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Informal and formal open activities: Innovation protection methods as antecedents and innovation outputs as consequences

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ABSTRACT

Firms' open strategies are tied to their innovation protection mechanisms. Extant theoretical and empirical research provides valuable insights, which generally conclude that stronger intellectual property protection is likely to be associated with increased openness. However, current research still has a limited understanding of the relationship between the choice of protection mechanisms and the mode of openness. We propose that firms adopt different modes of open activities when they choose corresponding effective protection mechanisms. We further investigate how these open activities affect innovation output and whether the impact of open activities on innovation output is contingent on innovation types. The empirical results from 1,202 firms in the IRC Open Innovation Survey show that firms pursue formal open activities when they incorporate legal methods to protect innovation. In contrast, firms pursue informal open activities when they incorporate strategic methods to protect innovation. We further find that formal open activities favor incremental innovation, while informal open activities favor radical one.

1. Introduction

The popularity of open activities is acknowledged in a growing body of research and practice. Firms should protect their knowledge and minimize value appropriation in these open relationships (Dyer and Singh, 1998; Wadhwa et al., 2017). Protection mechanisms might be important factors in explaining why and how firms participate in open activities. In the stream of literature addressing the importance of misappropriation in openness, research has reached a consensus that firms' open strategies might be tied to their intellectual property (IP) strategies (Chesbrough, 2003; Gassmann, 2006; Huizingh, 2011; Lichtenthaler, 2011; West, 2006). These studies provide valuable insights, and they reach an agreement that the stronger protection, the greater openness. Firms are more likely to participate in specific open activities only if they have corresponding innovation protection for these activities. However, we still have a limited understanding of the antecedents of open activities, from the perspective of variety in protection mechanisms.

As Laursen and Salter (2014) suggest, there's more work to be done to explore the relationship between the choice of protection methods and that of the mode of openness. Recent studies replied to this call and

distinguished between types of protection mechanisms by considering how management choices regarding the nature of protection related to the characteristics of open activities (Freel and Robson, 2017; Henttonen et al., 2016; Zobel et al., 2017). For example, De Zubielqui et al. (2019) found that a firm's legal IP protections underpin firm–university interactions. These studies generally suggest that firms' varying use of protection methods and the ability to protect their innovation from imitation determine their innovation modes (Pavitt, 1984). Because the concepts of protection mechanisms and openness have more than one dimension (Chang et al., 2012), it seems rather unenlightened to consider the various protection methods and different openness modes as simply additive.

Protection mechanisms may take various forms (Miric et al., 2019). We distinguish innovation protection methods as either legal or strategic. Legal protection methods involve several legal and contractual mechanisms (Gallié and Legros, 2012). Strategic protection methods include several non-contractual mechanisms, e.g., lead-time advantage on competitors, which are used to protect firms' innovations from imitation by competitors. In a similar vein, two different types of sources of open activities can be distinguished: informal (noncontractual) and formal (contractual) (Mina et al., 2014; Salavisa et al., 2012). We focus

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on informal and formal open activities as they commonly coexist in open resource access (Salavisa et al., 2012). They are strongly associated with different attributes of knowledge that can be protected by different protection mechanisms. We argue that firms pursue formal open activities when they use legal methods to protect innovation. In contrast, firms pursue informal open activities when they incorporate strategic methods to protect innovation. By linking innovation protection mechanisms and the openness mode, we advance the understanding of the antecedents of open activities.

Furthermore, firms are increasingly participating in open activities to access complementary resources, new knowledge, and market opportunities (Martín-de Castro, 2015). Firms exert enough effort to maximize innovation value in their open relationships. Innovation output might be an important consequence of open activities. In general, both formal and informal open activities are important for innovation output (Wang et al., 2012). Nonetheless, formal and informal open activities might be more effective for innovation output in some conditions than in others. One significant contingent factor is the innovation type. Specifically, formal and informal open activities are strong in different collaborative strength and contribute to different types of knowledge search, therefore improving different types of innovation output.

We categorize innovation output into radical and incremental innovation according to its novelty degree. Radical and incremental innovations have distinct definitions and emphasis. Radical innovations indicate a major departure from the extant technology base, and they are fundamental changes (Ettlie et al., 1984; Kobarg et al., 2019). Incremental innovations indicate continuous improvements or minor adjustments, which are built on current technology (Yin, 1994). We focus on incremental and radical activities as they require different knowledge, resource, and search processes, which vary considerably in formal and informal open activities (Ritala et al., 2018). We argue that firms pursuing formal open activities tend to produce incremental innovation. Firms pursuing informal open activities tend to produce radical innovation. By linking openness mode with the innovation types, we advance the understanding of the consequences of open activities.

We contribute to the literature on open activities by developing an integrative model that investigates the antecedents and consequences of open activities, which is still under-researched. By relating legal and strategic protection mechanism, and formal and informal open activities, we highlight the coherent links between them. By relating formal and informal open activities, and radical and incremental innovation, we explicitly investigated the different mechanisms through which different innovations are created.

2. Theoretical background and hypotheses development

2.1. Theoretical background

2.1.1. Open activities

Open activities have received increasing attention in scientific research and practice (Yun et al., 2020a). There is a fundamental dilemma in openness: one side is related to sharing knowledge and resource for value creation (Laursen and Salter, 2014). Specifically, organizations can increase their openness to utilize external partners and sources to achieve greater innovation. Openness can provide access to more new ideas than could be developed by themselves (Yun et al., 2020a). In this way, openness can speed the innovation process, reduce the uncertainty of technology and market. The other side is associated with potential costs, such as the leakage of core knowledge for value appropriation (Bönte and Keilbach, 2005; Laursen and Salter, 2014). Specifically, to obtain knowledge from external actors, organizations have to share some details of their own valuable knowledge with them, which is called “involuntary outgoing spillover”. Some critical knowledge of these organizations may be leaked to their rivals. In this case, skilled rivals can know where these organizations are focusing their innovative efforts, then shape their own technologies and target the

same fields.

