Exploratory and Exploitative Linkages and Innovative Activity in the Offshore Renewable Energy Sector

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Shane Barrett[a] Frank Crowley[a] Justin Doran[a] Mari O'Connor[a]

[a] Spatial and Regional Economic Research Centre, Department of Economics, Cork University Business School, University College Cork, Cork, Ireland.
[b]

Abstract:
Purpose – This paper examines the relationship between open innovation (as measured by exploratory and exploitative linkages) and firm-level innovative activity in the offshore renewable energy (ORE) sector.
Design/methodology/approach – This paper makes use of a unique, purpose-built survey which was targeted at UK, Irish and other EU firms operating in the ORE sector and its supply chain. The survey provides novel insights into the research activities and networking capabilities of an industry in the infant stages of development consisting of many diverse actors, including start up technology developers, traditional energy providers, academic spinoff firms, specialist knowledge service firms and companies from established sectors looking to diversify into new markets. Regression models are used to estimate the relationship between firm level external linkages and innovative activity
Findings – More exploratory linkages are positively related to more innovative activity. This relationship is subject to diminishing returns, but is not an inverted U-shape, which is contrary to previous research from other sectors. When the types of linkages are disaggregated, collaborating with suppliers, and accessing scientific journals are conducive to R&D activity and process innovation, while collaborating with customers is associated with the decision to introduce new products and processes.
Originality/value – Previous firm level studies have provided evidence of a positive, but curvilinear relationship between external knowledge linkages and innovative activity. However, these studies focus on samples of firms from the national economy and for mature sectors. This analysis sheds light on firms which are predominantly in the introductory stages of the technological life cycle with limited commercialization experience in ORE. Furthermore, the paper answers the call from the literature to examine the relative significance of each knowledge search channel in stimulating innovation.

1. Introduction

The sustainable development of offshore renewable energy (ORE) technologies is at the forefront of the European Commission's energy policy (2020, 2014). In order to meet the ambitious 2050 EU energy targets, innovation in the development and deployment of large scale ORE technologies which reduce carbon emissions, increase energy security, contribute to policy objectives, and provide affordable energy to consumers is essential (Jacobsson and Karltorp 2013). In recent years, the potential of the ORE sector has attracted large power companies and investment has increased (Roesch et al. 2020, Jay and Jeffrey 2010). 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 ORE sector (Jeffrey et al. 2013, Richter 2013).

ORE innovation involves several interdependencies across a highly complex and diversified knowledge domain (Medina-Lopez et al. 2021, Wieczorek et al. 2013). Firms' innovation strategies often involve searching for commercially exploitable technologies or knowledge from outside their organisation (Laursen and Salter 2014, Dahlander and Gann 2010, Nelson and Winter 1982). Scholars have placed increasing importance on open innovation strategies, emphasising how knowledge, resources, and individuals flow in and out of firms (Chesbrough et al. 2021, Enkel et al. 2020, Bogers et al. 2019, 2017, West and Bogers 2014). External collaboration has been shown to contribute to R&D performance (Asakawa et al. 2010) and plays a key role in the introduction of new and improved products (Köhler et al. 2012) and processes (Inauen and Schenker-Wicki 2011). Technological knowledge in the ORE is dominated by tacit knowledge, with companies reluctant to share their know-how with potential competitors, which is increasingly reflected by the efforts of ORE actors to use patents to protect innovations (Wieczorek et al. 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 (MacGillivray et al. 2015, Corsatea and Magagna 2013). This suggests that a greater understanding around the factors related to research and the wider innovation knowledge diffusion system in the ORE sector is needed. A primary objective of this paper is answering the following research question; what relationships do interactive and non-interactive linkages have with innovative activity for the emerging ORE sector?

This paper makes two distinct contributions to existing literature, which have implications for open innovation literature (Chesbrough 2017, Chesbrough 2003, West and Bogers 2014), the ORE sector and beyond. Firstly, this paper contributes to the open literature by testing for the presence of a curvilinear relationship between two types of external knowledge linkages; (1) exploratory linkages (i.e deliberate and purposive connections such as interactions with universities) and (2) exploitative linkages (i.e. exploit *existing* knowledge, technologies, and opportunities such as knowledge developed from reading scientific journals) and innovative activity for ORE firms (Lavie et al. 2010, Roper et al. 2017). This sheds light on whether the inverted U-shape relationship between external linkages and innovation previously identified in the literature for mature sectors (Ferreras-Méndez et al. 2015, Leiponen 2012, Garriga et al. 2013) also exists for an *emerging* sector. While previous studies such as Roper et al. (2017) have examined the relationship between firm level knowledge search strategies and innovative activities, there is a lack of understanding of this relationship for an industry dominated by young firms and unstandardised products and processes. Whilst many sectors consist of incumbents from other related industries; ORE activities are predominantly in the introductory stages of the technological life cycle, with limited commercialisation experienced to date (Corsatea and Magagna 2013). Furthermore, whilst most studies find a curvilinear relationship for industries as a whole, 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. The further investigation of this phenomenon in a young high-tech sector like ORE (i.e. data suggests high levels of R&D activity across firm operators) will broaden the understandings of whether this also translates to a *nascent and emerging* sector like ORE.

Secondly, there is more research on exploratory linkages relative to that of exploitative linkages, with some limited number of papers discussing both modes simultaneously (Gianiodis et al. 2013, Cassiman and Valentini 2016). This research contributes to the literature by focusing on both types of linkages, which is rare in the OI literature. It further contributes to the literature by disaggregating exploratory linkages (interactions with customers, suppliers and consultants, competitors, and research institutes) and exploitative linkages (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) to individual indicators and by examining the extent to which an ORE firm's research and innovation activity is facilitated or hindered by the inclusion of each individual exploratory or exploitative linkage in their knowledge acquisition strategy. Previous literature examines the effects of external search breadth as a whole (Garriga et al. 2013, Love et al. 2014, Laursen and Salter 2014, Asimakopoulos et al. 2020) with less focus on the effects each individual type of linkage has with innovative activity (O'Connor et al. 2020). The inclusion of each individual level linkage answers the call of Ardito and Petruzzelli (2017) who suggest more work should be undertaken in examining the "*relative significance of each search channel*" in stimulating innovation.

This paper makes use of a unique, purpose-built survey which was targeted at UK, Irish and other EU firms operating in the ORE sector and its supply chain. The survey provides novel insights into the research activities and networking capabilities of an industry in the infant stages of development consisting of many diverse actors, including start up technology developers, traditional energy providers, academic spin-off firms, specialist knowledge service firms and companies from established sectors looking to diversify into new markets. Regression models are used to estimate the relationship between firm level external linkages and innovative activity.

Section 2 reviews previous literature regarding open innovation, external linkages and innovative activity and outlines the hypotheses which will be tested. Section 3 discusses the novel data set used, while Section 4 presents the empirical methods employed. Section 5 presents the empirical results and discusses the hypotheses. The paper concludes in Section 6 with a discussion around the implications of the findings.

2. Literature Review

2.1 Open Innovation Strategies, External linkages, and innovation activity

Since Chesbrough's (2003) first book, open innovation (OI) has garnered a lot of popularity as a research topic and an innovation strategy (West and Bogers, 2014). A company's openness to outside players and "purposeful inflows and outflows of knowledge" is often necessary for the development and commercialization of breakthrough technology (Chesbrough 2006, West and Bogers 2014). OI prioritises external search and engagement for exploitable knowledge and such devoted search supports innovative performance, firm competitiveness and international entrepreneurship (Laursen, 2012; Garriga, Von Krogh and Spaeth, 2013; Roper, Vahter and Love, 2013; Mostafiz, Ahmed and Hughes, 2022; Gimenez-Fernandez et al., 2022).

OI prioritises external search and engagement for exploitable knowledge and such devoted search supports innovative performance, firm competitiveness and international entrepreneurship (Laursen 2012, Garriga et al. 2013, Roper et al. 2013, Mostafiz et al. 2022, Gimenez-Fernandez et al. 2022). 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). External sources of knowledge have been widely recognised to have a good impact on innovation performance across several potential collaboration partners, as well as for businesses of various sizes and industries (Love et al. 2014, Garcia Martinez et al. 2014).

