0.059	0.119
	(0.082)	(0.094)	(0.099)	(0.088)	(0.088)
Observations	199	199	199	199	199
Wald Chi-square (prob)	110.00	71.02	63.08	39.43	91.05
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)
Pseudo R^2	0.539	0.321	0.256	0.171	0.420

Note(s): Robust standard errors in parentheses
***$p < 0.01$, **$p < 0.05$ and *$p < 0.1$
Firm type and country controls included but not reported
Source(s): Authors' own work

Table 3. Output from Eq. (2) reporting marginal effects

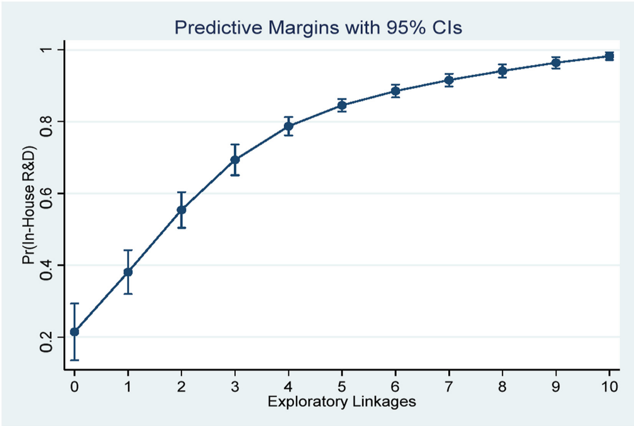
Customers are deemed more crucial for product and process innovation, whereas interactions with suppliers and public linkages and obtaining analytical knowledge from scientific journals are more critical in the R&D and process innovation stages.

Finally, to examine a potential nonlinear relationship between linkages and innovation activity, marginal plots are reported for exploratory links and presented in Figures 2–6. Exploitative linkage marginal plots are not reported due to the insignificance of these variables. As can be identified, the more exploratory links firms utilise, the higher their innovation probabilities for all types of innovation activity, but at a diminishing rate of return.

5. Discussion of the hypotheses

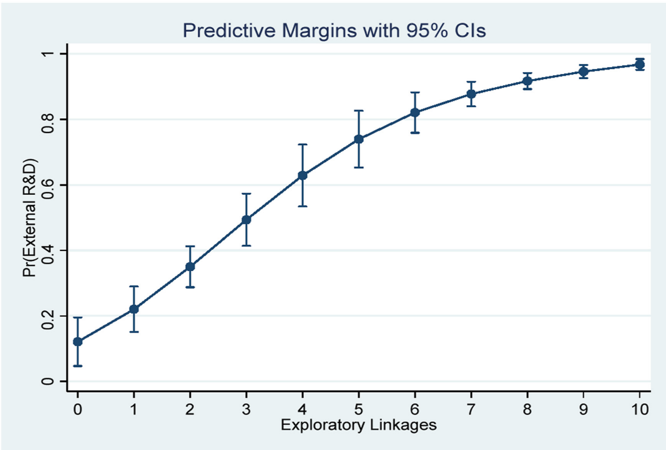
5.1 Hypotheses 1a and 1b

The first hypothesis (H1a) developed in Section 2 posits a positive yet gradually diminishing impact of exploratory linkages on R&I in ORE firms. The results presented in the preceding section along with Figures 2–6 indicate strong support for this hypothesis due to the positive coefficients for exploratory linkages and negative coefficients on the square terms for most



Source(s): Authors' own work

Figure 2. Margins plot displaying the returns to in-house R&D activity from exploratory linkages



Source(s): Authors' own work

Figure 3. Margins plot displaying the returns to external R&D activity from exploratory linkages

innovations [4]. The observed positive relationship highlights the critical role of exploratory linkages in navigating the uncertain and evolving knowledge landscape, characteristic of the early technological cycle of emerging sectors. Such linkages, as supported by the insights of Xia and Roper (2016), are essential for cultivating first-mover advantages by harnessing new knowledge, technologies and opportunities. The observed diminishing returns may stem from the managerial challenge of maintaining an extensive network of external partners. Such challenges may impede the efficiency of innovation activities due to the dilution of focus and resources (Ferreras-Méndez *et al.*, 2015, 2016; Ocasio, 1997). However, in the case of ORE, there is no "tipping point" (Laursen and Salter, 2006), where more exploratory linkages lead to less innovative activity, emphasising the complex interplay between exploratory linkages and R&I activity in the sector.