Open activities are considered as a dynamic process (Rasiah, 2019; Yun, 2015; Yun and Liu, 2019; Yun et al., 2016b, 2018). Firms need to dynamically manage external relationships, adopt protection approaches, and develop their knowledge capacities to profit from openness. For example, Yun et al. (2020a) suggested that the process of dynamic open activities includes the outside-in, inside-out and coupled process, which requires boundary-crossing. Scholars argued that the Fourth Industrial Revolution could reshape openness and collaboration in innovation (Cooke, 2019; Pyka et al., 2019), and it features the creative and dynamic connection between technological field and market through open activities (Kodama, 2018; Lee et al., 2018). Yun et al. (2019a) explored the factors of open innovation dynamics. Yun et al. (2016b) proposed conceptual models to investigate the dynamic effects of openness in innovation.

2.1.2. Protection methods and open activities

Potential misappropriation causes uncertainty for firms when they are engaged in open activities. Efficient innovation protection methods can mitigate this uncertainty (Katila et al., 2008). Firms can anticipate misappropriation risk; therefore, they tend to avoid open activities with high potential for misappropriation when they incorporate weak innovation protection methods. A firm would engage in open activities only when they have effective protection mechanisms to protect their critical knowledge (Katila et al., 2008). Therefore, protection mechanisms are important antecedents and divers of open activities.

Some theoretical evidence supports this view. For example, Motohashi (2007) found that stronger patent protection encourages external technological transactions. Zobel et al. (2016) found that patenting is positively associated with different types of external collaborations. However, the patent protection method is not the only available method, and protection methods may take multiple forms (Freel and Robson, 2017). Innovation protection methods represent the mechanisms that a firm uses to protect and defend its innovation from its competitors or other firms (Amara et al., 2008). These methods are generally distinguished into two types. Some systematic IP rights, such as patents and copyrights, are classified into legal protection methods. Other alternative methods, such as keeping secrets and making it difficult for products or services to be imitated, are classified into strategic protection methods.

Because protection mechanisms are various, it appears rather crude to consider the various openness activities as one dimension (Freel and Robson, 2017). Legal protection methods having a legal basis emphasize more on formal IP protection, while strategic protection methods having an extra-legal basis emphasize more on informal IP protection (Freel and Robson, 2017). In this vein, we categorize open activities into formal and informal (Vanhaverbeke, 2006). Examples of formal open activities are alliances or research conducted through contractual agreements (Li et al., 2010). Informal open activities reflect informal relationships that a firm establishes with external partners through agreements other than contracts, such as agreements made during informal meetings or discussions (Elmqvist et al., 2009).

It is necessary to distinguish between types of protection methods and modes of open activities because different protection mechanisms have inconsistent ability to prevent a firm's knowledge from copied, and therefore deciding the variety in openness modes (Freel and Robson, 2017). In other words, specific open innovation activities need specific protection tools. However, it is still not clear about the relationships of legal and strategic protection methods with formal and informal open activities, which is the focus of this study.

2.1.3. Open activities and innovation output

The literature suggests that open activities might help a firm access external knowledge and resources, better understand new opportunities and reduce uncertainty for greater innovation performance (Grant and Baden-Fuller, 2004; Zhu et al., 2017). Therefore, open activities, both in

terms of formal and informal open activities, might be impactful to innovation output.

However, innovation output may take various forms regarding its novelty degree, i.e., incremental and radical innovation. It is necessary to categorize innovation output into these two types when talking about the consequences of formal and informal open activities for two reasons. First, formal and informal open activities represent two distinct modes of openness and thus involve distinct learning processes, knowledge search, resource properties associated with them (Taminiau et al., 2009). For example, formal and informal external relationships may be associated with different collaborative strength and contribute to different types of knowledge. Formal activities are likely to involve strong ties and contribute to knowledge depth or specific know-how. Meanwhile, informal activities are likely to involve weak ties and contribute to knowledge breadth and tacitness (Barrutia et al., 2014; Kang and Kang, 2009). Incremental and radical innovation vary considerably regarding their knowledge requirements and search processes. Therefore, it is highly plausible to distinguish incremental and radical innovation when discussing the mechanisms through which formal and informal open activities affect innovation output.

The other reason why we categorize innovation output into incremental and radical innovation origin from the coarseness of using simple one-dimension innovation output (Cooper, 1998). Using additive or aggregated levels of innovation output would lose some information on innovation output and therefore masking or mixing up the real effects of formal and informal open activities. Extant research demonstrates that open activities might have mixed effects on innovation. For example, Grimpe and Hussinger (2013) identified that formal and informal channels in collaborative research activities contribute to higher innovation performance. (Bascavusoglu-Moreau et al., 2013) found that formal external knowledge searches have a negative effect on innovation performance, while informal external knowledge searches have a positive one. (Wang et al., 2020) proposed that a firm's openness benefits its innovation up to a certain threshold. The conflicting finding motivates us to distinguish between incremental and radical innovation, which may help explain the current debate.

2.2. Hypotheses development

2.2.1. Antecedents of formal and informal open activities from the perspective of innovation protection methods

There is a consensus that a firm's protection mechanisms are significant antecedents for its openness, and the general conclusion is that more effective protections, more openness. Build upon the precedents, we distinguished different dimensions of protection mechanisms and open activities and contend that it is critical that firms use legal protection mechanisms when they engage in formal open activities. Making use of strategic forms of protecting innovation is particularly critical for firms that aim to engage in informal open activities. The attributes of knowledge associated with these open activities can help explain different roles of legal and strategic protections.