OI is linked with March's (1991) framework of exploration and exploitation choices (Xia and Roper 2016, Roper et al. 2017). Here, sources of open external engagement have been described as exploratory (or interactive) linkages or exploitative (non-interactive) linkages (Zahran et al. 2020, Roper and Love 2018, Hewitt-Dundas and Roper 2011). Exploratory linkages are considered linkages to customers, suppliers, consultants, competitors, research institutes and universities (Chunhsien Wang et al. 2020, Ganotakis and Love 2012). Firms pursue exploratory knowledge acquisition strategies to source external knowledge from outside the firm to improve their competitive advantage (Chesbrough 2017, Ferreras-Méndez et al. 2015, Leiponen and Helfat 2010) and to uncover new knowledge, technologies and opportunities (Xia and Roper 2016, March 1991). They are deliberate and purposive connections with the intent to develop collaborations that provide a platform that generates radical new-to-the-world commercial knowledge (Roper et al. 2016). Exploratory linkages are characterised by the strategic intent of both parties, the reciprocal knowledge transfer among parties, and the interactive learning of all involved (Glückler 2013).

In contrast, exploitative (i.e. non-interactive relationships) knowledge search strategies are employed by firms who 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).

Firms sourcing exploratory linkages require considerable time and effort through absorptive capacity channels to build meaningful working relationships and understanding (Criscuolo et al. 2018). Absorptive capacity, as defined by Cohen and Levinthal (1990) is viewed as the firm's ability to assimilate, absorb and exploit external knowledge, which influences the innovation performance of the firm (Radicic et al. 2019, Arranz and de Arroyabe 2008). Conversely, exploitative relationships are often more cost effective knowledge sourcing alternatives to exploratory linkages often involving less time, effort and avoids reciprocal uncertainty (Ordanini et al. 2008, Yang and Hyland 2006).

Previous literature suggests the more exploratory and exploitative linkages the firm has, the more likely they are to receive useful knowledge for the introduction of innovations (Ritala et al. 2015, Love et al. 2014, Leiponen and Helfat 2010). Searching for external linkages directly affects the firm's knowledge base and indirectly increases the likelihood of complementarities from internal and external knowledge combinations producing successful innovations (Garriga et al. 2013, Wu et al. 2013, Voudouris et al. 2012, Cassiman and Veugelers 2006). Access to exploratory or exploitative linkages allow firms to avoid cognitive myopia, particularly in contexts where incentives for learning new technologies and competencies are lower (Levinthal and March 1993). Having more external linkages also reduces the potential for cognitive lock-in, ensuring firms are more open to technologies from outside their region which, in turn, increases their ability to keep up with market dynamics (Boschma 2005).

Even though more external linkages increase the probability of acquiring useful external knowledge for innovations (Baldwin and Clark 2006), the step changes between more interactions and innovation is unlikely to be smooth or linear (Love et al. 2014). Leiponen and Helfat (2010) note the uncertain nature of the innovation process, meaning the anticipated returns from innovation are unpredictable and variable. Firms often do not have the ability to recognise and identify the most relevant knowledge sources, and as a result face a risk of over-searching (Koput 1997, Laursen and Salter 2006). 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 increase (Duysters and Lokshin 2011, Prahalad and Bettis 1986). Consequently, the number of external knowledge linkages and the innovation performance of the firm have been argued to follow an inverted U-shape (Marullo et al. 2021, Garriga et al. 2013, Leiponen and Helfat 2010) previously referred to as the *"paradox of openness"* (Triguero and Fernández 2018). As management have limited cognitive capacity (Simon 2013), firms reach a saturation juncture where additional external linkages hinders the returns to their innovation performance (Radicic 2020, Cruz-González et al. 2015, Ghisetti et al. 2015, Laursen and Salter 2006).

Another cause of diminishing returns from external linkages refers to the attention allocation problem (Ocasio 1997). Firms may have difficulty exploring new knowledge once they exceed the number of external linkages that they can effectively dedicate time and resources to (Radicic 2020, Ferreras-Méndez et al. 2015). Ardito and Petruzzelli (2017) provide an additional concern, noting how firms may not be able to fully exploit an innovative idea as it simply came at the wrong time and when other R&D investments have already commenced. Koput (1997) describes how the scale and variety of external knowledge sources and perspectives make it difficult for firms to be able to select the right time to exploit innovative ideas.

2.2 External linkages for Offshore Renewable Energy

The preceding section focused on discussing the general patterns expected between external knowledge sourcing and research and innovation for firms in all types of sectors. This reflection is used to conceptualise the expected patterns anticipated for ORE firms. Outside of offshore wind, technologies to unlock the potential of ORE are at an early stage of development (Uihlein and Magagna 2016). Radical technological breakthroughs are being sought in the sector to overcome many remaining obstacles (Uihlein and Magagna 2016). The sector currently suffers from a lack of design convergence (Magagna and Uihlein 2015), which is limiting cost reductions, which would otherwise occur through economies of scale and increased active engagement from players in the wider industry supply chain (Magagna and Uihlein 2015). Exploratory linkages due to their investigative nature is more conducive to making breakthrough innovations happen (Mention 2011, Nieto and Santamaría 2007). Evidence of exploratory collaborations already exist in ORE such as between developers and blade manufacturers for design specification and fabrication requirements in tidal energy, and in efforts to create common power take off systems in wave energy (Magagna and Uihlein 2015).

Any firms drawing from exploitative linkages in ORE may benefit from reduced uncertainty and costs, an increased internal knowledge base, and improved innovative performances (Ali 2021, Onufrey and Bergek 2020, Lee and Tang 2018, Doha et al. 2018, Lavie et al. 2010). But they will likely forego first mover advantages (Roper and Love 2018). A technology 'wait and see' follower approach at this point in the technology life cycle would not appear to be a reliable strategy. In the early stages of the life cycle, uncertainty is high, knowledge creation is disorderly and can quickly be rendered obsolete and so knowledge exploitation is often less relevant (Asimakopoulos et al. 2020). However, given the make-up of exploitative linkages, including the sourcing of knowledge from scientific journals and attendance at conferences, there could be important resources for analytical knowledge and basic research (Davids and Frenken 2018). Indeed, Popp (2017, Popp 2016) identified that high quality scientific articles led to applied technological development in renewable energies. Consequently, whilst the empirical evidence is scarce, exploitative linkages could be equally as important for ORE. Consequently, the following hypothesis is proposed:

Hypothesis 1: Exploratory and exploitative linkages have a positive relationship with research and innovation in ORE firms.

Returning to the inverted U-shaped relationship between linkages and innovation that has been found in other sectors (Roper et al. 2017, Laursen and Salter 2014); should the same be expected in ORE? Technological intensity varies by sector type creating different contexts for knowledge exploration, production, and exploitation (Garcia Martinez et al. 2017, Sáenz et al.

2009). Asimakopoulos *et al.* (2020) argue that high tech firms (like that of ORE) are more likely to extend the benefits of external knowledge sourcing for longer, for two reasons. Firstly, they have a need to continuously update their internal R&D resources and capabilities to maintain a competitive edge forcing more extensive engagement, which in turn flattens the inverted U-shaped relationship between linkages and innovation for high tech firms. Secondly, as high-tech firms routinely grapple with complex scientific and technical challenges, they 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. The following relationship is conceptualised:

Hypothesis 2: Exploratory and exploitative linkages have a positive relationship with research and innovation in ORE firms, at a diminishing rate, but there is no inverted U-shaped relationship.

2.3 Individual level linkages and research and innovation activities

Whilst existing literature typically focuses on the importance of external knowledge search breadth as a whole (Garriga et al. 2013, Love et al. 2014, Laursen and Salter 2014, Asimakopoulos et al. 2020), less is understood on the relative significance of each search channel in stimulating innovation (Ardito and Petruzzelli 2017). Some external linkages may be stronger, or more important than others (O'Connor et al. 2020, Brunswicker and Vanhaverbeke 2015, Tomlinson 2010). ORE firms share cognitive proximity of knowledge and expertise, and consequently if decreasing returns to knowledge sourcing exist, firms knowing the best ways to use search channels independently or jointly to their advantage, will be important.

The types of knowledge needed from any given exploratory linkage depends on the development stage of the innovation and the type of innovation activity (Flor et al. 2018, Arvanitis et al. 2015, Cassiman and Veugelers 2006). The innovation value chain (IVC) is used to provide a framework (Hansen and Birkinshaw 2007, Roper et al. 2008), to consider how different external knowledge sources may affect research and innovation performance in different ways. The focus is on the first two sequential phases of the IVC which consists of idea generation (knowledge sourcing) and idea development (knowledge production). The IVC process is potentially ‘open’ where firms may appropriate external knowledge and networking benefits (Roper and Arvanitis 2012) whilst also drawing on their own internal resources to innovate (McEvily and Chakravarthy 2002).

