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The implementation of inbound open innovation at the firm level: A dynamic capability perspective

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1. Introduction

The rise of globalisation, the innovative capability of high-technology start-ups supported by venture capitalists, and the growth of new information and communication technologies are among the main factors that explain the emergence of open innovation (henceforth, OI) (Chesbrough, 2006b; Gassmann and Enkel 2004). The extant literature provides a clear understanding of the benefits and limitations of inbound OI (Asimakopoulos et al., 2020; Laursen and Salter 2014; Ritala et al., 2015). These studies have typically conceptualised inbound OI in terms of specific OI activities, such as collaboration with external partners (Laursen and Salter 2014), searching for different sources of information (Bianchi et al., 2011; Brunswicker and Vanhaverbeke 2015; Damanpour et al., 2018; Laursen and Salter 2006), interactions with customers (Foss, et al. 2011), opportunity exploitation (Foss et al., 2013), outsourcing (Bianchi et al., 2016), and external knowledge sourcing (Asimakopoulos et al., 2020). Although these studies have contributed to our understanding of a diverse range of possible OI activities that managers can implement as part of their innovation strategy at the firm level, they have focused only on single OI activities in isolation. In practice, companies can improve their permeability to external knowledge by developing a portfolio of different OI activities (Teplov et al., 2019).

For instance, Electrolux, a leading global appliance company and an experienced and conscious adopter of OI, as exemplified by the presence of dedicated OI teams and OI managers (Electrolux 2021), undertakes OI through a novel set-up: an Innovation Factory, a hub and collaborative space where different types of OI activities take place in the firm. In this hub, the company facilitates a sharing-driven collaboration model to exchange ideas (Electrolux 2021). Electrolux stimulates alliances between suppliers, customers, incubators, start-ups, universities, SMEs, and other business partners, illustrating their engagement in idea and start-up competitions. In particular, the company seeks proposals from start-ups, SMEs and university spin-offs to participate in their OI "Booster" Programme (Electrolux 2021). It also conducts crowdsourcing activities, looking for innovative solutions to innovation challenges through external opportunities. Specifically, Electrolux searches for partners who are interested in working to co-develop and co-create customised solutions for products or processes (BoosterProgram 2021). These multiple OI activities appear to be relatively focused and mutually exclusive at the firm level, but the complementarity effect of multiple OI activities may perhaps be more visible at the project level. Such an example demonstrates that in practice, an OI strategy is operationalised in more complex ways than are often portrayed in studies that only consider a single activity.

The challenge for firms is to move beyond the traditional networks of collaboration with longstanding suppliers, customers and universities to collaborate with non-traditional partners from new ecosystems with expertise far away from that of the firm. This is shown in the example above, highlighting a range of different types of OI activities. The challenge for many firms is to connect with new and remote ecosystems to acquire more diverse, unfamiliar knowledge and resources to accelerate products, services, business models and manufacturing innovations. To further stimulate the network, they are more likely to simultaneously conduct both traditional OI activities such as search and collaboration, and new emerging OI activities such as crowdsourcing, idea and start-ups competitions, and partnering with OI intermediaries.

Reflecting on such practices, studies have recently started to look beyond single OI activities by including two or more OI activities simultaneously as a way of addressing the above limitation of studies related to single OI activity (Cano-Kollmann et al., 2017; Chesbrough and Brunswicker, 2014; Markovic et al., 2020; Pinarello et al., 2022; Podmetina et al., 2018; Rangus et al., 2016; Teplov et al., 2019). Examples include scanning for external ideas, collaborative innovation

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with external partners, IP in-licensing, crowdsourcing and customer co-creation. However, while these studies have provided a clear idea of the broad range of different types of OI activities firms can undertake, they have not examined the outcome of the breadth of OI activities. The very few studies that have looked into the outcome of the breadth of OI activities are confined to only two or three OI activities (Cheng and Huizingh 2014; Stephan et al., 2019), thus overlooking the wide range of OI activities that firms can include in their OI portfolio, as is comprehensively described in the studies by Chesbrough and Brunswicker (2014), Podmetina, et al. (2018) and Teplov et al. (2019).

From a theoretical perspective, such a shift from specific single OI activities to a large portfolio of OI activities brings new challenges as multiple OI activities increase the complexity of implementing an OI strategy at the firm level. Multiple activities can add additional resource overheads in terms of additional financial resources that are to be invested, and the time and attention that the R&D team has to allocate to such activities. Therefore, it is important to have a better understanding of the actual outcome of the breadth of a large number of OI activities. In order to address this gap, our paper considers the breadth of OI in the form of nine activities, and examines its effect on innovativeness. The activities are intellectual property (IP) in-licensing, external technology acquisition, subcontracting R&D, using external networks, idea and start-up competitions, collaborative innovation with external partners, crowdsourcing, customer co-creation in R&D projects, and scanning for external ideas (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019).

While developing a portfolio of different types of OI activities, we argue that it is also important for managers to understand the key learning routines and capabilities that support these activities. Only a few recent studies have explored the changes that firms apply to their organisational capabilities to support the implementation of OI at the firm level (Bianchi et al., 2016; Foss et al., 2013; Foss, et al. 2011; Pinarello et al., 2022; Zobel 2017). For instance, top management support, absorptive capacity, project management, and dedicated OI teams have been found to be among the competences and capabilities that support the implementation of specific OI activities, especially collaboration with external partners and access to technological resources (Cheah and Ho 2020; Grama-Vigouroux et al., 2020; Lakemond et al., 2016; Zobel 2017). Not many studies have moved beyond a single activity to explore the capabilities, competences, and routines that support a diverse portfolio of OI activities (Cheng and Huizingh 2014; Chesbrough and Brunswicker, 2014; Markovic et al., 2020; Podmetina et al., 2018). Based on this gap in the literature, our paper seeks to contribute to this emerging stream of research by investigating the organisational capabilities that support the breadth of the aforementioned nine OI activities at the firm level.

To this end, building on the theory of dynamic capabilities (Eisenhardt and Martin 2000; Helfat et al., 2009; Teece et al., 1997), this study contributes to the implementation of the OI literature at the firm level. Dynamic capabilities are an organisation's ability to integrate, create, and reconfigure internal and external competences to respond to rapidly changing environments (Teece et al., 1997). They can be differentiated into two categories: first-order and second-order dynamic capabilities. First-order dynamic capabilities help the firm's basic capabilities and resources to change and provide a competitive advantage (Eisenhardt and Martin 2000; Teece et al., 1997); second-order dynamic capabilities are those that are adopted to create and support the development of first-order dynamic capabilities. They are also known as "learning-to--learn" capabilities, "higher-order" (Collis 1994), "meta", or "regenerative" dynamic capabilities (Ambrosini et al., 2009). For example, in the context of strategic alliances, alliance management is a first-order dynamic capability, whereas alliance learning is a second-order dynamic capability (Schilke 2014).

Our first research objective in this study is therefore to examine the outcome of the breadth of OI activities, a potential first-order dynamic capability that will potentially provide firms a competitive advantage in terms of innovativeness. Enhancing innovativeness, or the capacity to introduce new products and services, is a key source of competitive advantage and growth (Crossan and Apaydin 2010; Damanpour 1991). Our second research objective is to shed light on second-order dynamic capabilities, such as social information systems capabilities, the anticipation of new technologies, and relational capability, and a second-order learning routine, OI training (Nelson Richard and Winter Sidney 1982; Zollo and Winter 2002). The second-order routine and dynamic capabilities considered in this study represent learning mechanisms and antecedents that could potentially support the breadth of OI activities, which we conceptualise as a first-order dynamic capability that provides firms with a competitive advantage in terms of the level of innovativeness (Ambrosini et al., 2009; Schilke 2014). Based on pilot interviews with OI practitioners and from prior OI studies, these second-order dynamic capabilities were selected as being potential antecedents to the breadth of OI activities (Ambrosini et al., 2009; Schilke 2014).

Our findings, based on a survey of the high-value manufacturing sector in the UK, support the importance of differentiating between two levels of capabilities for the implementation of OI at the firm level. On the first level, our study shows that the breadth of OI activities is an important first-order dynamic capability that has a positive impact on firm innovativeness. On the second level, the proactive deployment of second-order dynamic capabilities and routines, namely open innovation training, social information systems capabilities, and relational capability, are effective information processing and learning mechanisms that enable firms to better perform and implement their first-order dynamic capability, the breadth of OI activities.

The rest of the paper is structured as follows. The second section provides a review of the literature on the conceptualisation of inbound OI, its outcomes and implementation. This is followed by the theoretical framework and hypotheses for the study, after which we present our methods and results. We then discuss our findings and contributions, before concluding with the limitations and future areas of research.

2. Literature review

2.1. Conceptualisation of inbound OI and its outcomes

The traditional closed model of innovation represents a situation where innovations are created in-house via the processes through which firms create their own ideas, which they subsequently develop, promote, finance, and support internally. In contrast, inbound OI is a model that purposively integrates external knowledge with internal R&D by leveraging ideas from different external partners (Chesbrough 2003). In terms of the outcomes of single OI activity, searching broadly and deeply in different search channels, and collaborating with different types of external partners, have positive effects on performance at both the firm and project levels (Bahemia et al., 2017; Baker 2012; Laursen and Salter 2006; Leiponen 2012; Salge et al., 2013). There are "learning" benefits from openness to the knowledge of external partners as firms create routines of processing information to find and choose appropriate partners.

However, there are several limitations to two main inbound OI activities namely search or collaboration. The benefits of openness only operate up to a certain point, beyond which decreasing returns set in (Du et al., 2014; Garriga et al., 2013; Grimpe and Kaiser 2010; Laursen and Salter 2006; Laursen and Salter 2014). Although inbound OI is mainly conceptualised in terms of the breadth of search of different sources of information and the breadth of collaboration with different types of external partners such as suppliers, universities and customers, these represent only two OI activities (Laursen and Salter 2006, 2014). Other important activities include crowdsourcing, idea and start-up competitions, using external networks, customer co-creation in R&D projects, and external technology acquisition (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019). As noted, some

studies in the OI literature have started to conceptualise OI in terms of the diverse range of OI activities other than search and collaboration. Some of them have examined only one OI activity in isolation, such as crowdsourcing (Afuah et al., 2012; Majchrzak and Malhotra 2013; Pollok et al., 2019), customer co-creation (Williams 2012; Zwass and Vladimir, 2010), and external technology acquisition (Hung and Chou 2013). Recently, scholars have moved beyond single OI activities to consider two or more. Table 1 below summarises the key studies that have conceptualised inbound OI in terms of more than one OI activity.

