The paradox of openness: Appropriability, external search and collaboration☆

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ABSTRACT

To innovate, firms often need to draw from, and collaborate with, a large number of actors from outside their organization. At the same time, firms need also to be focused on capturing the returns from their innovative ideas. This gives rise to a paradox of openness—the creation of innovations often requires openness, but the commercialization of innovations requires protection. Based on econometric analysis of data from a UK innovation survey, we find a concave relationship between firms' breadth of external search and formal collaboration for innovation, and the strength of the firms' appropriability strategies. We show that this concave relationship is stronger for breadth of formal collaboration than for external search. There is also partial evidence suggesting that the relationship is less pronounced for both external search and formal collaboration if firms do not draw ideas from or collaborate with competitors. We explore the implications of these findings for the literature on open innovation and innovation strategy.

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1. Introduction

This paper explores how the choices of firms to be open to different external actors are related to the choices they make about their appropriability strategy, that is, their approach to protecting their knowledge against being copied and to appropriating the returns from their innovative activities. The innovation process involves resource intensive search to find commercially exploitable new combinations of knowledge or technology (Nelson and Winter, 1982; Stuart and Podolny, 1996; Hargadon and Sutton, 1997; Fleming and Sorenson, 2004; Laursen, 2012). This requires organizations to work with and draw knowledge from many actors outside their organization (Shan et al., 1994; Rosenkopf and Nerkar, 2001; Katila, 2002; Laursen and Salter, 2006). In order to render these efforts effective, firms need to align their internal processes to the external environment: they need to configure their firm to enable successful absorption of knowledge from external sources (Cohen and Levinthal, 1990). Many scholars have suggested that seeking help from external actors for innovation is becoming an important part of managerial strategy, and argue that the innovation process is becoming more open, distributed and democratic (von Hippel, 1988, 2005; Chesbrough, 2003; Coombs et al., 2003; Chesbrough et al., 2006).

Research has shown that firms need to protect their knowledge when they engage in formal external collaboration (Cassiman and Veugelers, 2002; Heiman and Nickerson, 2004), which is one means that firms can use to access skills and knowledge not available within the boundaries of their organizations. In the present study we explore two aspects of firm openness—the breadth of the firm's innovation search efforts, and the range of types of partner organizations in formal collaborations for innovation. In the case of innovative search, we focus on the breadth of firms' external search strategies by looking at the number of separate search channels (sources of innovation), such as suppliers, users, competitors, research organizations and universities, that firms use in their search for innovative opportunities, which Laursen and Salter (2006), call "external search breadth". We also examine the breadth of collaboration with suppliers, customers, competitors, research organizations and universities. Formal innovation enables more sustained exchanges between the focal firm and its external environment, but it requires greater managerial effort to find suitable partners, agree on contracts and coordinate joint efforts (Dyer and Singh, 1998).

The current study helps to extend our knowledge about how firms' openness choices are linked to their need to protect their knowledge in order to appropriate the returns from innovative activities. A major problem associated with accessing external sources of knowledge relates to the fact that, in order to obtain knowledge, organizations have to reveal some parts of their own knowledge to external actors. Managers make their firm "open" by engaging with a broad set of external actors in their innovation activities, but also have to protect their own firm's knowledge from being copied by competitors. This represents an apparent paradox that openness may demand more attention to protection. Paraphrasing Arrow (1962), we describe this as the *paradox of openness*. Appropriating the benefits deriving from an innovation requires considerable managerial attention and effort, such as applying for patents, establishing a market lead time, keeping key technologies secret from competitors, and gaining access to complementary assets (Teece, 1986; Arora et al., 2001; Arora and Ceccagnoli, 2006; Teece, 2002; Ziedonis, 2004; Ceccagnoli, 2009). Following the open innovation literature, we contend that these efforts have a major influence on the firm's approach to the external environment in relation to who it works with, where it looks for ideas, and how it organizes its own innovative activities (Gans and Stern, 2003; Chesbrough, 2006; Somaya, 2012). By exploring the relation between the firm's managerial choices over appropriating the benefits from their innovations and its openness to the external environment, we hope to advance theory and practice on how best to manage the paradox of openness.

We suggest that the firm-level strength of overall appropriability strategy shows a concave relation to the openness of external search and collaboration for innovation.[2] Our argument suggests that appropriability and openness generally go hand-in-hand, but that high levels of appropriability are associated with decreasing levels of openness. Note that, in this paper, we do not make strong claims about causality. It might be that a strong appropriability strategy (up to a certain point) allows more openness, alternatively it might be the case that as firms become more open, they need to focus more on appropriability. However, in this paper, we do not consider it of central importance to identify precisely the direction of causality since our dependent variable and important independent variables are choice variables (we return to this point in Section 6).

We examine how the type of external engagement that firms choose is connected to the relationship between appropriability strategy and openness, suggesting that the negative effect of the link between appropriability and openness is stronger for formal collaboration breadth than for external search breadth. We also explore a particular case of "high-risk" openness—*competitor collaboration*, arguing that if firms do not draw from or collaborate with competitors, the association between appropriability and openness is weaker. Based on an analysis of a large sample of manufacturing firms from the 4th wave of the UK Innovation Survey, we find partial or full support for the hypotheses.