In the idea generation stage, firms source knowledge through R&D investment, and/or through external collaboration with universities, suppliers/consultants, competitors, customers and public research institutes (Roper et al. 2017). At this point, firms are likely to explore relationships with universities and public research institutes to access basic and applied knowledge (Asakawa et al. 2010, Murovec and Prodan 2009, Cassiman and Veugelers 2006, Mishra et al. 2015, Roper et al. 2008, Cockburn and Henderson 1998). Public linkages to universities and research institutes have previously been linked to improved firm-level absorptive capacity (Fabrizio 2006, Cockburn and Henderson 1998) and also to the exploitation of published scientific research informing methods and disciplines applied in R&D departments (Boehm and Hogan 2013). However, it has been cautioned that ‘academic research rarely produces 'prototypes' of inventions for development and commercialization by industry' (Mowery & Sampat, 2004: p118).

In both the idea generation and development stages, supply-chain linkages to customers and suppliers have been identified as important (Ganotakis and Love 2012). The involvement of lead customers in the development of novel or complex new products reduce the likelihood of poor product design (Grimpe and Kaiser 2010, Brockhoff 2003), therefore reducing the risk associated with the introduction of a new product to the market (Chen et al. 2011, Tödtling et al. 2009, Su et al. 2007). Competitors and suppliers separately provide access to resources that help firms reduce costs and complementary technical knowledge to assist tech development (Radicic et al. 2019, Tsai et al. 2011). Recent studies have noted the importance of supplier and competitor linkages for innovative activity in the form of process innovation and firm competitiveness (Li et al. 2019, Grandinetti 2018).

Whilst most of the conceptual and empirical findings discussed here relate to the importance of exploratory linkages, there is also a strong basis for firms to adopt an exploitation linkage strategy. 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 et al. 2006). They can also act as a platform for maintaining and establishing new exploratory linkages to help develop new products and processes (Bathelt et al. 2004, Lyytinen 2001, Maskell 2014). Roper et al. (2014) found exploitative linkages such as scientific journals and industry associations to be more common for incremental innovations and process innovation, as the knowledge exploited from these kind of sources already exists in the market (Katila and Ahuja 2002). However, exploitative linkages can also impact idea generation, with Popp (2016) previously identifying scientific journals to be positively related to undertaking R&D in the non-renewable energy sector. Jones and Craven (2001) also found attendance at trade fairs and reading scientific journals effective for R&D and the introduction of new products in SME's.

The complex, tacit and diversified nature of knowledge interdependencies required to unlock technological bottlenecks in ORE, condition the type of interactions that may be important for the idea generation and idea development phases. Previous work highlights the importance of scientific collaborations for knowledge diffusion in ORE (Corsatea 2014, Popp 2016, Popp 2017). Academics have played a key role in the sector since its inception as many of the marine start-ups were university spin-offs, with a third of personnel working in the area based in academia (Corsatea 2014). Consequently, exploratory links with actors from universities and research institutes and exploitative linkages such as scientific journals and conference attendance are expected to play a significant role in shaping research and innovation outcomes in the sector. In addition, close collaborative supply chain links between suppliers and developers (customers in this case) are helping to reduce costs and improve economies of scale in product development (Magagna and Uihlein 2015), but the sector is yet to experience consolidation in its supply chain (Magagna et al. 2017). Consequently, supplier, competitor, and customer interactions are expected to also be important. From patterns in the general innovation literature and in related ORE literature, the following hypotheses are proposed:

Hypothesis 3a: Linkages with universities and research institutes will be positively related to R&D activities.

Hypothesis 3b: Linkages with suppliers and competitors will be positively related to R&D and process innovations

Hypothesis 3c: Linkages with customers will be positively related to R&D and product innovations

Hypothesis 3d: Conference, trade fairs and exhibitions attendance will be positively related to R&D and incremental product and process innovations.

Hypothesis 3e: Accessing scientific journals will be positively related to R&D activities and product innovations.

3. Data

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 environmental survey which is similar in form and content to the Community Innovation Survey (CIS) and was specifically targeted at Irish, UK and European firms operating in the ORE sector and its potential supply chain.

The REIS[1] was conducted in 2021 and required completion of the survey by the CEO/Director or a top management actor within the firm. Respondents were asked to provide information on the firm's innovation activities, knowledge sourcing activities, networks, resources, and performance for the years 2017 to 2019. Performance data for 2020 was not collected due to bias that may occur because of the COVID-19 pandemic. Publicly available online ORE supply chain databases were used to compile the sampling frame. In total, 1,368 firms were in the sampling frame, which from previous estimates of firms active in the sector, suggests the number of firms has grown significantly in recent years (Magagna et al. 2017). These firms

[1] The REIS obtained ethical approval from the University College Cork Social Research Ethics Committee.

were contacted by email with follow up calls eliciting 227 responses and a response rate of 16.4%.

Survey data in the form of secondary sources such as the Community Innovation Survey (CIS), and the World Bank Enterprise surveys are commonly used to analyse firm innovation performance (O'Connor et al. 2020, Crowley and Jordan 2017). The ORE sector makes up a very small component (due to its size) of responses in such datasets and relying on such samples would lead to the misrepresentation of the economic activities of ORE firms.

The REIS was funded by the European Union's European Regional Development Fund SELKIE project through the Ireland/Wales Cooperation Programme. In terms of the REIS, 50% of respondents are from the UK, 31% of respondents are from the Republic of Ireland while the remaining 19% of respondents are based in the EU. Regarding the types of respondents in the sample, 33% of respondents are ORE direct technology developers or technology suppliers, 8% are academic or research performing institutes, 34% are consultancy or engineering companies, 14% are involved in maritime operations, and 11% are categorised as other firms. Business support organisations, safety providers, skills & training providers to ORE firms and legal firms are among the types of firms included in the "Other" category.[2]

[2] Please consult Table A1 in the supplemental documentation for a breakdown of respondents by country of main establishment. Table A2 in the supplemental documentation has the breakdown of respondents by firm type.

Table 1: Variable Definition Table and Descriptive Statistics

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.	0.667	0.473
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.	0.471	0.500
New-to-Market 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.	0.487	0.501
New-to-Firm 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.	0.619	0.487
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, non-profit organisations.	3.206	3.261
Exploitative Linkages	Count variable which takes the value of 0 to 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, other data sources.	1.540	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.	0.434	0.497
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.	0.529	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.	0.448	0.499
Public Linkages	A binary variable which takes the value of 1 where respondents had indicated they interacted with research institutes or non-profit organisations, 0 otherwise.	0.349	0.478
Conferences	A binary variable which takes the value of 1 where respondents indicated their attendance at conferences, or trade fairs, or exhibitions, 0 otherwise.	0.508	0.497
Scientific Journals	A binary variable which takes the value of 1 where respondents had consulted scientific journals, or trade/technical publications, 0 otherwise.	0.439	0.498
Industry Associations	A binary variable which takes the value of 1 where respondents are involved in professional associations or industry associations, 0 otherwise.	0.534	0.500
Other Data Sources	A binary variable which takes the value of 1 where other any other data source not previously mentioned are considered for the enterprise's innovation, 0 otherwise.	0.058	0.235
Employment (log)	The natural log of the number employees reported in 2019.	2.240	1.833
Firm Age	Continuous variable which is calculated by subtracting the year the firm was established from the current year (2021).	2.697	0.987
% University Education	The percentage of the organisation's employees who have obtained a third level qualification (i.e., University, College, HEI).	0.738	0.339
Multi Plant	A binary variable which takes the value of 1 if the organisation has more than one plant, 0 otherwise.	0.312	0.486
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, European level government during the years 2017-2019, 0 otherwise.	0.481	0.501

Table 1 provides definitions and descriptive statistics for each of the variables used in the analysis. This paper employs five different types of innovation activity: internal R&D; external R&D; new-to-market innovation; new-to-firm innovation; and process innovation. The definitions for these research and innovation indicators are in line with the definitions provided by the Oslo Manual (Eurostat 2018). A total innovation activity measure or what is also referred to as an innovation breadth variable is used as a robustness test when examining the curvilinear relationship that may exist between external linkages and innovation activity of the firm. In this paper, this is the sum of a firms' innovation inputs and outputs. Using an innovation breadth measure is an alternative approach to measuring firm innovation that captures the broader range of firms' innovation activities (Sinha et al. 2022).

67% of respondents (Table 1) report that they had in-house R&D expenditure during the reference period 2017 to 2019. Almost half of respondents have invested in external R&D activities during the three-year period. The percentage of the sample engaged in R&D is relatively high in comparison to the findings of previous studies (Roper et al. 2008, Doran and O'leary 2011, Berchicci 2013). Focusing on the different types of innovation, 48% of respondents have introduced a new-to-market innovation, 39% of respondents have introduced a new-to-firm innovation, while 49% of respondents introduced a new or significantly improved process to their business operations during the years 2017 to 2019.