More specifically, several studies have contributed to the inbound OI literature by addressing the conceptual ambiguity of the conceptualisation of OI, and the different interpretations of openness that still prevail (Dahlander and Gann 2010; Teplov et al., 2019; Trott and Hartmann 2009). They have broadened the conceptualisation of inbound OI beyond a single OI activity (Cano-Kollmann et al., 2017; Chesbrough and Brunswicker, 2014; Pinarello et al., 2022; Podmetina et al., 2018; Rangus et al., 2016; Teplov et al., 2019). For example, Cano-Kollmann et al. (2017) found that public support for innovation is related to a higher level of engagement in two inbound OI activities: subcontracting of R&D to other firms and collaboration with other firms.

Some studies have started to explore even more than two OI activities, describing the adoption patterns of firms from a portfolio of different types of OI activities. Rangus et al. (2016) examined the adoption patterns of five inbound OI activities between Slovenia and Italy, finding that both countries have identical patterns in relation to their adoption of these OI activities. Using an exploratory multiple case study analysis of nine firms, Pinarello, et al. (2022) have examined the temporal evolution of five inbound OI practices. They have shown that firms change the types of inbound OI activities they use over time, and the choice of specific type of OI activities at a given point of time is influenced by drivers, and their specific needs.

Other studies have broadened the portfolio of inbound OI activities to nine different types and have described at a more granular level the actual adoption patterns of firms (Refer to Table 1). For instance, Podmetina, et al. (2018) identified a changing landscape of OI, in which new crowd-driven innovation activities are adopted as intensively as more traditional activities such as technology sourcing. They found that collaborative innovation activities are the OI activity that most firms in Europe still adopt intensively. Similarly, Chesbrough and Brunswicker (2014) mapped the adoption trends of 10 inbound OI activities in Europe and the US. They found that customer co-creation, informal networking, and university grants were the three leading inbound practices, while crowdsourcing and OI intermediary services were rated lowest in importance. The adoption of OI activities also appears to be

Table 1
Key studies conceptualising inbound OI in terms of more than one activity.

		Outcomes are not measured						Outcomes are measured	
Authors	Cano-Kollmann et al. (2017)	Markovic et al. (2020)	Pinarello et al. (2022)	Rangus et al. (2016)	Podmetina et al. (2018)	Teplov et al. (2019)	Chesbrough and Brunswicker (2014)	Stephan et al. (2019)	Cheng and Huizingh (2014)
Name of Construct	OI activities	Outside-in OI activities	Inbound OI practices	Inbound OI activities	OI activities	OI activities	Inbound practices	External knowledge sourcing activities	Outside-in activities
1.IP in-licensing		✓	✓	✓	✓	✓	✓		✓
2.External technology acquisition					✓	✓			
3.Subcontracting	✓				✓	✓	✓		✓
4.Using external networks		✓	✓	✓	✓	✓	✓		
5.Idea & start-up competitions			✓		✓	✓	✓		
6.Collaborative innovation with external partners	✓	✓	✓	✓	✓	✓		✓	✓
7.Crowdsourcing		✓	✓	✓	✓	✓	✓		
8.Customer co-creation in R&D projects				✓	✓	✓	✓		
9.Scanning for external ideas					✓	✓		✓	
10.University research grants							✓		
11.Publicly funded R&D consortia							✓		
12.Supplier innovation awards							✓		
13.Specialised services from OI intermediaries		✓					✓		
Total number of inbound OI activities	**2**	**5**	**5**	**5**	**9**	**9**	**10**	**2**	**3**
Outbound open innovation activities	X	X	X	✓	✓	✓	✓	X	✓
Outcomes of OI activities	X	X	X	X	X	X	X	Innovation performance	Innovation performance
Antecedents to open innovation	Refer to Table 3	Refer to Table 3	Refer to Table 3	X	Refer to Table 3	X	Refer to Table 3	Refer to Table 3	X

dependent on the size of the companies' regions (Teplov et al., 2019).

Although these studies have contributed to a more granular and comprehensive view of inbound OI by taking a portfolio perspective on defining inbound OI in terms of different types of OI activities, they have not examined the relationship between the breadth of inbound OI activities and innovation outcomes (e.g., firm and innovative performance), as summarised in Table 1. There is only limited empirical evidence about the outcomes of adopting simultaneously two or three OI activities and their outcomes. For example, Stephan, et al. (2019) focused on only two activities of inbound OI: external information sourcing and collaboration. They found a positive relationship between these activities and innovation performance. Cheng and Huizingh (2014) focused on three OI activities: performing these activities was significantly and positively related to performance (e.g., new product/service innovativeness, new product/service success, customer performance, and financial performance). However, these studies have limited the conceptualisation of OI activities to two and three OI activities (Stephan et al., 2019) and (Cheng and Huizingh 2014) respectively. As has already been described empirically in previous large-sample studies in Europe and the US, firms have a choice between around 10 inbound OI activities when implementing an OI strategy at the firm level (Chesbrough and Brunswicker 2014; Podmetina et al., 2018; Teplov et al., 2019). Our paper seeks to address this research gap; our first research question will examine the relationship between the breadth of nine OI activities and the innovativeness outcomes. Table 2 defines each of these activities.

2.2. Capabilities and routines supporting inbound OI at the firm level

At the firm level, scholars have recently started to look into the capabilities and routines that facilitate and support the implementation of OI. We summarise these studies in Table 3 below by classifying them into three groups in terms of their conceptualisation of OI.

The first group conceptualised OI in a general way without specifying any particular OI activity. Top management support, dedicated OI team, development of an internal OI language (Mortara and Tim Minshall, 2011), diversity of employees' education and work history (Bogers et al., 2018), OI skills, training and incentive systems (Mortara and Tim Minshall, 2011; Salter et al., 2014; Urbinati et al., 2020), and digital technologies, budget formalisation for digital investments, development of new and formalised procedures for OI (Urbinati et al., 2020) are among the enabling competences and routines that support the implementation of OI at the firm level.

The second group conceptualised OI in terms of a single activity such as collaboration with external partners, interaction with customers, and outsourcing (Bianchi et al., 2016; Cheah and Ho 2020; Foss, et al. 2011; Grama-Vigouroux et al., 2020). Capabilities in project management, and portfolio management and knowledge matching (Lakemond et al., 2016), internal learning capacity, and absorptive capacity (Zobel 2017) facilitate the implementation of collaboration with external partners and access to technological resources at the firm level; good communication routines, rewards to employees, and delegation of decision making support another OI activity, interaction with customers (Foss et al. 2011).

Finally, the third group conceptualised OI in terms of more than one activity and studies have found few new enabling factors (different from those in Groups 1 and 2) such as entrepreneurial, market, and resource orientation, relying on OI intermediaries, and IP management that support the ability of firms to undertake different types of OI activities simultaneously (e.g. IP in-licensing, subcontracting R&D, collaboration, using external networks, crowdsourcing, specialised services from OI intermediaries) (Cheng and Huizingh 2014; Markovic et al., 2020; Pinarello et al., 2022). This implies that new skills and capabilities are required when firms adopt a portfolio approach towards their OI activities rather than focusing on a single OI activity.

Although these studies have shed light on the competences and capabilities that firms have developed to support a portfolio approach to OI (e.g., different types of OI activities), empirical evidence has been confined to only a limited number (3–5) of different types of OI activities. In contrast, Podmetina, et al. (2018) took a more comprehensive view of the conceptualisation of inbound OI. They included nine different types of OI activities and explored a range of skills such as IP management, negotiations, team working virtual collaboration, and communications, as well as a broad range of abilities such as technology

Table 2
Definition of the breadth of inbound open innovation activities.

Breadth of open innovation activities	Definition	Examples of papers looking into one open innovation activity in isolation
1-Scanning for external ideas	Scanning for external ideas can cover relying on different external knowledge sources, discovering new knowledge fields, creating models that encourage knowledge recombination in product innovation.	(Bogers and West 2012; Laursen 2012)
2-Crowdsourcing	Crowdsourcing is based on outsourcing a task to a "crowd," and not to a designated "agent" such as a contractor, in the form of an open call.	(Afuah et al., 2012; Howe, 2006, 2008; Jeppesen and Lakhani 2010)
3-Idea and start-up competitions	Idea and Start-up competitions refers to an invitation to entrepreneurial teams and start-ups to present business ideas through open competitive calls, with collaboration with and venture support for winning groups.	(Chesbrough 2006a; Van de Vrande et al., 2006)
4-Using external networks or "external networking"	External networking incorporates all activities to obtain and sustain connections with external sources of social relations.	(Chesbrough et al., 2006; Gulati 1998; Nieto and Santamaría 2007; Van de Vrande et al., 2009; Vanhaverbeke 2006; Zeng et al., 2010)
5-Collaborative innovation with external partners or collaborating	Collaboration refers to the cooperative creation of knowledge through relationships with external partners.	(Baum et al., 2000; Faems et al., 2005; Hagedoorn 1993; Jap 2001; Laursen and Salter 2006; Laursen and Salter 2014; Udwadia and Ravi Kumar, 1991)
6-Customer co-creation in R&D projects	Customer co-creation in R&D projects, is the engagement of consumers or customers in the creation, assessment, and testing of new ideas for products and services.	(Prahalad and Ramaswamy 2004; Ramaswamy and Gouillart 2010; West and Gallagher 2006)
7-External technology acquisition	External technology acquisition is related to the absorption of external technologies.	(Chesbrough 2006a; Edler et al., 2002; Granstrand et al., 1992; Jones et al., 2001; Van de Vrande et al., 2006; Veugelers and Bruno, 1999)
8-Subcontracting R&D	Contracting mechanisms are related to acquiring knowledge on a market basis, which can be referred to as "the buy decision".	(Beneito 2006; Santamaría et al., 2009; Ulset 1996; Veugelers and Bruno, 1999)
9-IP in-licensing	IP in licensing refers to the licensing of external intellectual property rights such as trademarks and patents.	(Chesbrough, 2006b; Chesbrough and Crowther 2006; Gassmann and Enkel 2004)

Table 3
Conceptualising OI and the associated capabilities and supporting routines.