The importance of protection mechanisms on open activities is contingent on the attributes of knowledge associated with these open activities (Nieto and Pérez-Cano, 2004). Formal and informal open activities are associated with different attributes of knowledge. Codifiability is one of the most central dimensions of knowledge (Cardinal et al., 2001). The knowledge codifiability indicates the extent to which they can be documented by figures/drawings, formulae, and structured data. Two knowledge categories have been defined according to their codifiable degree: explicit and tacit. Formal open activities are likely to be strong in terms of explicit knowledge, while informal open activities are likely to be rich in terms of tacit knowledge (Li et al., 2010).

When a firm participates in formal open collaborations, its knowledge assets in such open activities are relatively more explicit. It is likely to be forced to document their technological activities in its formal collaborations, e.g., joint venture. Legal protection methods are

particularly effective for codified knowledge (Gallié and Legros, 2012) because they explicitly specify obligations, sanctions, punishment, infringement clauses and how to resolve conflicts, which can effectively prevent outsiders from free-riding and opportunism (Laursen and Salter, 2005). Otherwise, without legal-basis protections, partner firms may have ambiguity in the boundaries of appropriate collaborative behavior and therefore are more likely to acquire each other's knowledge beyond the scope of the formal agreement. Thus, the higher the level of codification in a knowledge domain, the more efficient and useful the legal methods of protecting it (Pérez-Cano and Villén-Altamirano, 2013). When a firm participates in informal open collaborations, its knowledge assets in such open activities are relatively more tacit. Tacit knowledge is generally subjective, unstandardized, disembodied, and difficult to observe (Scuotto et al., 2020). Strategic protection methods are highly effective for protecting noncodified and tacit knowledge because strategic protection methods are simple to implement, easy to control and economical to use, and entail high levels of flexibility to protect tacit knowledge (Nieto and Pérez-Cano, 2004; Zobel et al., 2017). Firms that incorporate strategic protection methods tend to pursue informal open activities. Thus, we propose the following:

Hypothesis 1: Firms using legal innovation protection methods are more likely to pursue formal open activities instead of informal open activities.

Hypothesis 2: Firms using strategic innovation protection methods are more likely to pursue informal open activities instead of formal open activities.

2.2.2. Formal open activities, informal open activities and the implications for innovation output

Research has demonstrated that a firm's openness, both formal and informal open activities, improve its innovation performance to some extent (Fey and Birkinshaw, 2005). Build upon but depart from the precedents, we contend that formal open activities favor incremental innovation than the radical one. Contrarily, informal open activities favor radical innovation than the incremental one. Two different properties of formal and informal open activities, i.e., tie strength and search dimensions, can help to explain their different effects on innovation type.

One different property of formal and informal open activities is associated with the strength of external ties. Formal open activities are likely to involve strong ties, while informal open activities are likely to involve weak ties (Kang and Kang, 2009). Formal open activities need strong, long-term, compulsory, and scheduled interactions among participants. Strong ties need a relatively high cost of drafting, negotiating, and monitoring contracts to guarantee intense interaction and critical capability sharing. The strong ties represent useful conduits for transferring complex knowledge items (Hansen, 1999), benefit fine-grained and reliable information exchanges (Scholten, 2006), which are largely required when a firm pursues an incremental innovation (Forés and Camisón, 2016). Therefore, formal open activities are more positively related to incremental innovation. Contrarily, informal open activities require low cost for maintaining relationships. Weak ties provide a better conduit for novel and diverse information, as opposed to strong ties (Granovetter, 1973). Such knowledge diversity and novelty constitute a base for producing radical innovation (Flor et al., 2018). Therefore, the role of informal open activities in a radical innovation is more pronounced.

The other different property of informal and formal open activities is associated with the dimensions of knowledge search. Formal open activities are likely to be strong in terms of search depth, while informal open activities are likely to be rich in terms of search breadth (Barrutia et al., 2014). Conducting incremental innovation rely on a deep search because the in-depth knowledge drawn from deep search help firms to develop core competencies and continuously refine the understanding of extant knowledge base (Zang et al., 2014). Therefore, the benefits of

formal open activities become more reflected in incremental innovation. However, the innovation advantages gained through search breadth are different from the advantages gained through search depth. Access to a broad knowledge base facilitates detections of novel information and potential changes, enabling firms to seize technological challenges or remote market opportunities and expand their knowledge pool for radical innovation (Flor et al., 2018). Thus, the effect of informal open activities on radical innovations is more than its effect on the incremental type. Accordingly, we propose the following hypotheses:

Hypothesis 3: Formal open activities favor incremental innovation instead of the radical one.

Hypothesis 4: Informal open activities favor radical innovation instead of the incremental one.

In summary, we propose an integrative model that investigates the antecedents and consequences of formal and informal open activities, an unexplored topic in prior research. We summarize the research framework in Fig. 1.

3. Methods

3.1. Research background, sample, and procedures

This study mainly uses survey data obtained from the UK-Innovation Research Centre (IRC) Open Innovation Survey, which is an ad hoc survey of British businesses conducted by the Centre for Business Research (Cambridge University) and Imperial College Business School. The survey was conducted in 2010 to analyze the innovation activities of companies in the UK (Mina et al., 2014). In this survey, firms were asked detailed questions about their markets, finances, and innovation activities, such as sources of product and service innovation. The survey was sent out by post to firms with between 5 and 999 employees, thus including small- and medium-sized enterprises (SMEs). Compared with the widely used community innovation survey (CIS), the UK-IRC Open Innovation Survey has a unique advantage of collecting information on the open activities of firms. In this survey, firms answered questions about the formal (e.g., joint venture, joint market, research alliances) and informal (e.g., leader users, websites, network, sharing facilities) activities used to accelerate innovation.