The incidence of firms introducing more new-to-market compared to new-to-firm innovation is likely to be representative of emerging ORE market activities. ORE innovation is characterised by a combination of diverse knowledge bases at the early stage in the product life cycle and high levels of learning and experimentation (Løvdal and Aspelund 2011, Weinzettel et al. 2009, Garrone et al. 2014). Previous organisational economic studies suggest firms enjoy greater opportunities to innovate in emerging sectors than in maturing contexts (Lo et al. 2020, Klepper 1996). The stats suggest the ORE sector is more innovative relative to other sectors due to the larger proportion of respondents indicating they have introduced new products or processes compared to previous findings (Radicic 2020, Doran et al. 2020, O'Connor et al. 2020, Un et al. 2010).

The REIS asked respondents to indicate the number of innovation co-operation partners they were working with. The survey gave respondents a choice of ten innovation partner types. These innovation co-operation partners could consist of consultants, suppliers, enterprises that are considered competitors, other enterprises, enterprises within the firms’ enterprise group, 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 non-profit organisations.

Following the seminal contribution of Laursen and Salter (2006), the measurement of exploratory linkages is the sum of the number of innovation co-operation partners the firm had, a measure consistently used in the literature (Ko et al. 2021, Lacerda and van den Bergh 2020, Cainelli et al. 2020, Ferreras-Méndez et al. 2015, Wu 2014, Garriga et al. 2013). A firm with zero innovation co-operation receives an exploratory linkage value of 0, while a firm that had interacted with all innovation partners is assigned a value of 10. As illustrated in Table 2, firms on average had 3.2 innovation co-operation partners.

Exploitative linkages were measured in a similar way to the approach of Roper et al. (2017) and Hewitt-Dundas and Roper (2011). Respondents were asked to indicate which non-interactive data sources were considered for their innovations. Respondents were given four options: conferences and trade fairs; scientific journals or trade publications; professional and industry associations; and other data sources. Firms are assigned a value of 0 where they had zero exploitative linkages and firms are assigned a value of 4 where they had considered each exploitative data source for their innovations. On average, firms had consulted 1.5 exploitative data sources for their innovations.

Attention now turns to the individual level linkages, where Table 1 shows that 53% of respondents engaged with suppliers and consultants, 43% of respondents engaged with customers, 45% of respondents engaged with competitors, and 35% of respondents engaged with research centres or universities. Table 2 suggests the ORE sector is more open to external collaboration as the number of respondents who engaged in external linkages is higher than those found in the literature (Roper et al. 2008, Lee et al. 2010, Tsai 2009).

Looking at the individual level exploitative linkages, 51% of respondent's innovation strategy included conference attendance and participation, 44% of respondents had consulted scientific journals, 53% of respondents had consulted industry associations, and 6% of respondents had consulted other data sources during the reference period. The proportion of the sample engaging in exploitative linkages such as conference attendance and participation and consulting scientific journals is consistent with previous findings in the literature (Marullo et al. 2021, Lee et al. 2010).

4. Methodology

This paper employs an innovation production function which is a common empirical strategy in the innovation literature (Audretsch and Belitski 2020, Crowley 2017, Lööf et al. 2017, Doran et al. 2012, Hall et al. 2009). The innovation production function used in this paper shows the probability of the firm engaging in innovation activity and is regressed against several explanatory variables. Eq. (1) below is estimated using five distinct probit models, each examining a different type of innovative activity.

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

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). The types of innovative activity measures include: in-house R&D, external R&D, new-to-firm innovation, new-to-market innovation, and process innovation. The data used in this paper is cross-sectional in nature meaning the lagged effects of R&D spend cannot be examined. Consequently, an examination of endogeneity across indicators needs to be conducted.

Returning to equation (1), β_0 is the constant or intercept term. $Explor_i$ refers to the number of exploratory linkages for firm i. $Exploit_i$ refers to the number of exploitative linkages for firm i. This paper expects both $Explor_i$ and $Exploit_i$ to be positive, as more external linkages are more likely to yield useful external knowledge for innovative activity, which leads to economies of scope and can reduce cognitive lock-in (Garriga et al. 2013, Chiang and Hung 2010, Boschma 2005).

$ExplorSq_i$ and $ExploitSq_i$ are the squared terms of exploratory and exploitative linkages, respectively. These are included to test for possible quadratic effects (Love et al. 2014, Radicic 2020). In line with previous studies who have tested the returns of innovation activity from external linkages (Lacerda and van den Bergh 2020, Ardito and Petruzzelli 2017, Cruz-González et al. 2015, Chen et al. 2011), this paper expects both $ExplorSq_i$ and $ExploitSq_i$ to be negative. Negative $ExplorSq_i$ and $ExploitSq_i$ coefficients would suggest diminishing returns to innovative activity from exploratory and exploitative linkages (Roper et al. 2017). Z_i refers to several firm specific control variables which include firm size, firm age, recipient of subsidies, and operating multiple plants.

$$IA_{ih} = \beta_0 + \beta_1 Customers_i + \beta_2 Suppliers/Consultants_i + \beta_3 Competitors_i + \beta_4 Research\ institutions_i + \beta_5 Conferences_i + \beta_6 ScientificJounrnals_i + \beta_7 IndustryAssociations_i + \beta_8 OtherDataSources_i + \beta_9 Z_i + \varepsilon_i \quad (2)$$

Eq. (2) includes the disaggregated individual level exploratory and exploitative linkages and is estimated using five distinct probit models, with each probit model examining a different type of innovative activity as outlined in Eq.(1) (Roper et al. 2008).

5. Results and robustness checks

The probit estimation models used to test Eq. (1) report marginal effects and each model is statistically significant. Table 2 displays the results from Eq. (1) for each of the five innovation activities. Table 3 indicates the results from Eq. (2) and again each probit model is statistically significant. Firm size, firm age, percentage of the workforce with a third level qualification, the multi plant dummy variable and the subsidy dummy variable were included as control variables. Exploratory linkages are significant in eq (1) and when comparing the results of eq(1) with eq(2), the limited significant results for individual linkages (Table 3) contrasted with the synergistic effect of interactive linkages (Table 2), points to the importance of combining many interactions, rather than a few. This is particularly the case for exploratory interactions. As ORE innovation is known to be complex and requires a diverse range of knowledge (Garrone et al. 2014, Nemet 2012), these results emphasise the importance of ORE firms being open to external exploratory knowledge sources.

Table A5 and Table A6 in the supplemental document are multivariate probit models which examine if the error terms are related for equation (1) and (2). The multivariate probit models are significant and robust suggesting the error terms are related and unobserved characteristics are driving both R&D and product and process innovations. Due to these empirical considerations, this paper treats all indicators as innovative activity, but the independent probit models are reported as the results are very similar. The country of main establishment variable and type of firm variable were omitted from the regressions presented in Tables 2 and 3. However, robustness checks with their inclusion are presented in Table A7 and Table A8 in the supplemental document and the results remain robust.

Finally, to examine for a potential non-linear relationship between linkages and innovation activity, an "Inno_Activity" variable is constructed by adding the sum of each binary dependent variable and then dividing by the number of dependent variable (i.e., dividing by five to make a fraction). Table A9 in the supplemental document displays the fractional probit regression and Figure 1 indicates that a non-linear relationship is present between exploratory linkages and innovation activity.

6. Discussion of the Hypotheses

6.1 Hypothesis 1

Exploratory linkages were found to have a significant positive relationship with each innovation activity. This finding is consistent with the results of previous studies which indicate the positive effects of exploratory linkages on firm level innovation outcomes (Chesbrough et al. 2021, Berchicci 2013, Leiponen and Helfat 2010). Exploitative linkages appear to have a negligible effect on each type of innovative activity as exploitative linkages are not statistically significant. Hypothesis 1a is therefore only partly supported.

6.2 Hypothesis 2

Although exploratory linkages positively effect innovation activity, the negative coefficient of the squared exploratory linkage term suggests the relationship is subject to diminishing returns (Cruz-González et al. 2015, Ghisetti et al. 2015). Diminishing returns from exploratory linkages were found for internal R&D, external R&D, new to market innovation and process innovation. This finding supports the presence of a curvilinear relationship that has been previously found in the literature (Lacerda and van den Bergh 2020, Love et al. 2014). Therefore, this result offers support for Hypothesis 2. This indicates that once the cognitive capacity of management is reached (Radicic 2020, Simon 2013), it is more difficult for management to dedicate time and effort to external linkages, which hinders their returns to innovative activity (Ferreras-Méndez et al. 2016, Ferreras-Méndez et al. 2015, Ocasio 1997).

Fig. 1 displays the returns to innovative activity from exploratory linkages. It is worth noting that despite the relationship being subject to diminishing returns, it is not an inverted U-shape as other studies have found (Lacerda and van den Bergh 2020, Roper et al. 2017, Garriga et al.