2. Conceptual background: openness and appropriability

Central to our understanding of the innovation process is how organizations search for knowledge (Nelson and Winter, 1982). Schumpeter describes of these search processes as characterized by the need for firms to search for and carry out "new combinations"

of technologies, knowledge and markets: "To produce other things, or the same things by a different method, means to combine these materials and forces differently" (Schumpeter, 1912/1934: 65). In this context, innovative search can be defined as "an organization's problem-solving activities that involve the creation and recombination of technological ideas" (Katila and Ahuja, 2002: 1184). Indeed, firms invest considerable amounts of time, money and other resources in their search for these opportunities (Cohen and Levinthal, 1990; Chen, 2008). Part of this search effort is expenditure on R&D, but this is only one element in the search process and may account for only a small portion of investment in the search for innovations (Patel and Pavitt, 1995).

New models of open innovation suggesting that firms should make greater strategic use of external knowledge have spawned a new stream of research on the managerial dimensions of open innovation (Chesbrough, 2003, 2006; Chesbrough et al., 2006). This perspective is consistent with research that highlights the importance of horizontal and vertical relationships as sources of innovation (Pavitt, 1984; von Hippel, 1988). The benefits of dedicated search activities for innovative performance have been demonstrated in a number of empirical studies that support these models (Katila and Ahuja, 2002; Fleming and Sorenson, 2004; Laursen and Salter, 2006; Grimpe and Sofka, 2009; Garriga et al., 2013). In addition, the benefits of collaboration—with customers, suppliers, universities and others in the innovation systems—for innovative outcomes have been widely acknowledged in the literature (Powell et al., 1996; Ahuja, 2000; Belderbos et al., 2004; Cassiman and Veugelers, 2006).

Building on the emerging literature on open innovation, we focus on two related forms of openness—external search and innovation collaboration.[3] First, we follow Laursen and Salter (2006) and focus on the breadth of external search related to innovating, across a range of different sources or channels in the innovation system, such as suppliers, customers and universities, in order to capture the firm's openness to external knowledge. Each of these channels may involve interacting with a different community of practice with perhaps opposing sets of institutional norms, habits and rules. Firms choosing to work with these actors need to develop (costly) organizational practices that are suited to the domain in which they search. Cast in this light, external search can be seen as a form of "soft" openness, typically involving drawing knowledge from external parties without entering into legally binding agreements. Second, we examine the case of formal collaboration, focusing on the breadth of the firm's formal collaboration relationships for innovation. Although the setting up of formal collaborations is more problematic for managers, this type of cooperation can provide firms with access to complementary resources to enable the successful development of new products and processes (Powell et al., 1996). It may also enable them to be more adept at commercializing these ideas (Ahuja, 2000; Belderbos et al., 2004). Since formal collaboration requires a firm and its external partner to adhere to an agreed structure for the exchange, it can be described as a "hard" form of openness.

To try to advance the theory and research on the drivers of hard and soft openness, we explore the role of appropriability for the firm's decision to be open to a broad set of external actors in the context of innovation. A number of appropriability mechanisms (or methods) are available to managers to allow the firm to capture rents from its organization's intellectual assets. The importance attributed to a range of appropriability mechanisms can be

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[2] Note that this is consistent with both decreasing positive marginal effects up to a top-point (if there is a top-point) and increasing negative marginal effects after that possible top-point. Note also that our empirical estimations do not allow us to be very precise about the exact shape of the concave relationship within the pertinent confidence intervals.

[3] Of course, the concept of "open innovation" involves a wider range of mechanisms than those captured by external search breadth and formal collaboration. However, these are two mechanisms that are central to understanding and measurement of open innovation (Dahlander and Gann, 2010).

considered, what Cohen et al. (2000: 8) term the "appropriability strategy" of firms. An appropriability strategy frequently involves use of formal methods, such as patents or trademarks, as well as informal methods such as secrecy or lead times. In this paper, we focus on the overall importance attributed to a broad range of protection mechanisms, including patents, registration of designs, secrecy, lead times, product complexity and trademarks. We assume that more importance attributed to more appropriability mechanisms (of any type) means that the firm puts more emphasis on appropriability in general—which might have separate positive and negative effects on the relationship with openness.

Application of protection mechanisms is important for firms to ensure their technology is not copied by others and to inform negotiations over collaboration with a range of external parties (Cohen et al., 2000). The use of one form of intellectual property (IP) may lead to the acquisition of complementary forms of IP, such as trademarks and design registrations (Gambardella and Giarratana, 2013). Thus, formal and informal mechanisms generally appear to be complements (Cohen et al., 2000). Despite considerable evidence that such mechanisms provide only partial protection, the literature continues to emphasize innovation strategies related to the acquisition and use of different forms of appropriability (Arora and Gambardella, 2010).

However, relatively little is known about how the firm's attitude to appropriability is associated with the openness of the firm to external actors (see also, West, 2003). In exploring this, we want to understand how choices in one area of managerial practice are related to choices in other areas. Our approach is based on the idea that the firm can be seen as a bundle of related choices (Rivkin, 2000), and is rooted in the need for more insights into how managerial choices are induced or constrained by other sets of managerial decisions. In particular, we seek to extend understanding of the concept of open innovation by focusing on the appropriability strategy and its relation to hard and soft forms of openness. This responds to a call in the recent open innovation literature (Chesbrough, 2006; Dahlander and Gann, 2010) for more investigation into the strategic dimensions of firms' openness decisions.