Key papers	Group 1: Conceptualisation of OI: General Without Specific OI Activity	Capabilities and Routines supporting the Implementation of Open Innovation
Bogers et al. (2018)	Firms' use of external knowledge	Employees' educational diversity, employees' work history diversity
Mortara and Tim Minshall (2011)	Using internal and external resources	Top management change and reorganisation, open innovation team, open innovation skills and training, developing an internal language for open innovation, guaranteeing continual support to open innovation implementation from the top of the firm
Salter et al. (2014)	Bringing knowledge into the firm	Training, development programs, R&D incentive systems
Sisodiya et al. (2013)	Acquisition and leveraging of external inputs for new product development	Relational capability, network spillovers, financial resource slack
Urbinati et al. (2020)	The distributed innovation process based on purposively managed knowledge flows across organisational boundaries	Digital technologies; (i) technologies' features standardisation, (ii) budget formalisation for digital investments, and (iii) development of new and formalised procedures for innovation activities; and at the process level through enabling capabilities (e.g., training activities, routine scouting)
Key papers	**Group 2: Conceptualisation of OI: Single OI Activity**	**Capabilities and Routines supporting the Implementation of Open Innovation**
Cheah and Ho (2020)	Collaboration between public research institutes and firms	Project funding, top management team (TMT) capability in project approval, TMT capability in portfolio management
Grama-Vigouroux et al. (2020)	Collaboration with the firm's stakeholders	Knowledge lever: e.g., internal learning capacity, absorptive capacity
Lakemond et al. (2016)	Collaborative inbound open innovation	Project management and knowledge matching
Wang et al. (2015)	External collaboration	Three internal capabilities: innovation, information and relational capabilities
Zobel (2017)	External technological resource access	Components of absorptive capacity: recognition capacity, assimilation capacity, exploitation capacity
Foss, et al. (2011)	Interaction with customers	Communication, rewarding employees, delegation of decision rights
Bianchi et al. (2016)	Outsourcing	External consultants, dedicated R&D unit
Key papers	**Group 3: Conceptualisation of OI: More than 1 OI Activity (Refer to Table 1)**	**Capabilities and Routines supporting the Implementation of Open Innovation**
Cheng and Huizingh (2014)	3 Inbound OI activities	Entrepreneurial orientation, market orientation, and resource orientation
Markovic et al. (2020)	5 Inbound OI activities	Open innovation enablement, entrepreneurial culture, open innovation support
Pinarello et al. (2022)	5 Inbound OI practices	Relying on OI Intermediaries Changing the culture of the organisation
Podmetina et al. (2018)	9 Inbound OI activities	Skills: e.g., IP management, negotiation, team-working, multi-tasking, problem-solving, virtual collaboration, communication, networking Abilities: e.g., Technology and business mindset, project management, adaptability and flexibility, managing the inter-organisational collaboration process, cultural awareness, ability to share knowledge and ideas internally/within the organisation

and business mindset, project management, adaptability, and flexibility as enabling factors that support the ability of firms to undertake a broad range of different types of OI activities. Based on the limited number of studies that have examined the capabilities, competences, and routines that support the implementation of a wide range of different types of OI activities, our second research question seeks to contribute to this emerging stream of research by going beyond the dominant conceptualisation of OI in terms of a single activity (i.e. either search or collaboration), and by investigating the organisational capabilities and routines that support the breadth of OI activities (nine types of them) at the firm level.

3. Theoretical framework and hypotheses

In this paper, we have relied on the theory of dynamic capability (Teece et al., 1997), specifically on second-order and first-order dynamic capabilities, to develop two models as shown in Figs. 1 and 2 below. As dynamic capabilities illustrate firm processes that change the firm's resource base (Ambrosini and Bowman 2009), this resource base is renewed through the external knowledge obtained from OI. Being a dynamic capability, OI combines external and internal knowledge via different OI activities to match with the market and technology changes when conducting innovation (Eisenhardt and Martin 2000; Teece et al., 1997). This is because OI is not only based on outsourcing R&D to an external party (Bogers et al., 2019), but also about leveraging and improving internal capabilities, to enhance one's own business model, i.e., inbound open innovation (Chesbrough 2003).

First-order dynamic capabilities are those that alter and directly reconfigure the core resource base of the firm (Schilke 2014; Teece et al., 1997). Accordingly, we conceptualise the breadth of OI activities as the first-order dynamic capability in our research, altering the firm's resource base through the external knowledge obtained from the portfolio of OI activities. In turn, these activities can improve the firm's innovativeness (Schilke 2014). In fact, through dynamic capabilities, firms can constantly have competitive advantage, preventing the creation of core rigidities that hinder development, cause inertia and restrain innovation (Leonard-Barton 1992). What is more, enhancing innovativeness, or the capacity to introduce new products and services, is a primary concern and a key source for competitive advantage and growth (Crossan and Apaydin 2010; Damanpour 1991). Based on that, we conceptualise firm innovativeness as a competitive advantage in our

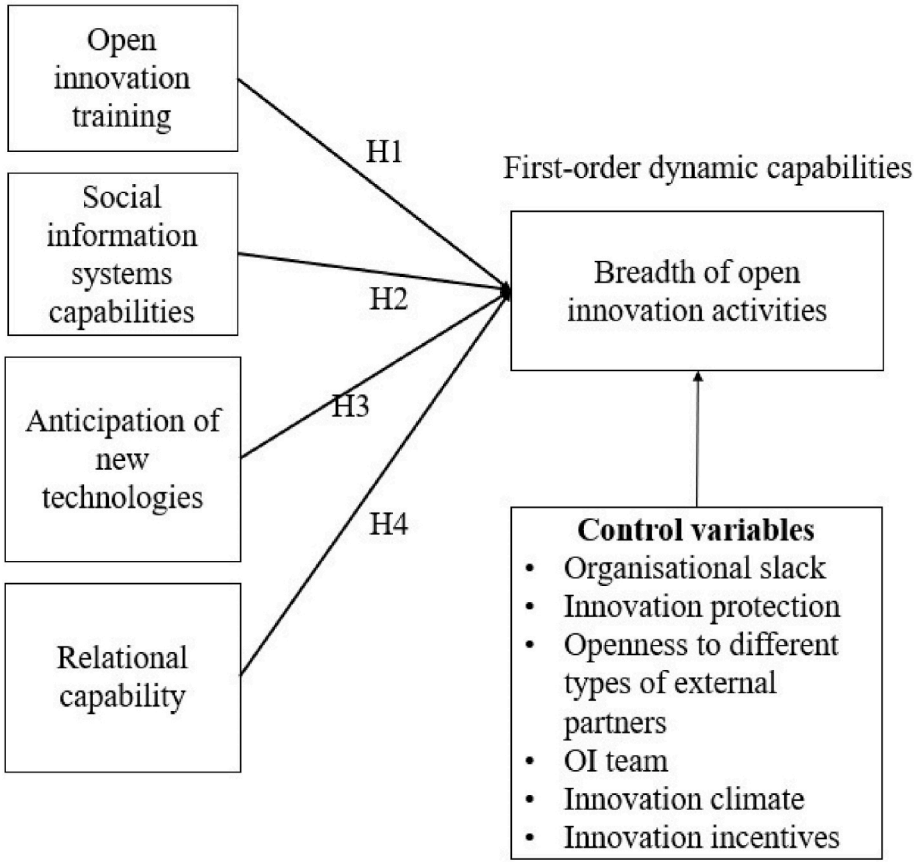

Fig. 1. Model 1.

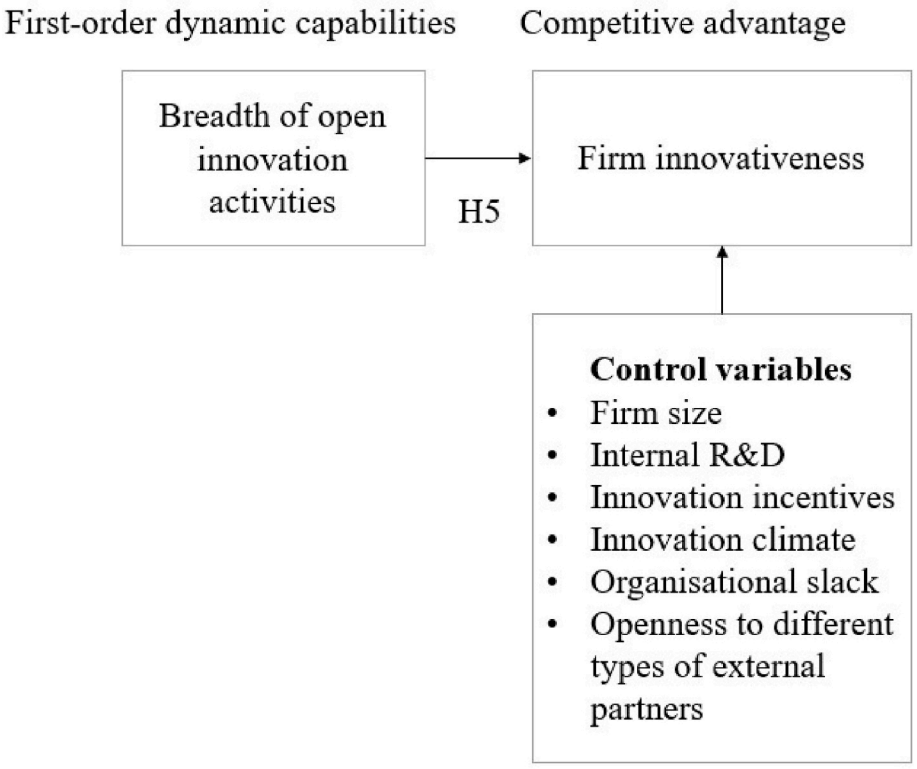

Fig. 2. Model 2.

model. As for second-order dynamic capabilities, they are antecedents to first-order dynamic capabilities. They are deployed to support the development of the first-order dynamic capabilities (Collis 1994; Schilke 2014). The four antecedents taken in our study can support the breadth of OI activities. They consist of open innovation training, social information systems capabilities, the anticipation of new technologies, and relational capability. OI training offers communication skills for effective interactions (Mortara et al., 2009). Particularly, we conceptualise open innovation training as a second-order learning routine. In fact, being organisational processes generally or routines (Zollo and Winter 2002), dynamic capabilities may have become embedded in the company over time, and used to reconfigure the firm's resource base; i.e., doing open innovation (Sirmon and Hitt 2003). Therefore, a dynamic capability can also be a routine, being a repetitive pattern of activity (Nelson Richard and Winter Sidney 1982). As for the three other antecedents, they are conceptualised as second-order dynamic capabilities. Relational capability is potentially important in the breadth of OI activities as it helps firms find and build relationships with appropriate partners (Morgan et al., 2009). Through this capability, firms can establish and control their relationships with external sources for higher value creation (Day 2000). As discussed previously, it is very likely that companies will have a smoother use of these OI activities when social information systems capabilities are developed. Finally, to conduct OI activities, firms may seek to acquire new manufacturing technologies beside knowledge, representing the anticipation of new technologies capability (Beheregarai Finger et al., 2014).

To illustrate the relationships between second-order dynamic capabilities and first order dynamic capabilities and between first-order dynamic capabilities and competitive advantage, we developed Model 1 and Model 2. In the next section, we will present Model 1 (Fig. 1 below) which tests the relationship between each of these four aforementioned antecedents and the breadth of OI activities (H_1–H_4), and we will develop the four hypotheses in Model 1. This will be followed by Model 2 (Fig. 2 below), which represents the relationship between the breadth of OI activities (independent variable) and firm innovativeness (dependent variable) (H_5).