2013). In other words, there is no “tipping point” (Laursen and Salter 2006) where more exploratory linkages lead to less innovative activity and consequently supports arguments of a flatter inverted U-shape for high tech sectors (Asimakopoulos et al. 2020).[3] There is no significant evidence that there is a curvilinear relationship between exploitative linkages and innovation activities[4]. This finding contradicts the inverted U-shape found by previous studies (Radicic 2020, Cruz-González et al. 2015). Therefore Hypothesis 2 is also only partly rejected.

[3] The “Inno_Activity” variable is the fraction of innovation activity variable and was constructed by adding the sum of each binary dependent variable and then dividing by the number of dependent variable (i.e., dividing by five to make a fraction). Table A9 in the supplemental document displays the fractional probit regression.

[4] Please find Fig. A1 in the supplemental document which displays the margins plot for exploitative linkages.

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

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Exploratory Linkages	0.172***	0.137***	0.112***	0.097***	0.192***
	(0.023)	(0.024)	(0.031)	(0.035)	(0.018)
Exploitative Linkages	-0.025	-0.123	-0.031	-0.077	0.026
	(0.078)	(0.089)	(0.086)	(0.093)	(0.070)
Exploratory Linkages Squared	-0.015***	-0.011***	-0.007*	-0.006	-0.016***
	(0.003)	(0.003)	(0.003)	(0.004)	(0.002)
Exploitative Linkages Squared	0.012	0.055*	0.012	0.030	0.006
	(0.025)	(0.028)	(0.028)	(0.029)	(0.023)
Employment (log)	0.025	0.033	0.040*	0.002	0.074***
	(0.021)	(0.022)	(0.023)	(0.025)	(0.019)
Firm Age (log)	-0.016	-0.046	-0.034	0.029	-0.058**
	(0.030)	(0.035)	(0.036)	(0.039)	(0.026)
% University Education	0.103	0.018	0.028	0.058	0.163**
	(0.080)	(0.085)	(0.092)	(0.105)	(0.075)
Multi Plant	0.135**	0.082	0.117	-0.055	-0.137**
	(0.065)	(0.064)	(0.072)	(0.078)	(0.063)
Received Subsidy	0.133**	0.143**	0.003	0.002	0.052
	(0.054)	(0.057)	(0.068)	(0.074)	(0.052)
Observations	189	189	189	189	189
Wald Chi-square (prob)	65.42	63.57	49.30	29.34	74.78
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
Pseudo R2	0.345	0.301	0.209	0.111	0.444

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Customer Linkages	-0.015	0.011	0.161**	0.238***	0.144**
	(0.064)	(0.080)	(0.081)	(0.090)	(0.071)
Supplier/Consultant Linkages	0.281***	0.204***	0.098	-0.014	0.224***
	(0.053)	(0.067)	(0.079)	(0.091)	(0.056)
Competitor Linkages	-0.080	0.088	0.126	0.086	0.109
	(0.081)	(0.086)	(0.089)	(0.091)	(0.093)
Public Linkages	0.095	0.072	0.092	0.004	0.007
	(0.072)	(0.077)	(0.087)	(0.092)	(0.076)
Conferences	-0.003	0.022	-0.031	-0.095	0.035
	(0.069)	(0.080)	(0.088)	(0.093)	(0.070)
Scientific Journals	0.274***	0.217***	0.003	0.151*	0.164**
	(0.062)	(0.074)	(0.086)	(0.089)	(0.065)
Industry Associations	-0.195***	-0.080	0.070	0.038	-0.030
	(0.069)	(0.080)	(0.084)	(0.086)	(0.066)
Other Data Sources	0.017	0.143	0.088	-0.004	0.001
	(0.104)	(0.126)	(0.149)	(0.149)	(0.135)
Employment (log)	0.034*	0.038*	0.045*	0.007	0.073***
	(0.020)	(0.021)	(0.023)	(0.024)	(0.019)
Firm Age (log)	-0.032	-0.048	-0.041	0.022	-0.078**
	(0.032)	(0.035)	(0.036)	(0.038)	(0.031)
% University Education	0.104	0.016	0.029	0.053	0.125
	(0.076)	(0.087)	(0.093)	(0.106)	(0.083)
Multi Plant	0.183***	0.127**	0.125	-0.013	-0.076
	(0.062)	(0.065)	(0.076)	(0.081)	(0.068)
Received Subsidy	0.143***	0.142**	0.019	0.033	0.091*
	(0.049)	(0.058)	(0.068)	(0.075)	(0.055)

Observations	189	189	189	189	189
Wald Chi-square (prob)	72.48	62.57	47.50	25.13	69.30
	(0.000)	(0.000)	(0.000)	(0.022)	(0.000)
Pseudo R2	0.380	0.290	0.198	0.101	0.377

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

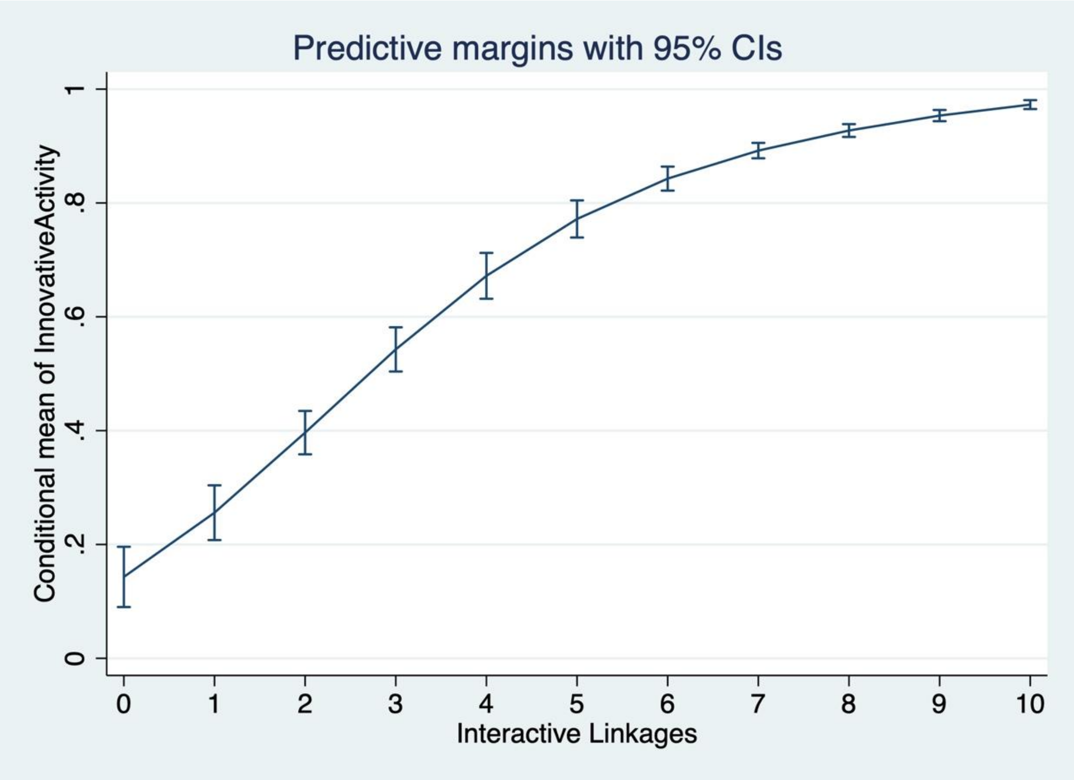

Fig. 1 Margins plot displaying the returns to innovative activity from exploratory (interactive) linkages.

6.3 Hypothesis 3a-3e

Starting with the results for exploratory linkages, there is an insignificant relationship between public linkages to universities, research organisations and innovative activities. This is a surprising result due to the unstandardised nature of products in the ORE sector and the need for complex knowledge combinations at the early stages of the product life cycle (Løvdal and Aspelund 2011, Weinzettel et al. 2009, Baumol 2002) and particularly since academics have played a primary role in the sector since its establishment (Corsatea 2014). Consequently, hypothesis 3a is rejected. However, linkages to suppliers and consultants are positively related to in-house R&D, external R&D, and process innovation. Cohen and Klepper (1996) describe how in the early stage of the product life cycle few actors have sufficient knowledge underlying the emerging innovations. As Laursen and Salter (2006) suggest, in the early stage of the product life cycle, innovative firms need to draw on the knowledge of *"lead users, component suppliers, or universities"* (Laursen and Salter 2006). The evidence presented here suggests that lead users and component suppliers, as opposed to university actors are critical drivers of innovation activities in ORE, providing part support for hypothesis 3b.