3. Hypotheses

3.1. The relationship between appropriability strategy and openness

There is a complex and intimate relation between how firms try to appropriate rents or profits from their innovations, and how open these firms are to the external environment. There are substantial risks from openness to external firms and organizations (Gans and Stern, 2003; Shane, 2003; Chesbrough, 2006), the most extreme being theft. More commonly, firms fear "involuntary outgoing spillover", that is, leakage of critical knowledge about the firm's innovation efforts to its competitors (Cassiman and Veugelers, 2002). For example, knowing where a firm is focusing its innovative efforts could provide important information to skilled rivals about how to shape their own search efforts and target the same markets.

In order to guard against theft and unwanted spillovers, firms can employ a range of legal protection methods, such as patents, secrecy, and trademarks. However, the value of formal types of protection mechanisms is limited to their defensibility in legal suits and/or the firm's ability to demonstrate a credible threat in a legal intervention (Gans and Stern, 2003; Sherry and Teece, 2004). Even if legal protection methods are enforceable, skilled rivals may be able to invent around existing patents relatively quickly (Mansfield et al., 1981). In addition, many of the key features of modern innovations do not lend themselves to formal IP protection because they

relate to customer experience or the "look and feel" of a product. Also, informal protection mechanisms, such as secrecy, can be breeched by competitors by "poaching" workers from incumbent firms or reverse engineering their products. In the case of lead times or first mover advantages, these can dissipate quickly in the face of strong competition and rapid technological change (Lieberman and Montgomery, 1998). As a result, firms often operate in environments of leaky knowledge, strong competition from skilled and experienced competitors, and the threat of new firms entering their product markets. Some of these competitors may have access to considerable complementary assets which may outnumber and be more effective than the incumbent firm's own assets and capabilities.

Therefore, it is clear that managing external sources of innovation and related linkages involves huge information asymmetries. In order to gain access to and convince potential partners of the benefits of exchange, it is necessary to negotiate formal contracts or at least informal agreements based on a degree of mutual understanding. External partners will require enough information about an idea to develop some belief in its eventual successful commercialization. In other words, they need to know about the idea before they invest in it. This introduces what Arrow (1962) described as the *paradox of disclosure*, where in "trading ideas, the willingness-to-pay of potential buyers depends on their knowledge of the idea, yet the knowledge of the idea implies that potential buyers need not pay in order to exploit it" (Gans and Stern, 2003: 338). When negotiating contracts in the market for ideas, disclosure can increase the bargaining power of the buyer and reduce the power of the innovator, especially in the absence of credible threats and IP rights protection.

This paradox of disclosure applies also to a range of external interactions between the innovating firm and the external environment, beyond the commercial transaction of selling the idea. Indeed, to win the support of external parties or to gain access to external knowledge sources, it is usually necessary for firms to share knowledge with other actors in the innovation system (von Hippel, 1987). For instance, working with suppliers on the development of innovations normally requires extensive mutual coordination and commitment (Dyer and Singh, 1998). In addition, von Hippel (1986, 1988) shows that many innovators work closely with lead users and other customers on the development of new products. As Nelson (1995) suggests, external knowledge sharing allows firms to build networks and communities around areas of mutual interest, facilitating the formation of institutions that help to support the development of a new area of practice (see also, Spencer, 2001; Alexy et al., 2013). Even working with a university partner on a collaborative research project will require the firm to provide some insights into its problems to allow the academic partner to tailor its research appropriately (Perkmann and Walsh, 2009).

Against this background, we suggest that it is crucially important for firms to align how they protect their innovations, with their engagement with external actors. One solution might be for firms to rely on a strategy that involves partial disclosure of some central part of the traded knowledge while controlling access to other parts of the knowledge. In the context of open source software, Henkel (2006) describes such an approach as "selective revealing" (see also Alexy et al., 2013). Firms can also use their behavior regarding appropriability to send "quality" signals to other parties. Signaling involves one entity credibly conveying some information about itself to another (Connelly et al., 2011). The idea that particular strategies resulting in certain behaviors can be interpreted as signals, which, in turn, can solve problems related to asymmetric information, has been applied to various contexts including, signaling individuals' abilities in the job-market (see the seminal signaling paper by Spence, 1973) and product innovation

strategies (Bhattacharya and Ritter, 1983). In our context, an emphasis on appropriability may be interpreted by external parties as signaling the focal firm's possession of valuable technological knowledge and, consequently, its potential value as a collaborator (or an attractive investment object for a financier).[4] It also signals to potential partners the firm's awareness of the importance of appropriability mechanisms, such as patents or secrecy.