The lack of significance attributed to exploitative linkages is surprising. Exploitative linkages are designed to exploit existing knowledge, technologies and opportunities (He and Wong, 2004; Zerjav *et al.*, 2018), with the focus being on the exploitation by firms of

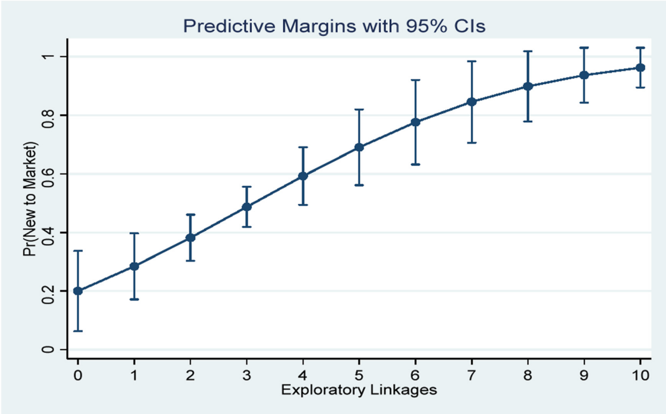


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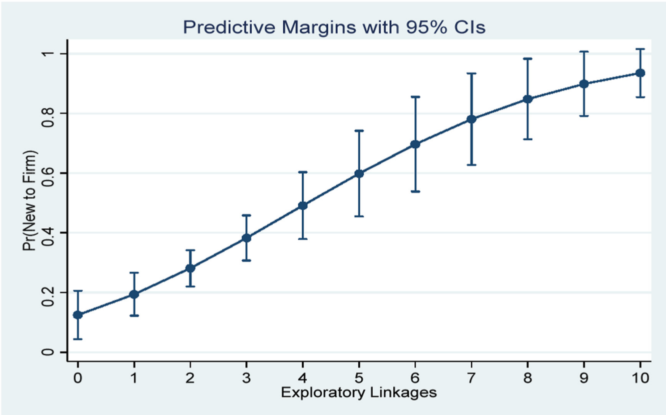
Figure 4.
Margins plot displaying the returns to new-to-market from exploratory linkages



Source(s): Authors' own work

Figure 5.
Margins plot displaying the returns to new-to-firm from exploratory linkages

knowledge previously implemented by others (Glückler, 2013). In all cases, the results presented in the previous section indicate no significant association between increased exploitative linkages and any form of R&I activity. This suggests that, in the ORE sector, more exploitive linkages are ineffective at stimulating R&I. This may be due to firms that are overly dependent on exploitative knowledge being slower than their competitors to respond to new market openings, essentially losing out on potential first-mover advantages as they are focused on existing knowledge rather than the co-creation of new knowledge (Roper and Love, 2018). This may be exacerbated by the fact that the ORE sector is in the early stages of its product life cycle. Therefore, the increased levels of uncertainty, along with the disorderly way in which knowledge is created at this stage, may result in existing knowledge becoming obsolete relatively quickly (Asimakopoulos *et al.*, 2020).