The final sample consists of 1,202 firms that involve 117 different industrial classifications. Fig. 2 shows the industrial distribution of our sample and displays the SIC industries that have more than 20 firm samples. We can see that the industries in the survey were diverse and evenly distributed. Furthermore, the non-response bias is examined by comparing early and late responses. We compare the first 602 and the last 600 responses on demographical characteristics, which shows no significant differences (i.e., tenure: $t = 0.59$, $p > 0.1$; size: $t = 0.62$, $p > 0.1$). Hence, we believe that nonresponse bias is not a threat to this study.

3.2. Measures

3.2.1. Antecedents of formal and informal open activities

The dependent variables used for Hypotheses 1 and 2 are firms' *formal and informal open activities*. During the survey, each firm was asked to evaluate the importance of various formal (10 contractual items) and informal (5 noncontractual items) open activities for accelerating innovation. Specifically, each firm was asked to measure the importance of each open activity using a Likert ranging from 0 (not used) to 3 (highly important). First, to construct these two separate variables, we calculated the internal consistency of formal open activities (Cronbach's $\alpha = 0.82$) and informal (Cronbach's $\alpha = 0.66$). The internal consistency of informal open activities is slightly lower than that of formal open activities, but it is still acceptable. We measure the value of formal (or informal) open activities by summing the values of

the corresponding items and dividing them by the total number of their activities.

The independent variables for Hypotheses 1 and 2 are legal and strategic innovation protection methods. During the survey, firms should indicate the importance of legal protection methods (5 legal items) and strategic protection methods (3 strategic items) of protecting innovation over the last three years. The items of legal protection methods are *Registration of design*, *Patents*, *Trademarks*, *Confidentiality agreements*, and *Copyrights*. The items of strategic protection methods are *Secrecy*, *Complexity of design*, and *Lead-time advantage over competitors*. The scale is 0: not used, 1: low, 2: medium, and 3: high. We measured the values of the legal (and strategic) innovation protection methods by summing the values of the corresponding items and dividing them by the total number of innovation protection methods.

3.2.2. Consequences of informal and formal open activities

Our dependent variable for Hypotheses 3 and 4 is the firm's *incremental and radical innovation output*. Firms should indicate whether they engaged in innovation with different newness levels. Consistent with prior studies in related contexts, we used the newness of innovation to the firm or the whole industry to categorize innovation into two dimensions (Chiung and Hung, 2010; Zouaghi et al., 2018).

Firms were asked whether they had introduced innovation new to them but not to the whole industry in the following aspects: technologically new or significantly improved manufactured product; methods of producing manufactured products; supply, storage or distribution systems for manufactured products; service product. Based on these items, *Incremental innovation output* is used as a dummy variable. The variable is set equal to one when the firm had introduced innovations novel to itself but not to the industry in any aspect, zero otherwise. They were asked further whether they had introduced innovation new to themselves and the industry in the same aspects. Based on these items, *Radical innovation output* is set equal to one when the firm had introduced innovations new to both itself and the industry, zero otherwise.

Following previous research, we control for several factors in the test of the antecedents and consequences of formal and informal open activities. *Largest Market* might affect a firm's capability to develop novel and diverse innovation ideas (Hitt et al., 1997). *Tenure* and *Firm size* are included as controls because they might affect investment in innovation output and organizational experience (Jiménez-Jiménez and Sanz-Valle, 2011). *R&D*, *Human capital* and *High technology* are controlled for because of their potential implications for both firm innovation productivity and human resource systems. We also include *Performance* to control for firm productivity. Following previous research (Kindström et al., 2013), we control for the impact of competition on innovation output by considering the *Competitors* of firms.

Another two industry-level control variables are *industry munificence* and *industry dynamism*, which indicate the average rate of industrial growth and the changing degree of the industrial environment, respectively. Industry information is from Orbis database available from Bureau van Dijk, which has good coverage for both public and private firms (Ribeiro et al., 2010), representing the industry characteristics well¹. Following previous research, we use data over the 11 years which contained the focal year as a midpoint (i.e., industry munificence for 2010 is based on the data over the years 2005–2015) (Dess and Beard, 1984; Misangyi et al., 2006). We regressed the annual sales of each industry against the year. *Industry munificence* was calculated by the regression coefficients divided by the mean of industry sales. We measure *Industry dynamism* by calculating the standard error of regression coefficients in regressions divided by the mean of industry sales.

¹ Because the survey provides the UK 2003 SIC Code for each firm, we used a website to convert the 2003 SIC Code into a 2007 SIC Code. Then, using 4-digit industry classifications (UK 2007 SIC Code), we retrieved and downloaded all the information on UK firms (e.g., sales) from the Orbis database.

Fig. 1. The research framework.

Fig. 2. Industrial distribution of the sample.

Table 1 shows the summary and descriptive statistics of all variables in this study.