Although an emphasis on appropriability can be associated with effective external engagement, the literature on open innovation shows that over-emphasis on this area can have significant negative consequences for the possibilities for external collaboration (Laursen and Salter, 2005; Chesbrough, 2006; Alexy et al., 2009; Reitzig and Puranam, 2009). For instance, legal departments can put strict limits on individual employees exchanging knowledge across the firm boundary, and adopt a defensive stance in order to ensure priority for subsequent patent claims (Davis and Harrison, 2001). Many large firms require their staff to obtain permission from the legal team before engaging with external parties, which acts as a significant hurdle to working with new external partners (Alexy et al., 2009). Legal departments often require collaboration agreements to be in place before embarking on an exchange with an external party, and complex negotiations may hamper the development of emergent collaboration. Mechanisms to ensure secrecy and protect lead times might discourage firms from engaging in informal exchanges with external actors (Liebeskind, 1997). Thus, while some emphasis on appropriability sends a positive signal to potential collaborators, too strong a focus could be interpreted as signaling that collaboration with the focal firm will be difficult, and that conflicts over control and ownership of knowledge might ensue. Application of overly restrictive protection mechanisms might reduce the interest of firm managers in collaboration, and scare off external actors in the innovation system.

The above discussion suggests that the firm's appropriability strategy is linked closely to the firm's level of openness. Although firms may need to be open to a range of external actors, they also need to appropriate the profits from their innovations, and whether this openness can be considered hard or soft, there needs to be means in place to protect their IP. Thus, openness and some sort of appropriability strategy go hand in hand: firms need to disclose some knowledge in order to gain from external parties, but they need also to protect parts of their knowledge if they are to gain value from the exchange. Too strong an emphasis on appropriability will weaken the relationship between appropriability and soft or hard forms of openness. Thus, we posit:

Hypothesis 1a. The strength of firms' appropriability strategies will show a concave relationship with external search breadth.

Hypothesis 1b. The strength of firms' appropriability strategies will show a concave relationship with innovation collaboration breadth.

We have addressed the implications of appropriability for external search and formal collaboration, but we need also to investigate the differences between these two forms of openness. There is a strong suggestion that the implications of high levels of appropriability play out differently for hard and soft forms of openness: firms that invoke strong protection mechanisms to help capture

value from their innovative efforts are likely to find it more difficult to find partners to collaborate with, but less likely to find that it hampers external search. This is because although a strong emphasis on appropriability might deter potential formal collaborators, it does not scare off external sources, such as universities or suppliers, from engaging in informal exchanges of knowledge. Relatedly, external search requires less two-way interaction. Accordingly, we suggest that the underlying negative effect of high levels of appropriability on openness will be stronger for formal collaboration than for external search breadth. Thus,

Hypothesis 2. The concavity of the relationship between strength of firms' appropriability strategies and openness will be stronger for formal innovation collaboration breadth than for external search breadth.

3.2. Openness, appropriability and competitor collaboration

It is clear that many firms rely on competitors to provide critical information to guide and shape their own innovative efforts (von Hippel, 1988). Firms can learn from their competitors directly or indirectly—indirect learning being more common than direct collaboration. Indirect learning includes reverse engineering of competing products or mirroring the innovative efforts of competitors in own product development efforts (Allen, 1977). Many firms make active efforts to track and monitor their competitors' activities by scrutinizing product announcements, patent applications and university collaboration partners (Slater and Narver, 1995). Although less common, an important mechanism to access external knowledge is collaboration with a competitor (Hamel et al., 1989), for example on the development of pre-competitive research projects (Spencer, 2003), in the standards setting process (Leiponen, 2008), over community building initiatives (Dahlander and Gann, 2010), or via licensing agreements (Leone and Reichstein, 2012).

However, learning from competitors is a risky game, and the dangers of theft or unplanned outward spillovers are great. Moreover, these risks are much greater in the context of external search or innovation collaboration with competitors than in relation to interactions with any other actor in the firm's portfolio of external search channels or innovation collaborations. This is because the content and structural compatibility of competitors' knowledge may be the same as that of the focal firm (Lane and Lubatkin, 1998), allowing competitors potentially to benefit relatively easy from any involuntary outward spillovers. Therefore, we suggest that working with competitors requires the firm to pay extra attention to appropriability to avoid unwanted spillovers of knowledge. It can be assumed that only firms with strong appropriability strategies will engage in collaborations with competitors; therefore, the presence of a competitor in the firm's portfolio of knowledge sources or collaboration partners will strengthen the association between appropriability and openness. Conversely, if there are no competitor firms in the focal firm's partner portfolio, then the need for appropriability mechanisms is reduced. Thus:

Hypothesis 3. The absence of competitors in firms' knowledge sourcing portfolios or collaboration partner portfolios weakens the connection between appropriability and openness in relation to external search breadth or formal innovation collaboration breadth.

4. Data and method

4.1. Data

The data for the analysis are from the 4th UK Innovation Survey. The background and motivation for innovation surveys is described

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[4] Bhattacharya and Ritter (1983) suggest that an important reason for firms disclosing private technological knowledge is that it is a quality signal to the capital markets. Haeussler et al. (2009) argue and corroborate empirically that investors are faced with considerable uncertainty and therefore rely on patents as signals when trying to assess the prospects of potential portfolio companies. While we note that signals to the capital market may be an important reason for a forceful appropriability strategy, addressing this issue in depth is beyond the scope of this paper.

in the Organisation for Economic Co-operation and Development's (OECD) Oslo Manual (OECD, 2005). Innovation surveys are part of a wider tradition of innovation studies that involve "subject-oriented" and "object-oriented" approaches to the collection of information on innovation activities (Smith, 2005). Innovations surveys are "subject-oriented" because managers are asked directly to describe their innovative activities. National innovation surveys are based on the Yale and other surveys of innovative activities, such as R&D surveys (for examples, see Pavitt, 1984; Levin et al., 1987; Cohen and Levinthal, 1990; Klevorick et al., 1995). Since the early 1990s, innovations surveys have been conducted by many governments and statistics agencies around the world, including most members of the European Union, South Africa, Canada, Australia and the US among others.