5.2 Hypotheses 2a–2f

Finally, the results are mixed when looking at the hypotheses related to the importance of individual linkages on the R&I activities of firms (Table 3). Beginning with 2a, we find

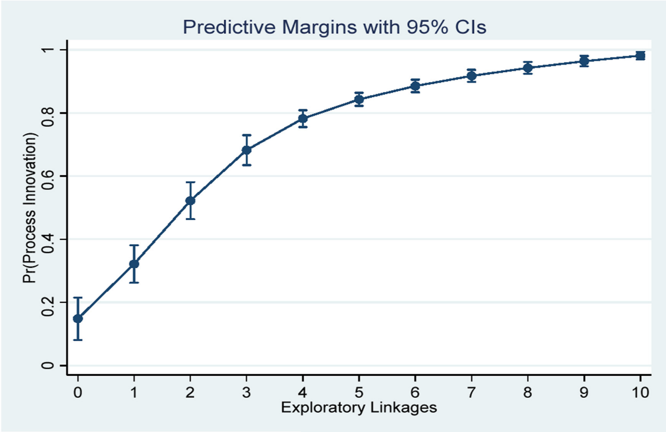


Figure 6.
Margins plot displaying the returns to process innovation

Source(s): Authors' own work

support for this hypothesis, which proposes a positive relationship between university and research institute (public) linkages and R&D activities. However, there is an insignificant relationship between public linkages to universities and research institutes and new-to-market or new-to-firm product innovation. This finding suggests that ORE firms are likely to explore relationships with universities and public research institutes to access basic and applied knowledge (Mishra *et al.*, 2015). The lack of a significant relationship with both incremental and radical product innovation may be due to the so-called "two-worlds" paradox, which emphasises the differences between the institutional setup and priorities of businesses and universities (Hewitt-Dundas *et al.*, 2019). Whilst Hewitt-Dundas *et al.* (2019) argue that learning effects can overcome these paradoxes, the relative newness of the ORE sector may mean that these learning effects have not yet been fully realised.

Regarding H2b, which proposes a positive relationship between supplier linkages and R&I activities, the results suggest partial support for this hypothesis. Supplier linkages are positively related to in-house R&D, external R&D and process innovation. By engaging with suppliers, firms in the ORE sector could potentially enhance their access to resources, knowledge and ideas, ultimately aiding in cost reduction measures (Radicic *et al.*, 2019). This may result from the development of new technical knowledge, which can result in process innovation. The lack of significance for supplier linkages and new-to-firm and new-to-market product innovation may reflect the importance of suppliers in production processes, but not as a driver of new ideas for product innovation. This finding supports existing empirical studies that highlight the importance of suppliers for process innovation in the renewable energy sector (Radicic *et al.*, 2019; Tang and Popp, 2016).

Turning to H2c, the results suggest that linkages to customers are positively and significantly related to new-to-market and new-to-firm product innovation and process innovation. Grimpe and Kaiser (2010) and Chen *et al.* (2011) highlight that by engaging with lead customers when developing novel or complex products, firms can reduce the risk associated with the introduction of new products to the market. The results suggest that this relationship is present for both incremental and radical product/service innovations, providing support for hypothesis H2c. This is in line with the findings of De Laurentis (2012). However, unexpectedly, customer exploratory links are also related to process innovation. Whilst reasons for this may be unclear, it may be that who the customer base is has a role to play in explaining this result. The customer in the ORE sector typically includes large utilities (MacKinnon *et al.*, 2019; Sovacool and Enevoldsen, 2015). These firms will ultimately benefit from process innovations, particularly those related to cost reductions (in the form of higher profits), thus creating an incentive for them to support process innovation in the industry.

Exploratory linkages with competitors are important for new-to-firm and new-to-market product innovations. This may be explained by the concept of co-opetition, which centres on the idea that firms can both compete and cooperate at the same time (Nalebuff and Brandenburger, 1997). According to Gnyawali and Park (2009), co-opetition is necessary in addressing major technological changes and is critical in high-technology contexts. Given the nascent, emerging technology in the ORE sector and the lack of design convergence, co-opetition may be an essential driver of product/service innovation within the industry.