Before discussing and presenting the hypotheses in Model 1, it is worth highlighting that not only these second-order dynamic capabilities play a potential role in supporting the breadth of OI activities, but also, they constitute a gap in the open innovation literature, specifically in the context of the breadth of OI activities. For instance, open innovation training has only been investigated with open innovation in general without focusing on a specific type of open innovation activity (Mortara and Tim Minshall, 2011; Salter et al., 2014; Urbinati et al., 2020). Social information systems capabilities have only been investigated with absorptive capacity and innovation (Limaj et al., 2016), whereas the anticipation of new technologies has been examined in the context of supply chain management (Beheregarai Finger et al., 2014). As for relational capability, it has been studied with open innovation in general (Sisodiya et al., 2013) and with external collaboration (Wang et al., 2015).

3.1. Open innovation training and the breadth of open innovation activities

Training facilitates the exposure of employees to different knowledge and openness to innovative ideas (Jaw and Liu 2003). It stimulates employees to learn and experience new things and develop innovative minds (Nonaka and Takeuchi 1995). In the context of external knowledge acquisition, training can be viewed as a major aspect of a learning environment that continually supports employees as they seize and use external knowledge, proficiencies, and know-how (Ajmal and U Koskinen, 2008). For instance, several large multinational firms that are conscious adopters of OI have created an internal language for it and provided their employees with training to support its implementation (Mortara and Tim Minshall, 2011). As training and employee development are an important part of an organisational culture that directs employees to operate using a particular approach (Alavi et al., 2005), it may also be useful to have external providers support such training. For instance, there are external training programmes that aim to enhance OI activities. Training providers offer OI workshops that cover a range of techniques and areas, developing within the necessary knowledge and skills to create one's own implementations. Such training courses need to be approached more holistically in order to underpin different strategies and associated portfolios of activities. For instance, these types of training cover OI methods, in terms of collaborative OI, OI tools for collaborating online and offline, crowdsourcing and creativity techniques (InnovationAcademy 2019).

Previous OI studies have highlighted the importance of specific skills, for example "extrospective", "interactive", "problem-solving", and "flexibility/adaptability". We explain in Table 4 below how each of these skills can help firms in their OI activities.

For instance, "extrospective skills" facilitate the evaluation of the value of each interaction from the perspective of the external party. They assess competences and opportunities generated from outside which is acquired through different OI activities (Mortara et al., 2009). There are ad hoc examples of other specific OI training; for instance, the OI training of Unilever employees includes scouting, mentoring and forming them into communities and collaborative networks to boost learning (Unilever 2011). Although previous studies (see Table 4) have focused on the importance of specific OI skills – teamworking skills which are important for employees working in an environment – they

Table 4
Skills relevant to OI activities.

Type of skills	OI activities
Extrospective skills (Mortara et al., 2009)	Through these types of skills, firms are able to look for, find and assess the quality of external ideas obtained through different OI activities. They can compare and contrast the different ideas acquired from different activities.
Networking and collaborative skills (Greer and Stevens 2015; Podmetina et al., 2018)	These skills help firms initiate, develop and succeed in relationships with external partners across the different types of OI activities.
Interactive skills (Mortara et al., 2009; Podmetina et al., 2018)	Such interactive or communication skills can guide firms and strengthen their abilities to manage a set of OI activities. Undertaking and managing a range of OI activities will be highly stimulated with firms that have good interactive and communication skills. These skills not only help firms in managing these different interactions, but also help them communicate the value of each OI activity to the relevant parties.
Problem-solving skills (Mortara et al., 2009; Podmetina et al., 2018)	These skills help firms identify and address the different problems that may arise when different OI activities are in place, and thus, help firms undertake these activities smoothly without any further problems.
Flexibility/adaptability skills (Podmetina et al., 2018)	Due to the variety of the types of OI activities conducted, having such skills will help firms adapt to and move easily across different types of OI activities, each of which, is of a different nature.
Team-working skills (Podmetina et al., 2018)	These skills are essential when firms perform different OI activities. The focal firm members have to work as a team to cooperate in managing different OI activities.
Multi-tasking skills (Hafkesbrink and Schroll 2014)	These skills can support firms performing different types of OI activities so they can understand how to manage and work on OI activities at the same time rather than only one OI activity.

have not examined the extent to which firms invest in OI training to enable employees to develop these important skills. The exception is the study of Mortara et al. (2009) which examined OI training related to improvements in communication skills. Neither have previous studies examined the extent to which OI training impacts on the ability of firms to develop a range of different types of OI activities at the firm level. To address this gap, we will use a measure of OI training (Douglas and Judge Jr 2001) that we have adapted to capture more the general commitment of management and the investment of resources to provide such training in different ways at the firm level, and the extent to which OI training is diffused across the organisation to managers, supervisors and employees. A high level of diffusion of OI training is likely to be effective in changing the mindset of employees to become more aware of the broad range of different types of OI activities that can be used to acquire resources. It is also worth noting that training is one of the ways management may use to get around a high level of internal emphasis on innovation, while developing incentives for external knowledge interactions, overcoming the not-invented-here (NIH) and not-shared-here (NSH) challenges (de Araújo et al., 2014). Training can help minimise employees' anxiety, insecurity, and negatively biased attitudes to external sources (Kraiger et al., 1993). This is because when implemented properly, well-constructed human resource programmes such as training enable employees to see themselves working in a social exchange relationship characterised by mutual trust, respect and support (Piening et al., 2013). Such an environment can in turn support the development of OI skills which will facilitate the experimentation and regular use of a broad range of different types of OI activities at the firm level. Accordingly, we expect that OI training will provide better information how to implement each of these OI activities to its full potential while mitigating the related risks. Thus, we hypothesise that:

H_1: *Open innovation training is positively related to the breadth of open innovation activities.*

3.2. Social information systems capabilities and the breadth of open innovation activities

Firms utilise advanced information technology to create and communicate information, they promote trust and reliability between partners (Wang et al., 2015). Social information systems (SIS) are information systems based on social technologies and open collaboration (Schlagwein et al., 2011). They typically involve web-based technologies that facilitate social relations, and enable co-workers to look for, obtain, and exchange important knowledge (Leonardi et al., 2013). As such, they can be catalytic in supporting activities that span the boundaries of an organisation such as those in an OI activities portfolio, e.g., crowdsourcing, idea and start-up competitions, the use of external networks, and customer co-creation in R&D projects. Table 5 below outlines their key features and relates these to the OI activities considered in this paper.

Deploying social information systems can result in firms having new capabilities that play an important role when it comes to accessing and acquiring external knowledge (Kilian et al., 2008). Bringing together internal users with external crowds can lead to new ways of acquiring knowledge, ideas, co-creation, higher creativity, and joint problem solving (Kirchner and Razmerita 2019). As such SIS can facilitate increased knowledge sharing, innovation activities, and idea generation (Kirchner and Razmerita 2019; Schmidt et al., 2020). This is of particular importance in the context of open innovation, as organisations need to adopt their knowledge management systems to foster the diffusion, sharing and transfer of knowledge within the firm, and between the firm and the external environment (Chiaroni et al., 2011). Shared usage of SIS affords new types of behaviours and changes organisational communication processes (Treem and Leonardi 2013), which, in turn, could lead to new organisational SIS capabilities. For instance, outside-in SIS capabilities simplify the process of accessing and looking for relevant external information (Boyd and Ellison 2007). These capabilities are likely to facilitate the implementation of several OI activities such as crowdsourcing, scanning for external ideas, external technology acquisition, and idea and start-ups competitions (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019). Effectively, such information systems can support the implementation of these OI activities to not just identify and bring into the firm new knowledge, but also to integrate and exploit it. This is in line with capabilities that information systems support when it comes to organisational and managerial practices. IT can complement organisational choices by acting as the vehicle on which relevant practices can be enacted (Iyengar et al., 2015). Such practices can involve not just internal facing ones but also external-facing activities (Steininger et al., 2021) such as those considered in this work. As a result, while the literature shows the importance of SIS capabilities in fostering external connections, external knowledge acquisition and exploratory and exploitative innovation (Limaj et al., 2016), it would be worth examining their impact on a larger portfolio of nine OI activities Therefore, we hypothesise that:

H_2: *Social information system capabilities are positively related to the breadth of open innovation activities.*

Table 5
Feature of Social Information Systems relevant to OI activities (Adapted from Schlagwein et al. (2011)).

Feature	Traditional Information Systems	Social Information Systems	OI Activities
Sociality	No community; focus on information processing	Community; focus on information exchange	Depending on the nature of the activity different communities can be supported, each with their own characteristics and norms.
Openness	Limited number of users; mandatory use	Large number of users; voluntary contributions	The number of users involved depends on the type of activity (e.g., crowdsourcing may involve a much larger number of users vs. a collaborative innovation activity with external partners)
Contributors	Employees	Externals, employees outside of formal hierarchy	Users may include very different stakeholders, such as sub-contractors, suppliers, existing customers, academics or the public.
Contents	Generated by professionals or generated automatically	User-generated	Content can be generated by the public but also by professionals/experts. This will very much depend on the nature of the activity.
Technology	Often complex, fixed structure; commercial software	Lightweight tools, flexible structures, open-source software	Technologies will depend on the nature of the activity; E.g., systems may facilitate crowdsourcing interactions, while external databases may be used for identifying technologies for acquisition
Location	Offline; local	Online; networked	Online either via public, shared or private spaces.

3.3. The anticipation of new technologies and the breadth of open innovation activities

The anticipation of new technologies (ANT) is the extent to which an 'organisation anticipates the new technologies that will be important to it in the future, acquires them and develops capabilities for implementing them, in advance of actual needs (Hayes and Wheelwright 1984). A firm that is skilled in ANT constantly invests in new processes and manufacturing technologies, supporting its future creation of products. ANT illustrates a distinctive trait of world class manufacturers, whose competitive strategy depends on their manufacturing capabilities (Hayes and Wheelwright 1984). These manufacturers are dynamic, learning firms that constantly push the boundaries of their expertise and aim to be better on every front (Hayes and Jaikumar 1988). An effective ANT necessitates a fair knowledge about future generations of customers and products, while having the resources and foresight to obtain new technologies prior to needing and developing capabilities to implement them (Beheregarai Finger et al., 2014).