The UK government has conducted an innovation survey every few years since the early 1990s, and in 2005 it administered the 4th UK Innovation Survey. Administration of the survey and data collection was managed by the Office for National Statistics (ONS), the UK official government statistical office (Robson and Ortmans, 2006). This was a postal survey sent to more than 28,000 business units in the UK, based on a sample of firms created by the ONS. The sample covers firms with more than 10 employees. In order to ensure adequate regional and industry response rates, the ONS conducted a census of all firms with more than 250 employees and a stratified sample of firms with less than 250 employees (small and medium sized enterprises—SMEs). The SMEs were from 23 industries and 12 regions based on information contained in the ONS Inter-Departmental Business Register (DTI, 2005). Although response was voluntary, the survey response rate was 58%. The response rates for individual sectors, regions and size classes were similar to the aggregate response rate (Robson and Ortmans, 2006). The sample of manufacturing firms included 4863 firms. In this study, we use the 2931 manufacturing firms with non-missing values that declared past or current innovative activities. Of the 2931 firms, 744 relied on past innovations, but did not innovate in 2004.

The questionnaire was addressed to the individual in the firm officially responsible for providing information on the firm's activities to the ONS (such as information used to calculate the UK's Gross Domestic Product). The questionnaire is based on the OECD's Oslo Manual, which has been extensively piloted and pre-tested in the UK and other European countries (Smith, 2005). The UK government also commissioned additional pilot studies (Bullock et al., 2004). To help avoid common method bias, the questionnaire was constructed to include different types of responses. For example, response types included Likert scales, yes/no answers, indications of percentages and questions requiring absolute numbers. To check for common method bias, we conducted a Harman's one-factor test on the items included. Since we identified a number of factors and since the primary factor accounted for less than the majority of the variance (the first factor accounted for 31% of the variance), there appear to be no potential problems associated with common method bias (Podsakoff and Organ, 1986). The survey was administered in a single wave which does not allow us to compare early and late respondents. A high response rate is commonly acknowledged to avoid non-response bias (Armstrong and Overton, 1977: 396): in this context, a 58% response rate can be considered excellent.

4.2. Measures

4.2.1. Dependent variable

We use two variables to measure *external search breadth* and innovation *collaboration breadth*. External search breadth is the number of external sources of knowledge or information used by the firm in its innovative activities. The survey lists ten possible external sources and firms were asked to indicate the importance (on a 0–3 scale) of each of these sources. The list of sources included

in the questionnaire was broad and the items were not exclusive. The list reflects the range of sources associated with the innovation system, including suppliers, clients and competitors, and also general institutions, such as regulatory and standards bodies (Lundvall, 1992; Nelson, 1993; Spencer, 2001). Following Laursen and Salter (2004, 2006), this measure has been used in numerous studies of open innovation to proxy for firm-level openness (see for example, Tether and Tajar, 2008; Grimpe and Sofka, 2009; Lee et al., 2010; Leiponen and Helfat, 2010; Garriga et al., 2013; Love et al., 2013). We use the six types of organizational sources—suppliers, clients or customers, competitors, consultants and private R&D institutes, universities, and public research institutes—which focuses on sources where interaction might be involved, in turn involving risk of knowledge outflows. We excluded sources where interaction would not occur (such as scientific publications, and technical standards). First, each of the six sources is coded as a binary variable indicate the importance of the knowledge source with 0 indicating no or low and 1 indicating medium or high importance. Then the six sources are summed with the firm scoring 0 if no knowledge sources are used and 6 if all knowledge sources are used. The set of items appears to have a high degree of internal consistency (Cronbach's Alpha Coefficient = 0.80). In order to apply fractional response regression (see below), we normalize the variable by dividing by the highest possible number of sources used (6), so that the resulting variable takes a minimum value of 0 and a maximum of 1. To measure collaboration breadth, firms were asked to indicate whether or not they had collaborated on innovation activities with any of the six types of organizations listed above, in the period 2002–2004. The measure was then computed similar to search breadth (Cronbach's Alpha Coefficient = 0.88).

4.2.2. Explanatory variables

To obtain some insight into the role of appropriability methods at firm level, we draw on the responses to a question in the survey on the degree of importance to the firm of different methods of protection. The survey question is similar to those used in previous studies of appropriability methods (Levin et al., 1987; Cohen et al., 2000; Jensen and Webster, 2009). Based on the responses, we created a measure of the overall strength of the firm's *appropriability strategy* by adding up the uses of the six measures of formal and informal protection listed in the survey (scored on a 0–3 scale). The six items are patents, registration of design, trademarks, secrecy, lead time, and complexity. The set of items appears to have a high degree of internal consistency (Cronbach's Alpha Coefficient = 0.86).[5]