3.3. Statistical models

$$\begin{cases} \text{Incremental innovation output} = \gamma_0 + \gamma_1 * \text{Formal open activities} + \gamma_2 * \text{Informal open activities} + \gamma * \text{Controls} + \delta_1 \\ \text{Radical innovation output} = \eta_0 + \eta_1 * \text{Formal open activities} + \eta_2 * \text{Informal open activities} + \eta * \text{Controls} + \delta_2 \end{cases} \quad (3)$$

3.3.1. Innovation protection methods and open activities

To test Hypotheses 1-2, we used seemingly unrelated regression (sureg) in Stata14.0. Because formal and informal open activities are our two dependent variables in the estimated equations, and they might be correlated, a simple linear regression is not suitable. Sureg technique can account for a correlation between the error terms of the two regression equations, i.e., heteroskedasticity and contemporaneous correlation in the errors across equations (Zellner, 1962). It is appropriate to be applied in regressions models with several dependent variables (Globerman and Shapiro, 1999). The estimation equations of Hypotheses 1 and 2 are as follows:

$$\begin{cases} \text{Formal open activities} = \alpha_0 + \alpha_1 * \text{Strategic protections} + \alpha_2 * \text{Legal protections} + \alpha * \text{Controls} + \varepsilon_1 \\ \text{Informal open activities} = \beta_0 + \beta_1 * \text{Strategic protections} + \beta_2 * \text{Legal protections} + \beta * \text{Controls} + \varepsilon_2 \end{cases} \quad (1)$$

3.3.2. Open activities and Innovation output

Given our use of a binary dependent variable to test Hypotheses 3-4, and the inclusion of industry-level control variables, we relied on multilevel mixed-effects logistic regression for the dichotomous measures (i.e., melogit in Stata 14.0). The appropriation of this regression

technique comes from the distribution of our dependent variable (binomial) and explanatory variables (some of them are continuous, some are categorical). Logistic regression model is an alternative classification method when the observed variables do not follow a multivariate normal distribution. It is justified for continuous and categorical predicting variables in the same model (Afifi and Clark, 1990). According to previous studies (Daily and Dalton, 1994), if the absolute value of a regression coefficient increases, Wald statistic will rapidly lose power. In logistic regressions, the outcome variable indicates that the probability of the firm has or doesn't have innovation. Logistic regression models allow us to evaluate the probability that a firm is introducing innovation as a function of two kinds of open activities and some industry characteristics. We adopted, therefore, the likelihood ratio approach. The specification of the logistic model is displayed as follows:

$$\text{Prob.}(Y = 1) = 1 / \left[1 + e^{-(A + \sum \alpha_i C_i + \sum \beta_j X_j)} \right], \quad (2)$$

where $\text{Prob.}(Y = 1)$ refers to the probability of generating innovation, A is a constant, C means a vector of all control variables, X refers to a vector of all the explanatory variables, and e is the logarithm base, approximately 2.718. The estimation equations of Hypotheses 3 and 4 are as follows:

The aim of our models is to establish the influencing factor profile of the firms generating innovation. The regression coefficients in the logistic regression analysis indicate the influence of open activities on the probability of generating incremental or radical innovation, with a positive regression coefficient indicating that the predicting variable increases the probability of innovation output.

4. Results

Table 2 shows correlation coefficients. The Variance Inflation Factor

(VIF) tests in all the regressions showed a maximum of 4.28, which was well below the suggested threshold of 5. Further, as Zheng and Yang (2015) suggested, we conducted an alternative multicollinearity test using the coldiag procedure in Stata. The results show the condition number of the complete model to be 27.70, which was well below the

Table 1

Descriptions of variables in this study.

Variables	Description	Mean	SD	Min	Max	Obs
Radical innovation	Technologically new or significant improved innovation that is new to the focal firm and the industry.	0.458	0.498	0.000	1.000	1,200
Incremental innovation	Technologically new or significant improved innovation that is new to the focal firm but not to the industry.	0.528	0.499	0.000	1.000	1,200
Largest market	Largest market based on sales revenue (1 Local; 2 Regional; 3 National; 4 International)	3.301	0.743	1.000	4.000	1,042
Tenure	The number of years from the formation year to the survey year	22.688	19.121	2.000	126.000	1,169
Size*	Logarithm of the employee number.	3.549	1.391	0.693	10.240	999
R&D*	Logarithm of the total R&D expenditure (£000s).	2.911	2.941	0.000	12.707	1,032
Human capital	Percentages of employees with a first or higher degree in science and engineering subjects or other subjects.	22.957	29.880	0.000	100.000	963
High technology	High tech or conventional. (1 High tech; 2 Conventional)	1.601	0.490	1.000	2.000	1,202
Performance*	Logarithm of latest turnover/ Sales/ Revenue	8.077	1.909	0.000	15.274	955
Competitors*	Logarithm of number of firms that the focal firm regards as serious competitors.	1.974	1.341	0.000	9.210	990
Industry munificence	The rate of sustained growth in the industry.	3.171	3.346	-5.040	22.160	1,202
Industry dynamism	The rate of dynamic change in the industry.	0.069	0.065	0.005	0.628	1,202
Strategic protection methods	Secrecy, Complexity of design and Lead-time advantage over competitors.	1.567	0.972	0.000	3.000	442
Legal protection methods	Registration of design, Trademarks, Patents, Confidentiality agreements and Copyright.	1.192	0.890	0.000	3.000	444
Informal	Engaging directly with lead users etc.	0.581	0.555	0.000	3.000	1,109
Formal	Joint ventures etc.	0.468	0.529	0.000	2.900	1,106

Note: * The variable was logarithmic transformed in regressions.