The positive link between ANT and the breadth of OI activities can be explained through the lens of absorptive capacity (Cohen and Levinthal, 1990). In an ever more demanding and fast-paced business environment where technological innovation is fast paced and occurs outside of the firm, organisations are more likely to need to develop a portfolio of OI activities as a way to acquire and assimilate future technologies as part of their effort to develop an ANT capability. Previous research suggests that ANT is facilitated both through search of traditional sources of external knowledge such as trade fairs and technology sales representatives, and integration with non-traditional sources such as suppliers and their extended networks (Beheregarai Finger et al., 2014). Although this study hints at the importance of conducting a few OI activities to acquire and develop future technologies and customers' needs for new products as part of ANT, it is limited to only search and collaboration activities. It bypasses the range of OI activities such as subcontracting R&D, crowdsourcing and external technology acquisition, and idea and start-ups competitions (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019). Based on the concept and role of ANT, it may be worth studying how it can have an impact on a portfolio of nine different OI activities. In fact, firms can conduct these activities while searching, assimilating and implementing future technologies. For instance, firms may access the necessary knowledge about potential new technologies not only from their suppliers, but also by involving customers more actively, and through different OI activities, to develop future value propositions for such technologies (Vargo and Lusch 2004). Following this line of argument, we hypothesise that firms investing resources in ANT are likely to develop a broad range of different types of OI activities as a conduit to search, assimilate and develop future technologies.

H3: *The anticipation of new technologies is positively related to the breadth of open innovation activities.*

3.4. Relational capability and the breadth of open innovation activities

Relational capability illustrates the ability of firms to find the best partners with whom to develop relationships, and plan means of governance for adequate collaboration (Day 2000; Faems et al., 2008; Morgan et al., 2009). Previous studies that have examined the importance of relational capability in the context of OI have focused on single activities such as acquisition of external inputs (Sisodiya et al., 2013) and external collaboration (Wang et al., 2015) (see Table 3). There are several reasons why relational capability is important for a single OI activity, namely collaboration. First, it makes it possible for the firm to differentiate between transactional and collaborative relationships and organise them with different governance tools (Day 2000; Faems et al., 2008). Second, it simplifies the exchange of tacit knowledge available within firms by developing relational governance and informal communication networks (Lorenzoni and Lipparini 1999). Third, the ability to design contractual and relational governance mechanisms efficiently is valuable to external partners, because it guarantees adequate collaboration (Faems et al., 2008). As a result, high relational capability gives collaborators confidence that problems which may occur in relationships can be prevented or reduced (Fang et al., 2008). Although these studies have contributed to our understanding of the importance of relational capability for collaboration, they have not considered the extent to which the development of relational capability will enhance the ability of firms to conduct a broad range of different types of activities.

Given the important role of relational capability in managing relationships during a single OI activity (Sisodiya et al., 2013; Wang et al., 2015), it is worth examining its effect on undertaking diverse OI activities such as subcontracting R&D, crowdsourcing, and external technology acquisition (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019). Relational capabilities may be relatively of higher importance than usual for organisations having to manage relationships with potentially very different types of partners who come from different types of OI activities. In this context, relational capability may be more needed to manage different OI activities. For instance, managing collaboration with longstanding suppliers will be different from managing relationships with new start-ups who have been identified in an idea contest or from crowdsourcing. In such cases, the challenge is to manage OI relationships derived from different types of activities that are very different in nature in terms of risks and uncertainty. Based on the above arguments, we posit that:

H_4: *Relational capability is positively related to the breadth of open innovation activities.*

Model 2 is presented in Fig. 2 below, illustrating the relationship between the breadth of OI activities and firm innovativeness (H5).

3.5. The breadth of open innovation activities and firm innovativeness

Previous research has shown the positive effect of a single OI activity on performance (Bianchi et al., 2016; Foss, et al. 2011; Zobel 2017). Inter-organisational collaboration has a positive effect on firm innovativeness (Alexiev et al., 2016). Similarly, sourcing knowledge and ideas from customers and end-users when developing a new product is helpful as customers have close links to markets (Pittaway et al., 2004). They can offer first-hand information, including important insights with reference to market needs and future demand (Von Hippel 2009). In addition, engaging customers in the early stages of innovation considerably reduces risks in development and enhances the likelihood of innovation success (Foss, et al. 2011). Another example of an OI activity is crowdsourcing, which leads to higher levels of innovation as a result of expertise diversity. External crowds are more diverse in experience than internal research and development teams. In turn, expertise diversity derives a potential for higher quantity and diversity of ideas, leading to more innovative ideas (Bingham and Spradlin 2011; Terwiesch and Ulrich 2009). In all, based on the positive innovation outcomes generated from a single OI activity, one could reasonably expect that adding more activities to a firm's inbound portfolio would have a positive effect on firm innovativeness due to the synergistic effect that emerges from different types of OI activities as several of these OI activities at the firm level. By engaging in different types of OI activities, managers increase the exposure of their firms to a broader and more diverse pool of information, knowledge and resources. Thus, we hypothesise:

H_5: *The* **breadth** *of open innovation activities is positively related to firm innovativeness.*

4. Method

4.1. Pilot study

Before conducting the survey, a pilot test of six qualitative semi-

structured interviews was undertaken with managers that deal with (open) innovation and R&D at high-value manufacturing firms in the UK. The main aim of these interviews was to explore the open innovation strategies adopted and ensure the relevance of each of the four antecedents and nine inbound OI activities considered in this research. Also, through this pilot test, we attempted to ensure that every factor in the conceptual model of this study was relevant and clear to the participants. We started each interview with a brief overview about our research project. We then highlighted to each manager the point that the interview conducted would enable us to understand their innovation strategy, and identify capabilities and routines they use to support OI in their firm. Finally, we clarified to them that there would be a total of 12 questions and that the interview would take no longer than 45 min. Out of all the antecedents to open innovation initially included in our conceptual model, "innovation incentives", "inter-functional coordination", "decentralisation", "analytics capability", and "open innovation team" were not as applicable and relevant to firms as the remaining four antecedents, "open innovation training", "social information systems capabilities", "anticipation of new technologies", and "relational capability". As a result, these four antecedent capabilities were then included for testing quantitatively. "Innovation incentives" and "open innovation team" were kept, but moved to be control variables. "Innovation climate" was the only factor that was not initially included in our conceptual model, but emerged as an important one. Although it does not represent a novel factor and capability in the literature, it was added as a control variable in each of Model 1 and Model 2 in view of its support to inbound open innovation (Popa et al., 2017), and potentially firm innovativeness.

4.2. Research setting and design

Following the pilot test, an online survey was distributed to high-value manufacturing firms in the UK. The respondents to our survey were mainly R&D, innovation, engineering, new product development, technical and design managers, CEOs, managing directors, and general managers, being the most relevant respondents. In addition, in light of the pilot interviews we conducted in this research before sending the questionnaire, we concluded that managing directors and technical directors were also highly knowledgeable about the open innovation strategy in their firm. Equally important, since firms in our study were called over the phone before sending them the survey, we ensured that the survey was sent to the relevant manager in charge of open innovation.

High-value manufacturing is defined as firms that benefit from highly-skilled, knowledge-intensive manufacturing operations while competing on distinctive value and innovation (May, 2015). Based on how high value manufacturing companies are conceptualised, they tend to be highly engaged in open innovation. Particularly, the sectors to which the companies in the target sample of our study relate were categorised as per the Organisation for Economic Co-operation and Development (OECD) classification of the manufacturing firms according to their R&D intensities (OECD 2011). The dataset used to collect data for this study included the contact details of a large number of managers, out of which 1000 managers agreed to participate in our study. Other managers in this dataset did not agree to participate, whereas some others were not reachable. Out of the 1000 surveys sent to those that accepted, 336 responses were obtained, from which 211 questionnaires were fully completed and appropriate to be used in the data analysis. This represented a satisfactory response rate of 21.1% (Hair et al., 2014). The 1000 managers to whom the survey was sent met the sample criteria relevant to our research. We ensured these managers were all in positions where they deal with open innovation and in companies that are in the high-value manufacturing sector according to their SIC code, as discussed above.

4.3. Measurements

The unit of analysis of the study is the firm level. At the beginning of the survey, open innovation or collaborative innovation was defined as a model that integrates external knowledge with the internal research and development (R&D) of a firm during the development of new products, services, or processes (Chesbrough 2003). It was also specified to participants that firms engaging in open innovation tend to collaborate with different types of external partners and undertake several OI activities. Respondents were asked to consider their firm's (rather than an open innovation project's) general open innovation strategy within the last three years inclusively. A seven-point scale ranging from strongly disagree to strongly agree was used for all the measures, except for the binary variables.

Dependent variables. The dependent variable in Model 1, is the breadth of OI activities. Building on Chesbrough and Brunswicker (2014), Podmetina, et al. (2018) and Teplov et al. (2019), firms were asked to evaluate their adoption of nine inbound OI activities in the last three years. These activities were IP in-licensing, external technology acquisition, subcontracting R&D, using external networks, idea and start-up competitions, collaborative innovation with external partners, crowdsourcing, collaborative innovation with external partners, and scanning for external ideas. Each of the nine activities was coded with 1 when the respondent firm reported using this activity and 0 when it reported not using the activity. Each company's scores on the nine OI activities were subsequently added up so that they received a score of 0 when no open innovation activity was used and of nine when all OI activities were used (Laursen and Salter 2006). Table 6 below summarises the number of respondent companies that reported the usage of each open innovation activity in our survey.

A high number of firms uses each activity except for crowdsourcing activity, adopted by a lower number of companies relative to the other activities in our sample. This was not very surprising as crowdsourcing was also among the inbound OI activities that were rated lowest in importance in the study by Chesbrough and Brunswicker (2014). It is worth noting that among the 211 responses we obtained, there were 59 different portfolio configurations, with about half of the responses belonging to three configurations. In Table 6 we also report the depth of each activity (on a frequency scale of 1 never engage to 7 always engage).

In Model 2, the dependent variable is firm innovativeness, which refers to the outcomes of the innovation process, was represented by scale items to assess the extent to which firms invented new products and services, experimented with them in their local market, commercialised products and services completely new to them, and utilised new opportunities in new markets (Alexiev et al., 2016).

Independent variables. Open innovation training was measured using six items (Douglas and Judge Jr 2001). Social information systems capabilities were measured using thirteen items from Limaj et al. (2016). The anticipation of new technologies was operationalised with four items, which measured the extent to which the firm anticipated and acquired new manufacturing technologies and capabilities essential for them in the future (Beheregarai Finger et al., 2014). Relational capability was also measured using four items assessing the extent to which firms identified external partners with whom they developed and managed mutually beneficial relationships through governance mechanisms/channels (Wang et al., 2015).