To control for the importance of absorptive capacity, we use firm-level *R&D intensity* (R&D expenditure divided by sales) (Cohen and Levinthal, 1990). The numerator is taken from the UK innovation survey, while the denominator—firm sales—is based on ONS register data, supplied with the survey data, for the same year (2004). We control also for firm size, measured as *number of employees* (expressed in logarithms). Number of employees is taken from ONS register data, supplied with the survey data, for year 2004. In order to control for breadth of openness of new firms, we include a measure for whether the firm was established after 1 January 2000. Here, we focus on the subset of startups with formal R&D activities, to create the variable *R&D active startups*. However, we do not have information on small startups (less than 10 employees), nor do we have information on firms that did not survive. We include a

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[5] Note that our main independent variable takes account of both variation stemming from the number of appropriability mechanisms and the importance attributed to each, but our dependent variables do not take account of the importance attributed to each type of collaboration because we do not have information on the importance attributed to each of the innovation collaborators of the focal firm.

Table 1
Descriptive statistics and simple correlations ($n = 2931$).

	Variable	Mean	Std. D.	Min.	Max.	1.	2.	3.	4.	5.	6.	7.
1	External search breadth	0.39	0.26	0	1							
2	Innovation collaboration breadth	0.14	0.27	0	1	0.30						
3	Appropriability strategy	6.70	5.50	0	18	0.48	0.28					
4	R&D intensity	0.01	0.05	0	0.83	0.14	0.16	0.18				
5	R&D start-up	0.05	0.23	0	1	0.09	0.10	0.06	0.14			
6	Number of employees (log)	4.27	1.43	2.30	9.94	0.26	0.26	0.34	0.02	-0.03		
7	Part of an enterprise group	0.44	0.50	0	1	0.15	0.17	0.27	0.07	0.01	0.49	
8	Market size	3.16	1.62	1	5	0.20	0.21	0.35	0.14	0.03	0.30	0.25

Note: Correlations equal to or above |0.04| are significant at $p < 0.05$. Two-tailed tests.

control for firms' *market size* based on a measure of involvement local, regional, national or international markets. Finally, we include 14 industry dummies and 12 regional dummies to account for different propensities for openness across industries and geographic space.

Table 1 presents the descriptive statistics and simple correlations among our variables. None of the correlations are sufficiently strong to require further investigation of potential multicollinearity problems. Table 2 shows average values for the strength of the appropriability strategy, external search breadth, and collaboration breadth, by industry. In line with the results of the Yale and Carnegie Mellon surveys, chemicals and electronics have particularly high scores for appropriability, while the low-tech industries have relatively low appropriability scores. Overall, across industries, there is a broad correspondence between levels of appropriability, external search breadth and collaboration breadth.

4.3. Statistical method and regression results

Our dependent variables (external search breadth and collaboration breadth) take on non-negative integer values because they are counts of scores. A Poisson regression model (or negative binomial regression in the case of overdispersion) might seem a reasonable choice. However, in our setting we have two dependent variables that are restricted by an upper bound (6 is the maximum of sources/collaboration partners), making Poisson or Negative Binomial distributions not applicable. Instead, we follow Wooldridge (2002: 661) who suggests that the dependent variable can be "obtained by dividing a count variable by an upper bound", and that such a transformation means that fractional logit regression can be applied (Papke and Wooldridge, 1996). In this approach, $E(y|\mathbf{x})$ is modeled as a logistic function, where y is the dependent variable and $\mathbf{x}$ is a set of regressors: $E(y|\mathbf{x}) = \exp(\mathbf{x}\boldsymbol{\beta})/[1 + \exp(\mathbf{x}\boldsymbol{\beta})]$.

This model ensures that the predicted values of y are in (0, 1) and that the effect of any x_j on $E(y|\mathbf{x})$ diminishes as $\mathbf{x}\boldsymbol{\beta} \to \infty$. Accordingly, the method is non-linear. It can be estimated using quasi-maximum likelihood (Wooldridge, 2002). We estimate the models using seemingly unrelated estimations since this method allows us to take into account that decisions regarding external search and collaboration are often closely related. When computing the standard errors, the procedure estimates the simultaneous covariance of the coefficients in the two models (for search and collaboration).

To graph the relationships, we apply a simulation-based technique proposed by King et al. (2000) and introduced to management research by Zelner (2009). The simulation approach involves taking a number of draws from the multivariate normal distribution around the estimated coefficient vector from the non-linear model (in our case, the fractional response model), and the estimated variance–covariance matrix, for the coefficient estimates in the model. To perform the simulations, we take 10,000 draws and use a modified version of the Stata code provided by Brambor et al. (2006).

Table 3 presents the descriptive statistics for average level of external search and collaboration for each of the 19 possible outcomes for the strength of appropriability strategy variable. The descriptive statistics seem to be consistent with the idea of a concave association (in terms of decreasing positive marginal effects) with a somewhat stronger concave relationship in the case of innovation collaboration breadth, although we cannot draw firm conclusions based only on the descriptive statistics.

The main results of the seemingly unrelated fractional response regressions are presented in Table 4. The estimations in Models

Table 2
Strength of appropriability strategy, External search breadth and Innovation collaboration breadth, industry averages.