Table 2

Correlation matrix.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Radical innovation	1.000														
2 Incremental innovation	0.365	1.000													
3 Largest market	0.258	0.108	1.000												
4 Tenure	-0.031	0.077	0.013	1.000											
5 Size	0.235	0.237	0.145	0.271	1.000										
6 R&D	0.446	0.199	0.390	0.070	0.366	1.000									
7 Human capital	0.135	-0.111	0.219	-0.253	-0.259	0.210	1.000								
8 High technology	-0.147	-0.054	-0.164	0.079	-0.005	-0.269	-0.246	1.000							
9 Performance	0.176	0.221	0.148	0.222	0.834	0.276	-0.276	0.002	1.000						
10 Competitors	-0.049	0.063	-0.007	0.030	0.083	-0.083	-0.065	0.052	0.076	1.000					
11 Industry munificence	0.098	0.045	0.087	-0.066	0.031	0.147	0.077	-0.467	0.001	-0.059	1.000				
12 Industry dynamism	-0.001	0.026	-0.061	0.033	0.016	-0.062	-0.118	0.301	0.039	0.059	-0.304	1.000			
13 Strategic protection methods	0.383	0.106	0.287	0.031	0.315	0.472	0.086	-0.228	0.310	-0.088	0.087	-0.043	1.000		
14 Legal protection methods	0.309	0.103	0.330	0.061	0.286	0.437	0.054	-0.199	0.280	-0.067	0.141	-0.122	0.594	1.000	
15 Informal	0.256	0.099	0.118	-0.067	0.113	0.337	0.228	-0.170	0.083	-0.019	0.058	-0.058	0.294	0.192	1.000
16 Formal	0.240	0.108	0.237	0.011	0.148	0.440	0.304	-0.178	0.073	-0.033	0.036	-0.081	0.319	0.387	0.557

Note: Each correlation, whose magnitude is bigger than 0.06, is statistically significant at a 5% level.

Table 3

Regression of SUR models.

	Formal open activities:M1	Informal open activities: M2	Formal open activities: M3	Informal open activities: M4
Largest market	0.025(0.025)	-0.051 [†] (0.028)	-0.036(0.041)	-0.063(0.044)
Tenure	0.001(0.001)	-0.002 [†] (0.001)	0.001(0.001)	-0.001(0.002)
Size	0.026(0.023)	-0.007(0.026)	0.029(0.039)	-0.036(0.042)
R&D	0.054***(0.007)	0.061***(0.008)	0.060***(0.012)	0.054***(0.013)
Human capital	0.004***(0.001)	0.003***(0.001)	0.003***(0.001)	0.002(0.001)
High technology	-0.032(0.040)	-0.079 [†] (0.044)	0.031(0.065)	-0.019(0.071)
Performance	-0.001(0.016)	0.017(0.017)	-0.019(0.027)	0.019(0.029)
Competitors	0.005(0.013)	0.016(0.015)	0.010(0.025)	0.017(0.027)
Industry munificence	-0.011 [†] (0.006)	-0.012 [†] (0.006)	-0.021*(0.009)	-0.020 [†] (0.010)
Industry dynamism	-0.370(0.241)	-0.270(0.265)	-1.057 [†] (0.615)	-0.434(0.668)
Strategic protection methods			0.020(0.036)	0.143***(0.039)
Legal protection methods			0.122***(0.038)	-0.026(0.041)
Constant	0.108(0.136)	0.545***(0.149)	0.284(0.213)	0.559***(0.231)
R-sq	0.209	0.167	0.247	0.178
Chi2	196.28**	149.26**	109.82**	72.51**
Observations	743	743	335	335

Notes. [†]p<.1

* p<.05

** p<.01.

suggested value of 30.

We report the regression results for testing Hypotheses 1 and 2 in Table 3. Models 1–2 are the baseline models, which test the effect of the control variables on formal and informal activities. Models 3 and 4 test H1 by regressing formal and informal open activities on legal and strategic innovation protection methods. The results show that legal protection methods have a significantly positive effect on formal open activities ($b=0.122$, $p<0.01$, see Model 3). However, the regression coefficient of legal protection methods on informal open activities is nonsignificant ($b=-0.026$, $p>0.1$, see Model 4); thus, H1 is supported. The results indicate that strategic protection methods have a significantly positive impact on informal open activities ($b=0.143$, $p<0.01$, see Model 4)². However, the regression coefficient of strategic protection methods on formal open activities is nonsignificant ($b=0.020$, $p>0.1$, see Model 3); thus, H2 is supported.

We measured the practical significance of legal protection methods by calculating the influence on formal open activities of increasing one standard deviation (SD) of an interested variable in Model 3. All other variables are held at their mean values. The results show that one SD increase of legal innovation protection methods causes a 0.15 increase in formal open activities, which indicates a 31.08% increase compared with the mean of formal open activities. Likewise, the results of Model 4 illustrate that one SD increase of strategic innovation protection methods is related to a 0.14 increase in informal open activities, which indicates a 23.92% increase relative to the mean of informal open activities.

We report the regression results for testing Hypotheses 3 and 4 in Table 4. Model 1 reports the baseline model, which examines the effects of the control variables on innovation output. Models 2 and 3 test H3 and H4 by regressing incremental and radical innovation output on open activities and incorporates the control variables, respectively. By adopting the prior approach (Phelps, 2010), we used likelihood-ratio tests for incremental fit improvements compared with the baseline model. The likelihood-ratio test results indicate that Model 3 significantly improves the fit compared with baseline Model 1 (63.80, $p<0.01$), and Model 4 significantly improves the fit compared with baseline Model 2 (77.22, $p<0.01$), indicating that entering these two independent variables significantly improves the model fit.

The results indicate that increasing the use of formal open activities increases the probability of generating incremental innovation output ($b=0.521$, $p<0.05$, see Model 3). For every one-unit increase in formal open activities, the odds of generating incremental innovation increased by 68.37%. Informal open activities have a statistically significant and positive impact on the probability of generating radical innovation output ($b=0.898$, $p<0.01$, see Model 4). A one-unit increase in informal open activities increases the odds of generating radical innovation by 145%. Thus, Hypotheses 3 and 4 are fully supported.