Control variables. In Model 1, we controlled for organisational slack, innovation protection, openness to different types of external partners, OI team, innovation climate, and innovation incentives. Organisational slack is a key factor, representing resources in a firm exceeding the minimum necessary to generate a specific level of organisational output (Nohria and Gulati 1997). This factor was measured in our study using four items developed by Atuahene-Gima and Kwaku (2005). Innovation protection is important in the context of OI to mitigate misappropriation of knowledge by external partners. The more OI activities a firm

Table 6
Breadth and depth of open innovation activities.

Activities	IP in-licensing	External technology acquisition	Subcontracting R&D	Using external networks	Idea and start-up competitions	Collaborative innovation with external partners	Crowd-sourcing	Customer co-creation with R&D projects	Scanning for external ideas
Breadth (Number of companies)	179	187	161	176	129	190	64	187	188
Depth (Average intensity)	3.9/7	3.7/7	2.9/7	3.5/7	2.5/7	3.9/7	1.7/7	3.9/7	3.8/7

undertakes, the higher the risks (Bahemia et al., 2017; Laursen and Salter 2014). We measured it using two items: the extent to which the company had implemented firm and legal mechanisms to protect innovations (Becker and Dietz 2004). Openness to different types of external partners can also potentially help in undertaking different types of OI activities as different partners such as suppliers, customers, and universities are likely to be engaged in different types of OI activities. To measure this construct, participants were asked to indicate which of 10 types of external sources of knowledge (customers, universities, suppliers, public research organisations, entrepreneurs and start-ups, contracted R&D service providers, external consultants, competitors, unrestricted communities, and OI intermediaries) they had collaborated with in their innovation activities in the last three years (Chesbrough and Brunswicker 2013). As with the breadth of OI activities, we added up the 10 types of sources: 0 represented "no" and 1 represented "yes" (Laursen and Salter 2006).

The OI team represents a key control factor in Model 1 as teams in conscious adopters of OI possess skills such as intellectual property, technology and business intelligence, creativity, and innovation management; these support the implementation of OI (Mortara and Tim Minshall, 2011). Therefore, such OI teams will provide better support to employees when they are undertaking different OI activities, hence contributing to these activities. To measure this, we used a binary variable, which took the value of 0 when the respondent firm did not have an OI team and 1 when it did. Innovation culture or climate was also highly important to include as a control variable since it represents values within firms that facilitate innovation (Martín-de Castro, et al. 2013). It was measured using four items adapted from Popa et al. (2017). Finally, we included innovation incentives as a relevant factor in potentially stimulating employees to engage in different types of OI activities. These are the company's use of strategic compensation strategies that represent employees' learning and innovative practices (Wei and Atuahene-Gima 2009). We measured them by three items (Wang et al., 2018).

As with Model 1, in Model 2 we also controlled for innovation incentives, innovation climate, organisational slack, and openness to different types of external partners. In addition, we controlled for firm size and internal R&D. Internal R&D cannot be ignored due to its complementary relationship with external knowledge acquisition in supporting innovation outcomes (Berchicci 2013; Cassiman and Veugelers 2006). Accordingly, it is expected to play a role when examining the effect of the breadth of OI activities on firm innovativeness. It may also be worth considering whether firm size plays any role when examining the effect of OI activities on firm innovativeness. Size was measured by number of employees, whereas internal R&D was measured using three items adopted from Yam et al. (2011). We did not control for OI team and innovation protection in this model, as these factors are more likely to support firms in the implementation stage of OI rather than when assessing its outcomes (Bahemia et al., 2017; Laursen and Salter 2014; Mortara and Tim Minshall, 2011). Table 7 below presents the adapted/adopted measures, and their sources in the existing literature, for the variables in Models 1 and 2.

4.4. Convergent and discriminant validity

Prior to data collection, all corresponding indicators of the constructs were assessed based on their internal consistency reliability by checking their Cronbach alpha (α), ensuring it was above the threshold limit of 0.7 for each variable (Nunnally and Jum, 1978). A factor analysis was conducted on SPSS to assess the construct reliability, validity, and unidimensionality. Two items were removed to improve further the fitness of the model, increase some factor loadings as well as the reliability of some constructs. The first item that was deleted, was the second item of the organisational slack construct. In fact, being a reverse-coded item, removing it has increased the Cronbach alpha of this construct, hence we deleted it (Hair and Joseph, 2016). In addition, for a further improvement of the model fit, and some higher factor loadings across the different items of the different constructs in our model, we also removed the fourth item of the innovation climate construct (0.648) that had the lowest factor loading in comparison to the other items of this particular construct. In addition, a statistical approach to scale purification was followed by a judgmental approach (Wieland et al., 2017), namely a qualitative assessment of the appropriateness of textual data, such as the wording of an item. As only two items were removed, this was not considered to impact significantly the measurements of the constructs covered in the survey. Table 7 shows the final factor loadings of all items, as well as the initial factor loadings of the two items prior to deletion. We also report the Cronbach alpha (α) value for all constructs, which all maintained good values higher than the threshold of 0.7 (Nunnally and IraBernstein, 1994).

4.5. Common methods variance

To check for common method bias, we followed Podsakoff et al. (2003). First, respondents were assured that their participation was voluntary, and their answers would be confidential and anonymous, enabling them to answer as honestly as possible. We also followed the suggestions by Nunnally and IraBernstein (1994) and Spector and Brannick (1995). For instance, when we developed the questionnaire, we made answers to all items of identical effort and we paid great attention to details of the wording of each item. We chose to include items that are less subject to bias, and we provided clear guidelines. Also, the ordering of the scale items was randomised, and there was reverse coding for one item, hence the same end of a Likert-type answer format was not always the positive end. Equally important, pilot testing the survey with different academics and managers before sending it to participants helped in making minor revisions and improvements to it, increasing clarity.

We then used Harman's single-factor test to check for common method bias (Podsakoff et al., 2003). Through this test, the presence of common method bias is proposed when a single factor accounts for most of the covariance. Based on our results, we found that the variance explained by the first factor was 34.023% (<50%), confirming that common method bias does not represent a problem in this study (Podsakoff et al., 2003). Equally important, common method bias is not possible when correlations are not excessively high (not >0.9) (Hu et al., 2016; Pavlou et al., 2007). Table 8, representing the descriptive statistics

Table 7
Measurements of constructs.

Constructs with sources and corresponding indicators	Factor loadings
1.Firm innovativeness (Adopted from Alexiev et al. (2016)) (α = 0.820)	
a-We invent new products and services	0.672
b-We experiment with new products and services in our local market	0.750
c-We commercialise products and services that are completely new to our organization	0.793
d-We frequently utilise new opportunities in new markets	0.689
2.Open innovation training (Adapted from Douglas and Judge Jr (2001)) (α = 0.933)	
a-Open innovation-related training is given to employees throughout our organization	0.848
b-Open innovation-related training is given to managers and supervisors throughout our organization	0.855
c-Training is given in the "open innovation strategy" (i.e., what open innovation signifies for the firm, individual and task) throughout our organization	0.767
d-Training is given in statistical tools and techniques in the organisation as a whole to collect and analyse information (i.e., market, technology, patents) quickly	0.577
e-Our organisation's top management is committed to employee training for open innovation	0.807
f-Resources are provided for employee training in open innovation	0.816
3. Social information systems capabilities (Adapted from Limaj et al. (2016)) (α = 0.955)	
a-Social information systems capabilities assist in searching for relevant external information	0.718
b-Social information systems capabilities assist in identifying and considering different types of external partners	0.734
c-Social information systems capabilities assist in acquiring relevant external information	0.777
d-Social information systems capabilities assist in analysing and sharing ideas and concepts	0.684
e-Social information systems capabilities assist in interpreting and understanding external information	0.692
f-Social information systems capabilities assist in quickly exchanging information between business units	0.673
g-Social information systems capabilities assist in discussing new insights	0.776
h-Social information systems capabilities assist in structuring and using newly collected information	0.844
i-Social information systems capabilities assist in preparing newly collected information for further purposes and making it available	0.790
j-Social information systems capabilities assist our employees in integrating new information into their work	0.785
k-Social information systems capabilities assist in accessing stored information, e.g., about new or changed guidelines or instructions	0.675
l-Social information systems capabilities assist in developing prototypes or new concepts	0.691
m-Social information systems capabilities assist in applying new knowledge in the workplace to respond quickly to environment changes	0.737
4. Anticipation of new technologies (Adopted from Beheregarai Finger et al. (2014)) (α = 0.915)	
a-We pursue long-range programs, in order to acquire manufacturing capabilities in advance of our needs	0.770
b- We make an effort to anticipate the potential of new manufacturing practices and technologies	0.778
c-Our plant stays on the leading edge of new technology in our industry	0.804
d- We are constantly thinking of the next generation of manufacturing technology.	0.815
5.Relational capability (Adapted from Wang et al. (2015)) (α = 0.899)	
a-To identify potential types of external partners and initiate relationships with them	0.700
b- To design effective governance mechanism for managing your relationship with key types of external partners	0.754
c-To develop and manage mutually beneficial relationships with key types of external partners	0.828
d- To establish effective working relationship with different types of external partners through both formal and informal channels	0.845
6. Innovation climate (Adopted from Popa et al. (2017)) (α = 0.760)	
a-Our company provides time and resources for employees to generate, share, exchange, experiment with innovative ideas and solutions	0.691
b- Our employees are working in diversely skilled work groups where there is free and open communication among the group members	0.700
c-Our employees frequently encounter non-routine and challenging work that stimulates creativity	0.647
d- Our employees are recognised and rewarded for their creativity and innovative ideas[a]	0.648
7. Innovation protection (Adopted from Becker and Dietz (2004)) (α = 0.873)	
a-Our organisation has implemented firm-specific mechanisms to protect innovations	0.840
b-Our organisation has implemented mechanisms to protect innovations by law	0.872
8. Organisational slack (Adopted from Atuahene-Gima and Kwaku (2005)) (α = 0.794)	
a-Our firm has uncommitted resources that can quickly be used to fund new strategic initiatives	0.752
b-Our firm has few resources available in the short run to fund initiatives[a]	0.776
c-We are able to obtain resources at short notice to support new strategic initiatives	0.669
d-We have substantial resources at the discretion of management for funding new strategic initiatives	0.735
9.Internal R&D (Adopted from Yam et al. (2011)) (α = 0.839)	
a-Our R&D department has high quality and quick feedback from manufacturing to design and engineering	0.754
b-Our R&D department has good mechanisms for transferring technology from research to product development	0.797
c-Our R&D department has great extent of market and customer feedback into technological innovation process	0.725
10. Innovation incentives (Adopted from Wang et al. (2018)) (α = 0.827)	
a-In terms of promotion and salary rises, our firm gives priority to employees who actively engage in innovation activities	0.626
b-Our firm recognises and rewards employees for their knowledge-sharing initiatives	0.808
c-Our firm gives commendation and praise to employees for their knowledge exchange and improvement	0.711

Note: Items marked with an "a" were deleted.

and correlations, shows that common method bias is not a problem in our study as we do not have multicollinearity issues.