Linkages to customers are positively and significantly related to new-to-market, new-to-firm, and process innovations providing part support for hypothesis 3c. In the theoretical discussion, it was not expected that interactions with customers would be important for process innovations. This level of significance may signal the importance of learning about all types of innovations in the early stages of sector development and between all actors. For example, although ORE technology/developer firms have the resources to design and develop ORE technologies, many do not have the capacity to install their devices offshore and they will require support from other companies (engineering/consultancy firms). In turn, it is likely that consultants and engineers will heavily rely on ORE technology/developers for process innovation development. Similarly, business support organisations, training or skills providers feeding into this sector will constantly need to upgrade process innovations by learning from their customers as the skill needs of the sector evolves.

Turning to the individual level exploitative linkages, an insignificant relationship occurs between conferences and innovation type (hypothesis 3d). This result contradicts the findings of previous scholars, who find firms who attend and participate in professional conferences are more likely to surpass their current level of innovative activities (Tether and Tajar 2008, Maskell et al. 2006), while studies such as Bathelt and Schuldt (2008) emphasise the importance of conference attendance and participation for new-to-firm innovation. Moon et al. (2019) provide a potential reason for the insignificant association between conferences and new-to-firm innovation, noting how the magnitude of importance for conferences diminishes as the firm's absorptive capacity increases.

Scientific journals have a positive and significant relationship with internal R&D, external R&D, new to firm innovation and process innovation providing support for hypothesis 3e. Analytical (scientific) knowledge may be required to solve fundamental problems in the product or production process particularly prevalent in the research and development phase (Davids and Frenken 2018). This further relates to the complementary relationship often found between a firms' internal knowledge generation and external knowledge sourcing (Roper et al. 2014, Vanhaverbeke 2012, Jones and Craven 2001). There is a negative relationship between industry associations and R&D. In hindsight, this is not all that surprising as membership of industry associations may be more pertinent for the commercialisation stage of the innovation process again signalling the type of interaction may be strongly related to the type of innovation objective (Todling et al., 2009). Other exploitative data sources have a negligible effect on all type of innovative activity.

7. Conclusion

7.1 The paper's contribution

Firms are increasingly relying on external knowledge linkages for their innovative activities, and openness to external knowledge sources is regarded as a key driver of innovation. (Ferreras-Méndez et al. 2016, Cruz-González et al. 2015, Laursen and Salter 2006, Chesbrough 2017). To gain further insight into the role of external knowledge linkages for innovative activity, this paper examines the relationship between exploratory, exploitative linkages and five types of innovation activity for a sample of EU and UK firms operating in the ORE sector and its supply chain, using data from a unique purpose-built survey.

This paper contributes to the open innovation literature (Chesbrough 2017, 2006, 2003) by distinguishing between two types of external knowledge linkages, exploratory linkages (interactive) and exploitative linkages (non-interactive) and examining the effects of each search strategy for innovative activity in a sector at the early stages of the product life cycle. This paper identifies that firms which are more open to exploratory linkages and exploitative linkages are more innovative, than firms which are less open to external linkages. Although exploratory linkages were found to be positively associated with all types of innovative activity, this paper finds exploratory linkages to be subject to diminishing returns. This effect sets in after five interactive linkages, in which over-searching hinders innovative activity. Conversely, there is an absence of a significant relationship for exploitative linkages and all types of innovative activity.

In addition to examining exploratory and exploitative linkages as a whole, this paper answers the call of previous literature (Ardito and Petruzzelli 2017) and disaggregates each type of linkage to individual indicators to examine the relative significance of each type of linkage for innovative activity. Customers are identified to be more important in the production and commercialisation innovation outcome stages for firms, whilst interactions with suppliers and sourcing analytical knowledge (from scientific journals) is more important in the basic technology research, feasibility, development, and process stages. Critically, the results indicate that different types of innovation are related to different, but specific combinations of knowledge linkages.

7.2 Implications of the research for management

The findings have implications for management practices. The results find diminishing returns to innovative activity, as the number of exploratory linkages increase. Importantly, this finding supports the findings of previous research (Radicic 2020, Cruz-González et al. 2015, Asimakopoulos et al. 2020) meaning that actors in sectors at the infant stage of development (like the ORE) suffer from the same diminishing returns from knowledge sourcing activities as actors in more established sectors, but there is not an inverted U-shaped relationship. Due to the cognitive limitations of management, some innovative ideas may not be fully exploited (Radicic et al. 2019). This paper recommends organisations who are focused on product innovation to interact with customers. Organisations who are prioritising R&D activity should interact with suppliers and consultants, while organisations focused on introducing new processes should interact with customers, suppliers, and consultants.

In using these findings organisations can prioritise and identify the most efficient linkages relative to their innovation objective, thus avoiding absorptive capacity exhaustion (Cohen and

Levinthal 1990). Of course, this is a difficult task which requires an understanding of the market (Lacerda and van den Bergh 2020). Due to the afore mentioned reason, Cruz-González et al. (2015) warns how scholars must be more cautious when interpreting the results of external knowledge searching.

7.3 Implications of the research for policy

The findings indicate the importance for policymakers to recognise the role of exploratory linkages, with customers, suppliers, and consultants for development of product and process innovation. To enhance product and process innovation in the ORE sector, policy interventions which promote and build collaborations or interactive partnerships among ORE firms may be fruitful. These types of relationships create a wider benefit which extend past participating firms through stimulating knowledge creation and diffusion (Roper et al. 2017). Exploratory relationships can be enabled by providing a legal and regulatory framework which supports external collaboration across ORE firms by lowering the cost of external collaboration and the development of the relevant infrastructure. The results show linkages to suppliers and consultants is positively related to ORE firms' R&D activity. This paper suggests policymakers support backwards linkages by providing tax incentives for ORE R&D collaboration, which improves the experience, skills, knowledge, and competencies between parties.

7.4 Limitations of the research and avenues for future research

The study has some limitations. Firstly, a cross-sectional survey was employed in this paper, meaning results show the directional evidence of a relationship, but fails 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. While the REIS had many benefits due to its novelty and its construction specifically for this research, the response rate was initially lower than anticipated due to business upheaval in the economy from COVID-19. Natural disasters inevitably bring crises to firms and finding alternative suppliers and external partners is more difficult (Yonggui Wang et al. 2020, Benson and Clay 2004). A study concentrating on the exogenous effect the COVID-19 pandemic had on the ORE firm's knowledge sourcing activities would be a fruitful avenue for research. Due to the sample size, this paper examined the ORE sector as a whole, rather than examining the ORE sector by ORE type (i.e., offshore wind versus tidal). Future research could work to increase the sample size to identify the differences in knowledge sourcing strategies of firms involved in different ORE types. This would provide rich results in how different knowledge search strategies could be more or less important to different innovative activities in different ORE sources. In doing so, policy could be more accurately informed for different sources of ORE.

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SUPPLEMENTAL DOCUMENTATION

Table A1. Breakdown of respondents by country

Country of Main Establishment	Percentage of Respondents
Republic of Ireland	31%
United Kingdom	50%
Europe	19%

Note: When rounded to the nearest whole number, the United Kingdom consists of England (20%), Wales (20%) and Scotland/Northern Ireland (10%). The European category consists of respondents from 9 EU based countries such as France, Denmark, Sweden, the Netherlands, Belgium, Norway, Spain, Italy, and Luxembourg.

Table A2. Breakdown of respondents by type of firm

Type of Firm	Percentage of Respondents
Academic/Research Performing Establishment	8%
Consultancy/Engineering Company	34%
Marine Operations	14%
ORE Technology/Developer	33%
Other	11%

Note 1: The type of firm categories was determined by members of the research team from the information of each company provided in the sampling frame.
Note 2: Firms such as business support organisations, training or skills providers and firms who offer legal services to the ORE sector are among the types of firms included in the "Other" category.
Note 3: Though ORE Technology/Developer firms have the resources to design and develop ORE technologies, some do not have the capacity to install the device. This is the key distinction between ORE Technology/Developer and Consultancy/Engineering. Subsea engineering companies have the capacity to install ORE technologies.