Robustness checks. To make sure that the findings are still robust, we performed several robustness checks to enhance our confidence in the results. First, we ran the full models by using the winsorized values of formal and informal open activities at the 98th and 99th percentiles. Second, while our regression models are appropriate for the distribution of our dependent variable, this study also used Probit regression models, which assumes that disturbances are normally distributed with variance one (Finney, 1952). We found that the results from these robustness checks are substantively similar to the main findings³.

Finally, endogeneity issue may exist in our model analysis. One source of endogeneity may arise from the possibility that modes of open activities are not exogenously given. Neglecting this source of

endogeneity will yield a biased estimation. We employ a form of instrument variable (IV) estimation to correct potential endogeneity problem. An IV should be correlated with endogenous variables but not directly correlated with dependent variables (Staiger and Stock, 1994).

Specifically, in the first stage, we regress the independent variables on the IV and all the control variables. In the second stage, we regress the dependent variables on the predicted value of independent variables from the first stage and all the control variables. The instrument for formal open activities is *Specialized resource access*, which is a dummy variable equal to one if the focal firm's purpose and design of activities with external parties are to gain access to new or specialized information, equipment or facilities, zero otherwise. The "*Specialized resource access*" is a proper IV for formal open activities because a firm aim for specialized information, equipment or facilities is likely to engage in formal open activities (Perkmann and Walsh, 2007). The instrument for informal open activities is *Monitor changes and opportunities*, which is also a dummy variable equal to one if the focal firm's purpose and design of activities with external parties are to monitor environmental changes and opportunities, zero otherwise. The "*Monitor changes and opportunities*" is a proper IV for informal open activities because a firm aim for keeping up with market changes and seizing market opportunities are likely to engage in informal open activities (Zhu et al., 2017).

Rejection of the null hypothesis in both cases at the $p<0.01$ level shows that the models are not underidentified (Anderson canon. corr. LM statistic= 24.78 for formal open activities, and 18.65 for informal open activities). The Cragg-Donald F-statistic from the two instruments exceeds the critical value of 10 ($F=25.30$ for formal open activities and 18.85 for informal open activities). We test endogeneity using Wu-Hausman and Durbin-Wu-Hausman tests. We found only formal open activities is endogenous (Durbin $\chi^2=16.89$; Wu-Hausman=16.99, $p<0.01$ for formal open activities). We reported the regression results with IV estimation for formal open activities. In the first-stage model (Model 1) shown in Table 5, the coefficient of *Specialized resource access* is statistically significant and positive ($b=0.19$ and $p<0.01$), suggesting the appropriateness of this variable as an IV. In the second stage, we use predicted formal open activities. The results for Models 2 and 3 are shown in Table 5. The results of this robustness check are mainly consistent with prior findings.

5. Conclusion and discussion

This paper tries to identify the conditions under which a firm is more likely to use open activities and how these open activities affect innovation performance. This study shows that a firm adopts different open activity modes when it has corresponding effective defense mechanisms to protect open activities. This paper further increases our understanding of the influential mechanisms of informal and formal open activities related to a firm's innovation output.

This paper makes two major contributions. First, we contribute to the appropriation literature by proposing that the protection methods that a firm uses to protect innovation activities are key factors that shape its likelihood to engage in informal and formal open activities. From the perspective of firms, losing control over knowledge is the principal risk associated with open innovation (Natalicchio et al., 2017). Firms might have specific preferences for formal or informal open activities (Mina et al., 2014) when they incorporate certain protection methods. The mainstream of literature on strategic and legal innovation protection methods provides valuable insights into why firms choose specific protecting mechanisms (Hall et al., 2014; Neuhausler, 2012). Using the same theoretical perspectives for different attributes of innovation protection and open activities might lead to inaccurate conclusions. We show that firms can choose to use various defense mechanisms when they engage in formal and informal open activities. This study finds that using strategic protection mechanisms can enhance the likelihood that a firm will engage in informal open activities, and the use of legal protection mechanisms that a firm will engage in formal open activities.

² We did a robustness check by removing "secret" from the measurement of "strategic protection methods", because "secret" sometimes is seen as a legal protection means. The regression result is consistent with the main findings. Thank the anonymous reviewer for pointing it out.

³ The results are available from the author on request.

Table 4

. Regression of logistic models.

	Incremental innovation: M1	Radical innovation: M2	Incremental innovation: M3	Radical innovation: M4
Largest market	0.047(0.120)	0.126(0.131)	0.105(0.126)	0.183(0.143)
Tenure	0.006(0.005)	-0.006(0.005)	0.005(0.005)	-0.006(0.005)
Size	0.107(0.115)	0.106(0.126)	0.113(0.119)	0.093(0.132)
R&D	0.145** (0.035)	0.386** (0.040)	0.076* (0.038)	0.346** (0.044)
Human capital	-0.009** (0.003)	0.005(0.004)	-0.012** (0.004)	0.002(0.004)
High technology	-0.330† (0.195)	-0.275(0.237)	-0.357(0.201)	-0.204(0.262)
Performance	0.109(0.078)	0.098(0.085)	0.112(0.079)	0.104(0.089)
Competitors	0.160* (0.066)	-0.020(0.071)	0.184** (0.070)	-0.004(0.074)
Industry munificence	-0.000(0.027)	0.008(0.033)	0.010(0.028)	0.017(0.036)
Industry dynamism	0.138(1.154)	1.677(1.408)	0.660(1.240)	2.605(1.632)
Informal open activities			0.293(0.188)	0.898** (0.220)
Formal open activities			0.521* (0.216)	0.205(0.240)
Constant	-1.050(0.663)	-2.110** (0.763)	-1.425* (0.697)	-2.873** (0.841)
Log likelihood	-477.341	-424.718	-445.439	-386.110
Wald chi2	70.71	151.70	75.13	148.86
Observations	782	782	743	743

Notes. †p<.1

* p<.05

** p<.01.

Table 5

Regression of logistic models with IV.