5. Results

5.1. Descriptive statistics

The Pearson correlation in Table 8 below reveals that the value for the bivariate correlations is below the threshold value of 0.8, which means that there are no multicollinearity issues in the sample data (Tabachnick and Fidell 2001). Also, multicollinearity in our study was checked through the "variance inflation factor" (VIF), which did not exceed the suggested cut-off value of 10 (Field 2013). To test our research hypotheses, multiple regressions were used.

5.2. Main effects

Table 9 below presents the multiple hierarchical regression results for Model 1 of our model, examining the effects of open innovation training, social information systems capabilities, the anticipation of new technologies, and relational capability (respectively, hypotheses H_1, H_2, and H_3, and H_4) on the breadth of OI activities. In Model 1, we controlled for organisational slack, OI team and innovation incentives, which were non-significant. We also controlled for innovation protection and openness to different types of external partners, which were both positively significant, and for innovation climate which was negatively significant.

In terms of the hypotheses-testing results, H_1 ($B = 0.391$; $p < 0.01$) and H_2 ($B = 0.264$; $p < 0.05$) are both supported, showing positive significant relationships between open innovation training (H_1) and

Table 8
Descriptive statistics and correlations.

	Mean	Std Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Breadth of OI activities	6.92	2.12	1													
2. Firm innovativeness	4.85	1.25	.172*	1												
3. OI training	3.11	1.45	.380**	.314**	1											
4. SIS capabilities	4.58	1.21	.263**	.404**	.437**	1										
5. Anticipation of new technologies	4.74	1.40	.174*	.535**	.381**	.302**	1									
6. Relational capability	4.87	1.16	.299**	.515**	.387**	.435**	.450**	1								
7. Organisational slack	3.85	1.35	0.069	.352**	.373**	.300**	.435**	.287**	1							
8. Innovation protection	4.90	1.61	.262**	.422**	.320**	.266**	.443**	.407**	.250**	1						
9. Openness to different types of external partners	4.65	2.04	.338**	0.106	.0.292**	0.101	0.122	.216**	0.04	.191**	1					
10. OI team	0.25	0.44	.186**	.273**	.426**	.293**	.216**	.225**	.209**	.201**	.240**	1				
11. Innovation climate	5	1.07	0.004	.533**	.286**	.360**	.455**	.441**	.275**	.322**	0.112	.213**	1			
12. Innovation incentives	4.49	1.24	0.064	.410**	.399**	.397**	.398**	.426**	.420**	.375**	.139*	.204**	.502**	1		
13. Firm size	2958	16055	0.128	0.094	0.02	0.057	0.064	0.089	−0.026	0.069	.165*	.205**	−0.038	−0.02	1	
14. Internal R&D	5.05	1.20	0.122	.483**	.343**	.254**	.487**	.376**	.292**	.389**	.149*	.224**	.548**	.405**	0.074	1

Notes: N = 211. *, **significant at 0.05 and 0.01 levels respectively (two-tailed)

Table 9
Dependent variable: The breadth of open innovation activities.

	Model 1	Model 2
Control variables		
Organisational slack	.040 (.112)	−.109 (.111)
Innovation protection	.306 (.094) **	.190 (.093) *
Openness to different types of external partners	.299 (.069) ***	.232 (.066) **
OI team	.471 (.332)	−.081 (.327)
Innovation climate	−.221 (.149)	−.393 (.148) **
Innovation incentives	−.064 (.137)	−.253 (.132)
Independent variables		
Open innovation training		.391 (.112) **
Social information systems capabilities		.264 (.126) *
Anticipation of new technologies		.057 (.117)
Relational capability		.330 (.139) *
R^2	.175	.297
Adjusted R^2	.150	.262
R^2 change	.175***	.122***

Note: ***, **, * indicate a significance level of 0.001, 0.01, and 0.05, respectively. This table presents the unstandardised coefficients (B) at N = 211 with coefficients standard error being reported in brackets. Two-tailed *t*-test has been used for hypothesised and control variables.

social information systems capabilities (H_2) with the breadth of OI activities. H_3 is not supported, showing a negative and non-significant relationship between the anticipation of new technologies and the breadth of OI activities. There is also a positive significant relationship between relational capability and the breadth of OI activities (B = 0.330; $p < 0.05$), supporting H_4.

Table 10 below shows the statistical results of the relationship between the breadth of OI activities and firm innovativeness. In this model, we controlled for firm size, innovation incentives and openness to different types of external partners, which were non-significant. Besides, we controlled for internal R&D, innovation climate and organisational slack, all of which were positively significant.

The results of our analysis showed that the breadth of OI activities had a positive significant coefficient (B = 0.078; $p < 0.05$). This confirms the positive relationship between the breadth of OI activities and firm innovativeness, supporting H_5.

6. Discussion and conclusion

6.1. Theoretical contributions

Drawing on the theory of dynamic capabilities (Teece et al., 1997), our paper contributes to the OI literature by shedding light on the implementation of inbound OI at two distinct levels. At the first level, our main contribution is related to the conceptualisation of open innovation in terms of a portfolio of nine different types of OI activities and

Table 10
Dependent variable: Firm innovativeness.

Control variables	Model 1	Model 2
Firm size	7.463 (.000)	6.796 (.000)
Internal R&D	.218 (.071) **	.203 (.070) **
Innovation incentives	.093 (.069)	.092 (.068)
Innovation climate	.386 (.083) ***	.402 (.082) ***
Organisational slack	.151 (.057) **	.145 (.056) *
Openness to different types of external partners	.002 (.035)	−.025 (.036)
Independent variable		
Breadth of open innovation activities		.078 (.034) *
R^2	.382	.397
Adjusted R^2	.364	.376
R^2 change	.382***	.015*

Note: ***, **, * indicate a significance level of 0.001, 0.01, and 0.05, respectively. This table presents the unstandardised coefficients (B) at N = 211 with coefficients standard error being reported in brackets. Two-tailed *t*-test has been used for hypothesised and control variables.

their effect on innovativeness. Early studies of OI conceptualised it in a broad and general way, defining it as a model that purposively integrates external knowledge with internal R&D (Chesbrough 2003; Chesbrough and Crowther 2006; Gassmann 2006; Gassmann and Enkel 2004). Scholars have highlighted the conceptual ambiguity of openness (Dahlander and Gann 2010; Teplov et al., 2019; Trott and Hartmann 2009). This conceptual ambiguity was subsequently addressed by unpacking inbound OI in terms of a specific single type of OI activity, such as collaboration with external partners (Laursen and Salter 2014), search for different sources of information (Bianchi et al., 2011; Brunswicker and Vanhaverbeke 2015; Laursen and Salter 2006), interactions with customers (Foss, et al. 2011), outsourcing (Bianchi et al., 2016), and external knowledge sourcing (Asimakopoulos et al., 2020).

As the OI literature started to gain more maturity, scholars moved beyond a single activity; however, they have covered not more than three OI activities. They have found a positive effect on innovation outcomes, thereby lending support to the importance of looking beyond a single OI activity (Cheng and Huizingh 2014; Stephan et al., 2019). Nevertheless, these studies have been confined to a limited number of OI activities; in practice, managers face the dilemma of choosing from a broad range of up to 10 different types of activities (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019). Therefore, it seems important for firms to take a portfolio approach, represented by choosing from a diverse range of OI activities (Teplov et al., 2019).

The majority of studies that have adopted a portfolio approach and defined inbound OI in terms of different types of OI activities have not examined its impact on firm innovativeness (Chesbrough and Brunswicker, 2014; Markovic et al., 2020; Pinarello et al., 2022; Podmetina et al., 2018; Rangus et al., 2016; Teplov et al., 2019). Only Stephan et al. (2019) and Cheng and Huizingh (2014) studied the effect of OI activities on innovation outcomes, but by focusing on two and three inbound OI activities respectively.

Accordingly, and to the best of the authors' knowledge, our paper is the first to look at the breadth of a larger number of different types of OI activities and their effect on firm innovativeness. Our findings suggest that the development of a portfolio of different types of OI activities is a first-order dynamic capability that results in a competitive advantage (Schilke 2014). This is illustrated by the positive relationship obtained in our study, between the breadth of OI activities and firm innovativeness, supporting H5. By employing a portfolio approach to the development of OI activities, these different activities act as channels to bring more diverse knowledge, opportunities, and resources into the firm, thereby amplifying the knowledge creation process. Equally important, different, and hence more diverse knowledge is extracted from each type of OI activity. Knowledge diversity does in fact stimulate the innovative process by allowing individuals to make novel associations and linkages (Cohen and Levinthal 1990). In fact, consulting external information sources includes scanning the external environment for information and interacting with external parties to acquire external knowledge and introduce it to the business (Birkinshaw et al., 2008; Huston and Sakkab 2006). For instance, information collected from customers offers firms important knowledge for the development of new or improved goods or services (Chiesa et al., 1996). Besides, monitoring the activities of suppliers and competitors is another approach to identify key information (Chiesa et al., 1996; Kang and Kang 2014).

The positive effect obtained between the breadth of OI activities and firm innovativeness can also be interpreted and understood from an organisational learning theory perspective (Crossan et al., 1999; Huber 1991) as well as from a knowledge diversity view (Dell'Era and Verganti, 2010; Frey et al., 2011). In essence, openness to different types of external partners stimulates positive innovation outcomes (Brunswicker and Vanhaverbeke 2015; Laursen and Salter 2006). Thus, engaging in several types of OI activities such as crowd-sourcing, external technology acquisition, customer co-creation in R&D projects and scanning for external ideas (Chesbrough and Brunswicker, 2014; Podmetina et al., 2018; Teplov et al., 2019) with these different partners will amplify the diversity of knowledge, which in turn, increase creative ideas and innovativeness within the firm. For instance, as firms do multiple OI activities, the knowledge resources become larger as compared to undertaking only one OI activity.