Table A3. Matrix of correlations Eq(1)

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	0.555	1.000												
(3) New-to-Market	0.442	0.417	1.000											
(4) New-to-Firm	0.330	0.210	0.315	1.000										
(5) Process Innovation	0.555	0.347	0.459	0.331	1.000									
(6) Exploratory Linkages	0.421	0.449	0.449	0.344	0.509	1.000								
(7) Exploitative Linkages	0.194	0.292	0.153	0.142	0.299	0.280	1.000							
(8) Exploratory Linkages Squared	0.286	0.338	0.379	0.298	0.362	0.952	0.240	1.000						
(9) Exploitative Linkages Squared	0.201	0.317	0.173	0.169	0.298	0.300	0.959	0.258	1.000					
(10) Employment (log)	0.141	0.161	0.200	0.077	0.162	0.135	0.048	0.121	0.102	1.000				
(11) Firm Age (log)	-0.065	-0.065	-0.002	0.029	-0.095	0.005	-0.148	0.058	-0.111	0.519	1.000			
(12) % University Education	0.127	0.099	0.078	0.069	0.140	0.141	0.162	0.142	0.164	-0.200	-0.291	1.000		
(13) Multi Plant	0.234	0.211	0.235	0.028	0.058	0.164	0.082	0.136	0.102	0.344	0.076	0.091	1.000	
(14) Received Subsidy	0.344	0.343	0.163	0.106	0.298	0.271	0.274	0.188	0.248	0.025	-0.116	0.128	0.128	1.000

Table A4. Matrix of correlations Eq. (2)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) In-house R&D	1.000																	
(2) External R&D	0.555	1.000																
(3) New-to-Market	0.442	0.417	1.000															
(4) New-to-Firm	0.330	0.210	0.315	1.000														
(5) Process Innovation	0.555	0.347	0.459	0.331	1.000													
(6) Forward Linkages	0.302	0.308	0.386	0.314	0.445	1.000												
(7) Backward Linkages	0.502	0.444	0.346	0.204	0.526	0.591	1.000											
(8) Horizontal Linkages	0.236	0.301	0.309	0.215	0.334	0.420	0.368	1.000										
(9) Public Linkages	0.353	0.376	0.352	0.217	0.392	0.568	0.513	0.449	1.000									
(10) Conferences	0.112	0.208	0.090	0.064	0.230	0.136	0.132	0.082	0.188	1.000								
(11) Scientific Journals	0.309	0.340	0.119	0.174	0.343	0.150	0.237	0.155	0.246	0.594	1.000							
(12) Industry Associations	0.060	0.158	0.145	0.109	0.185	0.154	0.118	0.028	0.172	0.566	0.484	1.000						
(13) Other Data Sources	0.032	0.082	0.074	0.035	0.009	0.102	0.008	-0.021	0.055	-0.027	0.008	0.006	1.000					
(14) Employment (log)	0.141	0.161	0.200	0.077	0.162	0.094	0.071	0.145	0.084	0.008	0.004	0.046	0.137	1.000				
(15) Firm Age	-0.065	-0.065	-0.002	0.029	-0.095	-0.009	-0.087	0.048	-0.058	-0.143	-0.147	-0.127	0.087	0.519	1.000			
(16) % University Education	0.127	0.099	0.078	0.069	0.140	0.118	0.080	0.081	0.106	0.141	0.114	0.122	0.076	-0.200	-0.291	1.000		
(17) Multi Plant	0.234	0.211	0.235	0.028	0.058	0.078	0.109	0.116	0.153	0.046	-0.044	0.148	0.125	0.344	0.076	0.091	1.000	
(18) Received Subsidy	0.344	0.343	0.163	0.106	0.298	0.161	0.294	0.135	0.294	0.186	0.257	0.220	0.077	0.025	-0.116	0.128	0.128	1.000

Table A5. Multivariate Probit output for Eq. (1).

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Exploratory Linkages	0.684***	0.516***	0.389***	0.303***	0.873***
	(0.123)	(0.110)	(0.112)	(0.110)	(0.134)
Exploitative Linkages	-0.176	-0.448	-0.088	-0.215	0.188
	(0.327)	(0.344)	(0.281)	(0.283)	(0.346)
Exploratory Linkages Squared	-0.061***	-0.041***	-0.024**	-0.019*	-0.073***
	(0.013)	(0.011)	(0.011)	(0.011)	(0.014)
Exploitative Linkages Squared	0.078	0.200*	0.039	0.085	0.020
	(0.106)	(0.110)	(0.090)	(0.087)	(0.110)
Employment (log)	0.111	0.128	0.135*	0.012	0.346***
	(0.085)	(0.082)	(0.075)	(0.074)	(0.077)
Firm Age (log)	-0.063	-0.184	-0.144	0.067	-0.309**
	(0.133)	(0.133)	(0.127)	(0.122)	(0.136)
% University Education	0.391	0.149	0.165	0.161	0.752**
	(0.330)	(0.321)	(0.288)	(0.316)	(0.353)
Multi Plant	0.507*	0.263	0.364	-0.174	-0.542*
	(0.262)	(0.243)	(0.237)	(0.235)	(0.293)
Received Subsidy	0.547**	0.528**	-0.033	0.002	0.187
	(0.243)	(0.225)	(0.221)	(0.218)	(0.259)
Constant	-1.117**	-1.248**	-0.944**	-1.184**	-1.535***
	(0.505)	(0.532)	(0.446)	(0.468)	(0.547)
Wald Chi-square (prob)	276.02				
	(0.0000)				
Log pseudolikelihood	-432.13037				
Observations	189	189	189	189	189

Table A6. Multivariate Probit output for Eq. (2)

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Customer Linkages	-0.087	0.019	0.499*	0.691***	0.556*
	(0.286)	(0.287)	(0.265)	(0.264)	(0.308)
Supplier/Consultant Linkages	1.145***	0.756***	0.342	-0.031	0.852***
	(0.287)	(0.265)	(0.252)	(0.261)	(0.285)
Competitor Linkages	-0.335	0.301	0.394	0.279	0.474
	(0.351)	(0.312)	(0.278)	(0.257)	(0.381)
Public Linkages	0.371	0.266	0.203	-0.026	0.055
	(0.332)	(0.284)	(0.279)	(0.262)	(0.339)
Conferences	-0.061	0.084	-0.068	-0.219	0.182
	(0.305)	(0.290)	(0.268)	(0.268)	(0.286)
Scientific Journals	1.154***	0.759***	0.082	0.439	0.728**
	(0.302)	(0.285)	(0.263)	(0.270)	(0.300)
Industry Associations	-0.721**	-0.263	0.181	0.096	-0.078
	(0.297)	(0.283)	(0.263)	(0.253)	(0.261)
Other Data Sources	0.154	0.597	0.220	-0.014	0.173
	(0.493)	(0.483)	(0.506)	(0.455)	(0.592)
Employment (log)	0.175*	0.151*	0.146**	0.031	0.332***
	(0.090)	(0.080)	(0.072)	(0.070)	(0.076)
Firm Age (log)	-0.162	-0.196	-0.170	0.043	-0.413***
	(0.149)	(0.131)	(0.126)	(0.120)	(0.147)
% University Education	0.423	0.155	0.153	0.184	0.535
	(0.339)	(0.318)	(0.275)	(0.311)	(0.339)
Multi Plant	0.750***	0.399*	0.379	-0.049	-0.285
	(0.285)	(0.242)	(0.247)	(0.241)	(0.291)
Received Subsidy	0.585**	0.498**	0.060	0.086	0.305
	(0.230)	(0.225)	(0.216)	(0.219)	(0.249)
Constant	-0.827	-1.230**	-0.842**	-1.134**	-0.787
	(0.535)	(0.496)	(0.422)	(0.446)	(0.540)
Wald Chi-square (prob)	334.03				
	(0.0000)				
Log pseudolikelihood	-434.12458				
Observations	189	189	189	189	189

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: Though not included in Table A6, the natural log of employees, firm age, the percentage of staff with a third level qualification, multi plant organisations and organisations who received a subsidy were included in the estimation.

Table A7. Output for Eq. (1) reporting marginal effects controlling for Country and Type of Firm

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Exploratory Linkages	0.176***	0.147***	0.113***	0.096***	0.196***
	(0.021)	(0.024)	(0.030)	(0.033)	(0.019)
Exploitative Linkages	-0.042	-0.130	-0.038	-0.033	0.035
	(0.069)	(0.085)	(0.085)	(0.094)	(0.069)
Exploratory Linkages Squared	-0.016***	-0.012***	-0.007**	-0.006*	-0.016***
	(0.002)	(0.003)	(0.003)	(0.004)	(0.002)
Exploitative Linkages Squared	0.022	0.060**	0.015	0.017	0.002
	(0.023)	(0.027)	(0.027)	(0.029)	(0.022)
Ireland	-0.136*	-0.024	-0.101	0.157	0.012
	(0.078)	(0.088)	(0.096)	(0.111)	(0.081)
UK	-0.063	-0.066	0.040	0.230**	0.014
	(0.076)	(0.078)	(0.091)	(0.096)	(0.079)
Academic or Research Institute	-0.038	-0.026	-0.102	-0.122	0.019
	(0.109)	(0.133)	(0.142)	(0.157)	(0.127)
Consultancy or Engineering	0.063	0.048	0.004	0.128	-0.007
	(0.068)	(0.105)	(0.111)	(0.107)	(0.075)
ORE Technology Developer	0.229***	0.187*	-0.001	0.141	-0.056
	(0.070)	(0.104)	(0.114)	(0.114)	(0.080)
Other Firm Type	0.128	0.055	0.059	0.127	-0.136
	(0.090)	(0.122)	(0.138)	(0.137)	(0.095)
Observations	189	189	189	189	189

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Note: Table A7 and Table A8 also control for the natural log of employees, firm age, the percentage of staff with a third level qualification, multi plant organisations and organisations who received a subsidy. The Europe and Marine operations dummy variables are the reference categories.