	Formal open activities: M1	Incremental innovation: M2	Radical innovation: M3
Specialized resource access	0.190*** (0.038)		
Largest market	0.016(0.028)	-0.038(0.143)	0.056(0.157)
Tenure	0.002(0.001)	-0.002(0.005)	-0.011† (0.006)
Size	0.017(0.026)	0.094(0.133)	-0.021(0.146)
R&D	0.046*** (0.008)	-0.129† (0.068)	0.215** (0.072)
Human capital	0.004*** (0.001)	-0.024*** (0.005)	-0.006(0.006)
High technology	-0.003(0.043)	-0.333(0.221)	0.016(0.291)
Performance	0.002(0.017)	0.104(0.085)	0.130(0.096)
Competitors	-0.005(0.014)	0.175* (0.073)	0.021(0.077)
Industry munificence	-0.007(0.006)	0.040(0.033)	0.039(0.042)
Industry dynamism	-0.366(0.263)	1.512(1.375)	2.013(1.811)
Informal open activities		0.218(0.194)	0.689** (0.217)
Predicted Formal open activities		4.183*** (1.017)	2.564* (1.100)
Constant	0.033(0.150)	-1.619* (0.776)	-3.028** (0.938)
Log likelihood	0.225 (R2)	-373.521	-342.391
Wald chi2	17.80 (F)	71.36	116.16
Observations	638	638	638

Notes. †p<.1

* p<.05

** p<.01.

Hence, this study confirms some of [Freel and Robson \(2017\)](#) and [Stefan and Bengtsson's \(2017\)](#) theoretical propositions that knowledge protection might influence a firm's willingness to involve in open innovation activities. ([Laursen and Salter, 2014](#)) provided new insights on appropriability strategy and openness, and called for future research to explore the links between different protection strategies and different types of openness. Our finding yields important insights into the multiple attributes of innovation protection and the concept of open activities, which respond to the call of ([Laursen and Salter, 2014](#)).

Second, we contribute to open innovation literature. Extant research provided valuable insights into open innovation ([Radziwon and Bogers, 2019](#); [Suh and Jeon, 2019](#); [Yun et al., 2020b](#)). These studies have yielded mixed findings for different attributes of open activities ([Bianchi et al., 2016](#); [Carlsson et al., 2011](#); [Wang et al., 2015](#)). Specifically, this study augments the arguments presented by [Mina et al.'s, 2014](#) that firms engage in a variety of informal and formal open activities to

accelerate their innovation. What they solved little and what is called for is the link between the dimensions of open activities and firm innovation. Our claim also aligns with that of [Bascavusoglu-Moreau et al.'s \(2013\)](#) study, which argued that a firm might be a participant in open knowledge exchanges with outsiders using informal or formal methods. They empirically test the importance and joint effects of informal and formal open activities in affecting innovation. However, the finding in this study differs from their arguments. Conceptually and empirically, we suggest that informal knowledge sourcing is a better way to achieve radical innovation, while formal knowledge sourcing favors incremental one.

Our findings have important managerial implications as well, especially for managers of a firm looking to leverage its open activities. First, when a firm decides to form external open relationships, evaluating the effectiveness of its strategic and legal protection strategies are essential for the implementation of informal and formal open activities. Second, firm managers evaluating the benefits of their external open relationships should consider their innovation emphasis. In other words, a firm needs to configure its external knowledge portfolios to align with the innovation type. For instance, if a firm wants to pursue fundamentally novel products, it can effectively engage in informal open activities to support such innovation. Since informal relationships are generally based on trust and interactions through interpersonal relationships, managers could formulate policies to create incentives for informal exchange. In contrast, if a firm wants to refine its knowledge base and innovate its products incrementally, it can engage in formal open activities. The policy implication here is that understanding the moderating role of innovation type on strategies for open activities can help managers build external knowledge portfolios that produce corresponding innovation output.

We are mindful of some of the limitations of this study. First, to obtain detailed information on open activities, our data analysis relies on firm-level data collected by the UK~IRC Open Innovation Survey, which includes a relatively small sample of observations. Further work is needed to determine the proper sample size, conduct more inquiries and use more analysis methods. Although we try to mitigate endogeneity using instrumental variables and 2SLS regression, this key econometric issue may not be fully addressed within the context of a cross-sectional dataset. Second, there are alternative ways to measure innovation output. In this study, we use a self-reported item to measure innovation output. One major limitation of such self-reported measures is that they are subjective. Firms' innovation output might actually differ from what they report. Future works could use an objective measure to evaluate firms' innovation output, such as trademarks or copyrights, to examine

whether our argument can be generalized to other conditions. Moreover, open innovation lets firms arrive at a new business model (Ardolino et al., 2020; Kim and Lee, 2019; Yun et al., 2016a). Future work can discuss the roles of formal and informal openness activities in new unified business models. The studies on formal and informal innovation strategy with a business model at catch-up and post-catch-up are also interesting and promising (Yun et al., 2019b).

Declaration of Competing Interest

On behalf of all other authors, we declare that we have no conflicts of interest. We certify that the submission is original work and is not under review at any other publication.

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