Focusing next on exploitative linkages, within this category, linkages with scientific journals and/or trade journals have a positive and significant association with R&D and process innovation activities, thus providing partial support for H2f. This may be due to the importance of analytical (scientific) knowledge for innovation in high-tech sectors (Davids and Frenken, 2018). Given that the knowledge in scientific journals is already in the public domain and potentially already exists in the market, this type of knowledge can be particularly conducive to process innovation (Roper *et al.*, 2022) but also of relevance to R&D as it can be used as further inputs in the innovation production process (Popp, 2016).

Conference and other data source linkages are found to have no significant relationship with any R&I activities, thus failing to support H2e. This insignificant relationship contradicts the typical findings in previous literature, where it is commonly observed that firms attending and actively participating in professional conferences are more likely to surpass their current level of innovative activities (Maskell *et al.*, 2006; Tether and Tajar, 2008). However, Moon *et al.* (2019) hypothesise that the importance of conferences as a knowledge source diminishes as the firm's absorptive capacity increases. Given that firms in the ORE sector are predominately high-tech, this may explain this lack of significance. H2d is also not supported, as industry association linkages have a positive relationship with new-to-market product innovation only and not with new-to-firm product and process innovation as expected. This positive relationship may relate to the focus of industry associations. Typically, these associations are most relevant for the commercialisation stage of the innovation process (Tödtling *et al.*, 2009), suggesting that they assist firms in the commercialisation of new products. Finally, other data sources (which include internet searches) are statistically insignificant with respect to firm R&I outcomes.

6. Conclusion

To gain further insight into the role of OI strategies for innovative activity in ORE, this paper employ March's (1991) exploration–exploitation framework to examine the relationship between external knowledge linkages and five types of R&I activities using data from a unique purpose-built survey.

In the context of OI, our results add to the weight of evidence highlighting the importance of exploratory linkages for firm innovation performance. The results also show that whilst diminishing returns to openness exist, there is no tipping point at which external search hampers firm R&I activities. Therefore, the effect of exploratory linkages is consistently positive in the case of ORE firms, which reinforces the industry-specific nature of OI dynamics. However, whilst they are positive, the returns are falling, highlighting the trade-offs and complexities involved in OI strategies, where firms may need to consider rebalancing their resources at some point towards other objectives important to the firm.

OI theory highlights the value of external knowledge, but this study finds exploitative linkages to be largely insignificant, indicating that not all types of external knowledge will be of value to innovation in an industry like ORE. Adding to this, our results stress that specific types of exploratory linkages and exploitative linkages are particularly vital for different forms of R&I activity. This granularity in understanding the role of different linkage types adds a layer of complexity to OI theory, suggesting that not all external relationships are equally beneficial for every aspect of research and innovation. These findings contribute to a deeper and more context-specific understanding of OI dynamics, enhancing theoretical understandings of OI and its relevance for firms operating in a nascent sector.

Our results also have important implications related to the exploration–exploitation framework developed by March (1991), which posits that organisations need to balance both activities effectively. A clear distinction emerges in the relative importance of exploratory and exploitative relationships within a nascent sector, with the former having a critical role in fostering R&I activities in ORE firms. It challenges any suggestions that exploitation of existing knowledge will be more or equally important for R&I activities. Indeed, in a nascent sector like ORE, exploratory linkages should take precedence and exploitative linkages are not always necessary for R&I returns. Again, the nuanced finding that specific linkages matter for certain R&I outcomes adds deeper complexity to March's (1991) framework, where tailoring certain exploratory or exploitative linkages to specific innovation activities will be important. Our results reinforce the idea that firms must invest in the discovery of new knowledge to secure future economic gains (Lavie *et al.*, 2010).