Table A8. Output for Eq. (2) reporting marginal effects controlling for Country and Type of Firm

VARIABLES	(1) In-house R&D	(2) External R&D	(3) New-to-Market	(4) New-to-Firm	(5) Process Innovation
Customer Linkages	0.001	0.029	0.142*	0.163*	0.111
	(0.060)	(0.083)	(0.082)	(0.092)	(0.071)
Supplier/Consultant Linkages	0.289***	0.207***	0.119	0.056	0.252***
	(0.052)	(0.068)	(0.078)	(0.091)	(0.058)
Competitor Linkages	-0.105	0.079	0.126	0.088	0.138
	(0.077)	(0.084)	(0.090)	(0.088)	(0.088)
Public Linkages	0.049	0.061	0.066	0.015	0.012
	(0.067)	(0.076)	(0.089)	(0.092)	(0.073)
Conferences	0.032	0.050	-0.012	-0.035	0.014
	(0.069)	(0.081)	(0.088)	(0.091)	(0.069)
Scientific Journals	0.268***	0.211***	-0.017	0.088	0.142**
	(0.063)	(0.074)	(0.086)	(0.089)	(0.068)
Industry Associations	-0.201***	-0.085	0.071	0.043	-0.013
	(0.069)	(0.083)	(0.083)	(0.085)	(0.063)
Other Data Sources	0.076	0.192	0.115	0.017	-0.011
	(0.123)	(0.142)	(0.150)	(0.142)	(0.127)
Ireland		0.014	-0.118	0.127	0.074
	(0.076)	(0.082)	(0.097)	(0.109)	(0.083)
UK	0.037	-0.013	0.050	0.213**	0.121
	(0.073)	(0.082)	(0.097)	(0.098)	(0.082)
Academic or Research Institute	0.028	0.046	-0.092	-0.108	0.084
	(0.113)	(0.129)	(0.140)	(0.162)	(0.136)
Consultancy or Engineering	0.112	0.108	0.003	0.126	0.015
	(0.071)	(0.100)	(0.103)	(0.112)	(0.082)
ORE Technology Developer	0.265***	0.233**	0.002	0.137	-0.050
	(0.070)	(0.099)	(0.107)	(0.117)	(0.087)
Other Firm Type	0.203**	0.113	0.040	0.128	-0.083
	(0.079)	(0.126)	(0.134)	(0.142)	(0.097)
Observations	189	189	189	189	189

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A9. Fractional Probit regression using explanatory variables for Eq. (1) with robust standard errors

VARIABLES	(1) Fraction of Innovative Activity
Exploratory Linkages	0.472***
	(0.061)
Exploitative Linkages	-0.114
	(0.165)
Exploratory Linkages Squared	-0.036***
	(0.006)
Exploitative Linkages Squared	0.061
	(0.053)
Employment (log)	0.097**
	(0.046)
Firm Age (log)	-0.062
	(0.076)
Third-level Education	0.223
	(0.161)
MultiPlant	0.094
	(0.136)
Received Subsidy	0.207*
	(0.123)
Constant	-1.094***
	(0.268)
Observations	189

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Fig. A1 Predictive Margins Plot with Exploitative Linkages

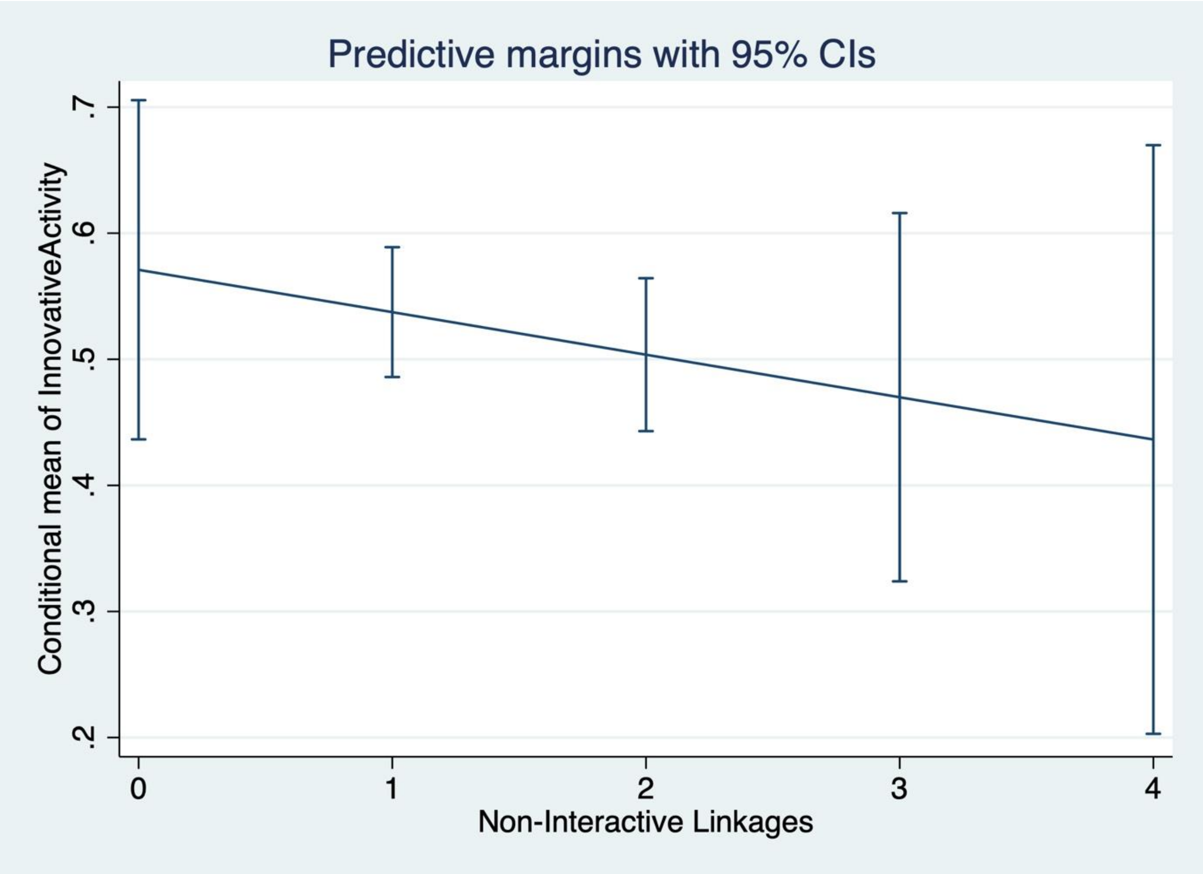

Fig A2 shows the confidence intervals overlap each other, which suggests no significant difference in innovative activity as the number of exploitative linkages increase. For the aforementioned reason, this paper rejects Hypothesis 2b.

Table A10.

Publicly Available Data Sources used to compile the Sampling Frame
1. https://www.oceanenergyireland.com/SupplyChain/Database.html
2. https://www.mescg.co.uk/
3. https://www.nweurope.eu/projects/project-search/opin-ocean-power-innovation-network/#tab-7
4. http://www.emec.org.uk/marine-energy/wave-developers/
5. https://www.offshore-energy.biz/companies/?fwp_market_checkboxes=green-marine%2Cmarine-energy%2Cfloating-solar-energy%2Cocean-thermal-energy%2Ctidal-energy%2Cwave-energy%2Csubsea
6. https://www.marineenergywales.co.uk/membership/members-directory/
7. https://www.geoscience.ie/member-companies/
8. http://www.british-hydro.org/bha-directory/
9. https://www.brydencentre.com/partners
10. https://www.uhi.ac.uk/en/contact-us/
11. https://www.ukdirectory.co.uk/manufacturing-and-industry/engineering/marine-engineering-companies/
12. https://www.oceanologyinternational.com/exhibitor-directory/#
13. PRIMRE/Databases/Technology Database | Open Energy Information (openei.org)
14. OEE: the largest global network of ocean energy professionals - Ocean Energy Europe (oceanenergy-europe.eu)
15. Members' Directory | Regen