Industry	Strength of appropriability strategy	External search breadth ($\times 6$)	Innovation collaboration breadth ($\times 6$)
Food, drink and tobacco	5.68	0.42	0.72
Textiles	6.68	2.20	0.77
Wood	4.40	2.19	0.62
Paper and printing	4.89	2.15	0.52
Refined petroleum products	6.00	1.86	1.00
Chemicals	10.05	2.82	1.31
Plastics	7.34	2.57	0.98
Non-metallic minerals	5.82	2.21	0.77
Basic metal	5.80	2.16	1.02
Fabric. metal products	4.82	1.99	0.48
Machinery	7.53	2.43	0.89
Electrical	8.40	2.80	1.14
Transport	7.67	2.47	0.99
Other	6.30	2.19	0.50
Average across industries	6.53	2.17	0.84

Table 3
Averages of external search breadth and innovation collaboration breadth averages for given levels of strength of appropriability strategy.

Strength of appropriability strategy, outcome #	Frequency	External search breadth ($\times 6$), average	Innovation collaboration breadth ($\times 6$), average
0	700	1.33	0.21
1	70	1.66	0.24
2	118	1.83	0.37
3	164	2.23	0.60
4	134	2.16	0.58
5	124	2.25	0.95
6	204	2.63	0.73
7	127	2.60	0.80
8	138	2.57	0.93
9	189	2.72	1.05
10	128	2.79	1.30
11	141	2.76	1.34
12	186	3.38	1.19
13	111	3.23	1.50
14	101	3.29	1.20
15	93	3.28	1.57
16	79	3.42	1.80
17	36	3.47	1.53
18	88	3.84	1.18

Table 4
Seemingly unrelated fractional response regressions: the relationship between appropriability strategy and openness.

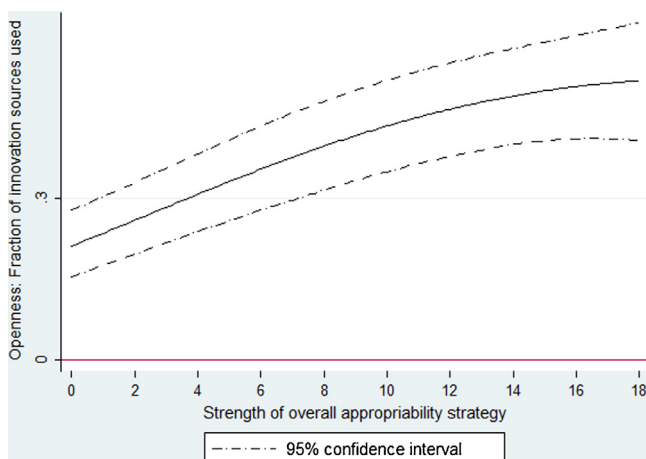|	External search breadth				Innovation collaboration breadth			
	Model I		Model II		Model III		Model IV	
	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Appropriability strategy	0.155***	(0.012)	0.142***	(0.013)	0.278***	(0.029)	0.215***	(0.029)
Appropriability strategy sq.	−0.004	(0.001)	−0.003***	(0.001)	−0.009***	(0.002)	−0.008***	(0.002)
R&D intensity			0.939**	(0.369)			2.714***	(0.664)
R&D start-up			0.308***	(0.073)			0.687***	(0.169)
Number of employees (log)			0.106***	(0.016)			0.267***	(0.036)
Part of an enterprise group			−0.082†	(0.045)			0.095	(0.098)
Market size			0.004	(0.014)			0.106***	(0.032)
Constant	−1.25***	(0.044)	−1.893***	(0.103)	−3.227***	(0.117)	−4.645***	(0.245)
Industry effects (14)	Yes		Yes		Yes		Yes	
Geography effects (12)	Yes		Yes		Yes		Yes	
No. of obs.	2931		2931		2931		2931	
Log likelihood	−1378		−1364		−957		−906	
ML (Cox–Snell) R^2:	0.23		0.26		0.08		0.15	

Model statistics are single equation statistics.

† Two-tailed test: $p < 0.10$.
* Two-tailed test: $p < 0.05$.
** Two-tailed test: $p < 0.01$.
*** Two-tailed test: $p < 0.001$.

I and III are excluding the control variables and in Models II and IV include the full set of controls. The results are (also) consistent with Hypotheses 1a and 1b—that the relationship between strength of the firms' appropriability strategy, and external search breadth and collaboration breadth is concave. The parameters of strength of appropriability strategy are positive and significant, and the parameters of strength of appropriability strategy squared are negative and significant. The predictions depicted in Figs. 1 and 2 are based on Models II and IV and illustrate that there is a concave relationship (at least in terms of decreasing positive marginal effects) between the strength of firms' appropriability strategies, and external search breadth and innovation collaboration breadth.

The curves indicate that the concave relationship is more pronounced for collaboration breadth, although the slope of the curve does not bend strongly downwards after a theoretical top-point of approximately 13 on the 18-point appropriability strategy scale. For external search breadth, the theoretical top-point of the curve is not within the range of the variable. These observations are in line with Hypothesis 2 that the concavity of the relationship between the strength of firms' appropriability strategies and openness will be stronger for innovation collaboration than for external search breadth. For further confirmation of these findings, we apply a

statistical test to assess whether the coefficient of (the strength of) the appropriability strategy is significantly higher for innovation collaboration than for external search, and whether the negative coefficient of appropriability strategy squared is significantly lower (more negative) for innovation collaboration than for external search. Using the "stacking" data method implemented in Stata's suest estimation procedure, we perform two Wald tests that take account of the covariance in the parameters across the two models, which ensures that the tests for the equality of the coefficients are correct (StataCorp, 2009, pp. 1812–1814). We find that the coefficient of (the strength of) appropriability strategy is significantly higher for innovation collaboration than for external search ($p = 0.0047$) and that the negative coefficient of appropriability strategy squared is significantly lower (more negative) for innovation collaboration than for external search ($p = 0.0025$). These tests also lend support for Hypothesis 2.