6.1 Management implications

This paper recommends that firms in the ORE sector who are focused on product innovation should develop exploratory linkages with customers and competitors. Organisations prioritising R&D activity should exploit scientific publications and engagement with universities, suppliers and consultants, whilst organisations focused on introducing new processes should interact with customers, suppliers and consultants and exploit scientific publications. By using these findings, organisations can prioritise and identify the most efficient linkages relative to their innovation objectives, thus avoiding absorptive capacity exhaustion (Cohen and Levinthal, 1990). However, in light of the diminishing returns to innovative activity reported, some innovative ideas may not be fully exploited due to the cognitive limitations of management (Radicic *et al.*, 2019).

6.2 Policy implications

To enhance innovation in the sector, policy interventions that promote and build collaborations or exploratory partnerships among ORE firms are likely to be fruitful. These types of relationships create a wider benefit, which extends beyond participating firms, through stimulating knowledge creation and diffusion (Roper *et al.*, 2017). Linkages to suppliers and consultants are positively related to ORE firms' R&D activity. Consequently, policymakers should support backward linkages by providing tax incentives for ORE R&D collaboration, which improves the experience, skills, knowledge and competencies between parties.

6.3 Limitations of the research and avenues for future research

The study has some limitations. First, a cross-sectional survey was employed in this paper, meaning the results show the directional evidence of a relationship but fail to provide conclusive evidence on causality between variables. Consequently, a longitudinal study has the opportunity for more complex causal analysis. A second limitation was the response rate of the REIS, limiting the examination of the ORE sector by ORE type (i.e. offshore wind versus tidal versus wave). Future research could work to increase the sample size to identify the differences in knowledge sourcing strategies of firms involved in different ORE types. In doing so, policy could be more accurately informed for different ORE sectors.

Notes

1. For an extensive background on the survey and data, please see the data report available at https://www.ucc.ie/en/media/projectsandcentres/srerc/WORKPACKAGE_9_DATA_Report_APRIL_2023.pdf
2. A matrix of the correlations of the variables is presented in Table A1.
3. Multivariate probit models were also estimated for robustness. Robustness tests were also estimated for (i) only a UK and Ireland sample and (ii) extra robustness tests were estimated for equation (2), which included firm type and country dummies. The results remain robust for all different estimations.
4. Diminishing returns from exploratory linkages were found for internal R&D, external R&D, new-to-market innovation and process innovation.

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Corresponding author
Frank Crowley can be contacted at: frank.crowley@ucc.ie

Supplemental documentation

Table A1. Matrix of correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) In-house R&D	1.000													
(2) External R&D	0.583	1.000												
(3) New-to-market	0.450	0.427	1.000											
(4) New-to-firm	0.318	0.219	0.323	1.000										
(5) Process innovation	0.553	0.353	0.495	0.312	1.000									
(6) Exploratory linkages	0.419	0.433	0.449	0.359	0.485	1.000								
(7) Exploitative linkages	0.231	0.321	0.167	0.125	0.279	0.274	1.000							
(8) Exploratory linkages squared	0.286	0.324	0.379	0.305	0.343	0.951	0.235	1.000						
(9) Exploitative linkages squared	0.239	0.337	0.178	0.153	0.292	0.291	0.964	0.251	1.000					
(10) Employment (log)	0.117	0.097	0.145	0.041	0.149	0.069	-0.018	0.064	0.031	1.000				
(11) Firm age (log)	-0.031	-0.069	-0.029	-0.013	-0.087	-0.070	-0.181	-0.029	-0.124	0.557	1.000			
(12) % University education	0.122	0.021	-0.054	0.065	0.041	0.080	0.081	0.097	0.081	-0.223	-0.265	1.000		
(13) Multi plant	0.202	0.191	0.247	0.082	0.119	0.228	0.082	0.180	0.103	0.199	0.062	-0.008	1.000	
(14) Received subsidy	0.322	0.324	0.155	0.083	0.262	0.259	0.285	0.185	0.256	-0.065	-0.179	0.099	0.078	1.000

Source(s): Authors' own work