At the second level, this paper has also shed light on the capabilities and routines that are key to the development of a portfolio of different types of OI activities. As our analysis of the OI literature has shown, the majority of studies examining the implementation of OI have conceptualised it either in general terms (Bogers et al., 2018; Mortara and Tim Minshall, 2011; Salter et al., 2014; Urbinati et al., 2020), or in terms of a single OI activity (Bianchi et al., 2016; Cheah and Ho 2020; Foss, et al. 2011; Grama-Vigouroux et al., 2020; Lakemond et al., 2016; Zobel 2017). These studies have highlighted the importance of enabling capabilities and routines such as top management support, delegation of decision making, dedicated teams, internal learning capacity, and absorptive capacity for a specific OI activity such as collaboration with external partners or interaction with customers (Cheah and Ho 2020; Foss, et al. 2011; Grama-Vigouroux et al., 2020). However, developing a portfolio of different types of OI activities brings the new challenges of managing multiple OI activities. This requires skills such as team working, virtual collaboration, communication, and networking; abilities such as project management, cultural awareness, working with different professional communities, sharing knowledge and ideas internally and externally, adaptability, and flexibility; and capabilities such as entrepreneurial, market, and resource orientation as well as relying on OI intermediaries (Cheng and Huizingh 2014; Markovic et al., 2020; Pinarello et al., 2022). Only a few studies have examined the capabilities and routines that support the breadth of OI activities (Cheng and Huizingh 2014; Chesbrough and Brunswicker, 2014; Markovic et al., 2020; Podmetina et al., 2018).

Our results show that the implementation of the first-order dynamic capability, namely the breadth of OI activities, appears to be dependent on the proactive development of second-order dynamic capabilities, such as OI training, social information systems capabilities, and relational capability, supporting H1, H2 and H4 respectively (Fig. 1). These antecedents act as effective information-processing mechanisms that reduce potential risks and the environmental uncertainty arising when undertaking OI activities (Bensaou and Venkatraman 1995; Tushman and Nadler 1978). The uncertainties that firms face include geographical distance between partners, potential opportunistic behaviour of external partners, misappropriation of knowledge, challenges of information search, a lack of OI skills among internal employees, and resistance from internal employees to OI (Chesbrough 2003; Faems et al., 2008; Mortara et al., 2009; Phene et al., 2006; Ritala et al., 2015). As a second-order learning routine, OI training acts as an enabler to mitigate the challenges when employees undertake multiple types of OI activities together; it also provides better awareness of OI methods and tools. OI training can help employees to understand how to develop skills and abilities to better manage each OI activity.

Our results also support the view that social information systems capabilities are another significant second-order dynamic capability that boosts the breadth of OI activities. They are effective information-processing mechanisms that reduce the challenges firms face when managing several OI activities simultaneously. Such challenges can include over-search of the external environment (Laursen and Salter 2006), finding and locating the knowledge in the network, and geographical distance from collaborators and external partners (Phene et al., 2006; Sidhu et al., 2007). These capabilities simplify the process of accessing and looking for relevant external information (Boyd and Ellison 2007).

We have also found that relational capability supports the breadth of OI activities. Aside from the main importance of this capability in helping firms to create and manage their relationships with external partners (Day 2000), this second-order dynamic capability can help firms manage knowledge leakage, one of the most common risks they

perceive in OI (Ritala et al., 2015). Relational capability enables firms to differentiate between transactional and collaborative relationships, apply the appropriate governance mechanisms to manage these inter-firm relationships, and reduce the potential risks of opportunistic behaviour and misappropriation of knowledge (Day 2000; Faems et al., 2008).

As for the anticipation of new technologies capability, although technological development and continuing digital disruption have transformed the manufacturing sector (Obradović et al., 2021), we did not find any significant positive relationship between the anticipation of new technologies, specifically new manufacturing technologies, and the breadth of OI activities, i.e., not supporting H3 (Fig. 1). Potential explanations for this include the absence of coherent digital strategies and the inability of companies to understand the practical applications of some of the transformational digital technologies of smart factories (Peters 2019). These issues are holding back firms in the UK from digital investment in the manufacturing process. Despite its potential, Industry 4.0 is only fully used or incorporated in internal and external processes by a relatively small number of firms in the UK. This is because of a mixture of workforce capabilities and a lack of maturity of some technologies, meaning that Industry 4.0 technologies necessitate investment for adopting industries to attain their full potential (Allinson and Yusuf, 2019).

Thus, as discussed throughout our paper, no studies have yet examined the effects of key facilitating capabilities and routine on conducting different OI activities together. Our research shows that OI training, social information systems capabilities, and relational capability are key antecedents for the breadth of OI activities.

6.2. Managerial contributions

Our study contributes to raising managers' awareness of the value and key facilitators of a portfolio approach to OI strategy, and the key facilitators of this specific approach. Designing an OI strategy at the firm level is more complex than conducting single OI activities such as searching for information or collaborating with external partners. Our findings move beyond the two most common OI activities (searching for external ideas and collaboration with external partners) to highlight to managers the broad range of other emerging OI activities they can choose from when designing the implementation of the OI strategy at the firm level; for example, IP in-licensing, external technology acquisition, subcontracting R&D, using external networks, idea and start-up competitions, crowdsourcing, and customer co-creation with R&D projects. Typically, managers mainly implement the two most common OI activities, search and collaboration, rather than using the full range of other OI activities. This tends to reduce the effectiveness of the implementation of OI at the firm level: our study shows a clear link between the implementation of several different types of OI activities and firm innovativeness.

Our study provides managers with a better understanding of how the development of a portfolio of OI activities has a positive effect on innovativeness due to the synergy that is created at the firm level from different and diverse OI activities. If managers undertake several different types of OI activities that go beyond search and collaboration, they will be in a better position to stimulate diverse domains of knowledge, and hence immerse themselves more deeply in a larger pool of diverse knowledge. By undertaking in a parallel way emerging and more targeted OI activities, such as setting up idea and start-up competitions and crowdsourcing, alongside the traditional search for external ideas, managers can improve their exposure to new and diverse knowledge domains and opportunities during the search process. This is because information and new ideas extracted from targeted OI activities such as idea and start-up competitions and crowdsourcing are likely to be different and novel compared to those from traditional search networks. In this way, the very first step to OI, the search for ideas, becomes more effective: implementing different types of sub-OI activities related to the main search activity will stimulate the overall knowledge network more effectively.

When managers undertake one specific OI activity, their focus and efforts are directed mainly towards that activity, to maximise the advantages from it. After some time and after getting used to the activity, there is a risk that the benefits it generates may no longer be useful; the activity may become repetitive and saturated, with nothing new coming out of it. To minimise this risk, our study recommends managers to undertake a variety of different types of OI activities where benefits and outcomes will be much more diverse, hence improving the level of innovativeness. In addition, by undertaking these different types of sub-OI activities related to search, managers improve the likelihood that they will have better access to a broader pool of potential ideas and partners to choose from when they implement other OI activities which generally follow the search process: collaboration with external partners, IP in-licensing, external technology acquisition, and subcontracting R&D.

Our research also deepens managers' understanding of successful implementation of OI at the firm level. We provide managers with suggestions as to how they can facilitate and support the breadth of OI activities. OI is a process that requires the development of specific and relevant capabilities to support activities at the firm level. This indicates that it is not enough to implement OI only by taking a portfolio approach as explained earlier; our study helps managers to understand that it is equally important to develop higher-level capabilities, routines, and competencies to support the different types of OI activities that are within this portfolio. Our study offers insights to managers on key facilitators to undertaking different types of OI activities, such as OI training, social information systems capabilities, and relational capability. First, OI training will help firms' employees to acquire different skills, for example extrospective, networking and collaborative, flexibility/adaptability, team-working, interactivity, problem-solving, multitasking, communication, and scouting skills. It will aid with mentoring and forming employees into communities and collaborative networks. It will also help employees to use OI methods, in terms of collaborative OI, OI tools for collaborating online and offline, crowdsourcing, and creativity techniques, all of which are important in an OI context. Besides, investment in OI training at the firm level will facilitate the cultural shift in companies: it will give employees a more OI mindset and sharper awareness of the value of different OI activities as conduits to acquiring resources. Moreover, OI training can help employees to understand which skills are necessary for specific types of OI activities.

Second, the development of social information systems capabilities will support those employees who are engaged in OI activities such as crowdsourcing, idea and start-up competitions, external networks and customer co-creation in R&D projects, external technology acquisition, IP in-licensing, and scanning for external ideas. Social information systems capabilities will simplify the searching, processing, accessing, transferring, and sharing of information.

Finally, our study highlights to managers the importance of developing relational capabilities. The more OI activities a firm undertakes, the higher the risks of knowledge misappropriation by external partners, as compared to a scenario when a firm conducts a single activity or a limited number of them. Relational capability can help in these contexts. An example of such a capability is the design of appropriate governance mechanisms with external partners in relation to the level of risks, which will tend to vary according to the types of OI activities.

To sum up, our findings inform firm strategy. They offer top management evidence to help them advocate and defend the pursuit of multiple OI activities. Managers who are focused on acquiring external knowledge might be best advised to concentrate their OI efforts on sourcing information through diverse OI activities that collectively boost their level of innovativeness. Our study informs managers of how the development of high-level capabilities and routines, such as social information systems capabilities, relational capability, and OI training, is likely to mitigate the potential risks and challenges that may arise

when conducting several OI activities simultaneously at the firm level. This is due to the supporting role of these capabilities/routines in orchestrating the activities.

6.3. Limitations and future research

Our findings pave the way for a number of future studies that may address this study's limitations. As our study was based on a sample of UK manufacturing firms, our findings are contextually limited and may not be generalisable to other countries. Future studies can examine the ecological validity of our results by collecting data from other countries. Second, as this study is based on quantitative work, longitudinal case studies could be conducted to explore how the development and requirements for routines/capabilities evolve at different stages of open innovation, such as being in the early stages of implementing OI activities, in the process of refining OI activities and/or in an advanced stage of implementing OI activities (Teplov et al., 2019). Third, it may be worth looking at the breadth of OI at the project level instead of the firm level as the dynamics of OI tend to differ at these two level of analysis (Markovic et al., 2020). It is likely that at the project level, the complementarity effect across each of these OI activities will be more visible. For instance, OI activities such as idea and start-up competitions, and crowdsourcing, during a particular innovation project may be a springboard to other OI activities, such as customer co-creation with R&D projects. Similarly, OI activities such as the use of external networks and scanning for external ideas during projects will facilitate and be precursors to other activities such as IP in-licensing, external technology acquisition, subcontracting R&D, and collaborative innovation with external partners. In fact, creating a network necessitates maximising the proportion of non-redundant contacts such as through these different OI activities, to total contacts in the network (Burt 1992). This is because a firm's innovation is significantly determined by the diversity of its direct contacts (Dell'Era and Verganti, 2010). In addition, it would be interesting to have the level of analysis as the OI portfolio, and to compare the performance of different configurations of OI portfolios. Therefore, the focus would be on looking at the different configuration of OI activities within portfolios and identifying the optimal OI portfolio in terms of the OI activities that are included. Fourth, the common limitations of cross-sectional data and its restricted potential to develop a reverse causality apply in our study, due to time and resource constraints. By examining reverse causality, future research could examine whether undertaking a breadth of OI activities can in turn help with further developing the open innovation capabilities.

Data availability

The data that has been used is confidential.

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