We use a split sample procedure to test Hypothesis 3 that the exclusion of competitors from firms' knowledge sourcing portfolios or collaboration partner portfolios weakens the connection between appropriability and openness in relation to external search or formal collaboration. We find only partial support for this hypothesis, since the results depend on which groups of firms are

Fig. 1. Relationship between external search breadth and the strength of firms' appropriability strategies.
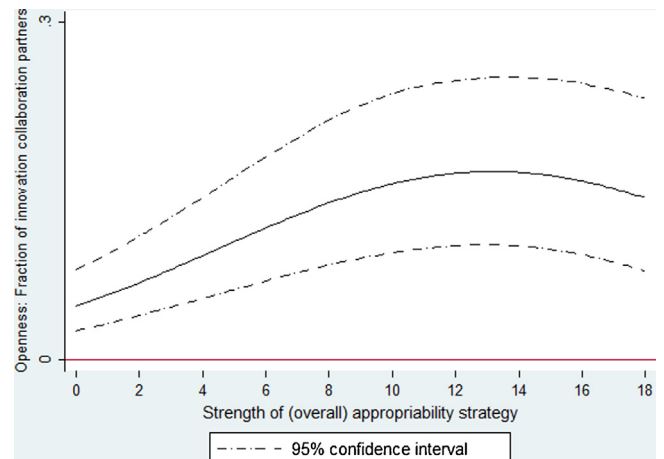
Fig. 2. Relationship between breadth of collaboration and the strength of firms' appropriability strategies.

Table 5
Seemingly unrelated fractional response regressions: The relationship between appropriability strategy and openness when considering competitors in the openness portfolio or not.

	External search breadth				Innovation collaboration breadth			
	Model I		Model II		Model III		Model IV	
	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Appropriability strategy	0.028***	(0.005)	0.040***	(0.004)	0.021*	(0.008)	0.070***	(0.018)
Appropriability strategy sq.	–		–		–		–	
R&D intensity	1.162**	(0.438)	0.914*	(0.400)	0.650	(0.488)	−1.473	(1.180)
R&D start-up	0.139	(0.106)	0.064	(0.069)	0.227†	(0.124)	0.355	(0.248)
Number of employees (log)	0.056**	(0.020)	0.055***	(0.016)	0.087**	(0.028)	0.008	(0.061)
Part of an enterprise group	−0.069	(0.050)	−0.077†	(0.046)	−0.074	(0.081)	0.224	(0.184)
Market size	0.001	(0.015)	−0.032*	(0.014)	0.077***	(0.024)	−0.087	(0.056)
Constant	−1.335***	(0.101)	−0.151	(0.105)	−1.309***	(0.181)	0.794	(0.499)
Industry effects (14)	Yes		Yes		Yes		Yes	
Geography effects (12)	Yes		Yes		Yes		Yes	
No. of obs.	981		1479		465		286	
Log likelihood	−423.1		−692.8		−216.4		−118.6	
ML (Cox–Snell) R^2:	0.21		0.21		0.10		0.04	
Sample	Not including competitors in the openness portfolio		Including competitors in the openness portfolio		Not including competitors in the openness portfolio		Including competitors in the openness portfolio	

Model statistics are single equation statistics.

† Two-tailed test: $p < 0.10$.
* Two-tailed test: $p < 0.05$.
** Two-tailed test: $p < 0.01$.
*** Two-tailed test: $p < 0.001$.

compared. If we consider only the group of firms that engage in external search or collaboration (and exclude those that do not), we find evidence that is consistent with Hypothesis 3—of a stronger relationship between appropriability and openness if firms include competitors in their openness portfolios compared to the alternative situations. This evidence is based on the "stacking" data method referred to above (StataCorp, 2009)—the method ensures that the results of the Wald test for equality of the coefficients are correct when comparing across models. Table 5 presents a split sample analysis comparing the relevant coefficients to appropriability (note that in the split sample analysis, we drop appropriability squared since this term is never significant in this analysis) pertaining to both external search breadth and external collaboration breadth. The coefficients are significantly smaller for the model including firms that do not use competitors for sources of knowledge or collaboration (Wald test significant at 0.1% in both cases), implying that that the positive relationship between both forms of openness and appropriability strategy are moderated resulting in a weaker relationship if competitors are not exploited.

If we expand the sample to our full sample by also including "closed" firms, that is, firms that do not engage in external search or collaboration for our the analysis, the results (not reported here for reasons of space) are not confirmed. For both types of openness, we find a linear relationship between appropriability and openness if competitors are included in the portfolio (very significant coefficients of 0.04 for search and 0.07 for collaboration), and a concave relationship between appropriability and openness if competitors are not used (very significant coefficients of 0.332 for search/−0.135 search squared and 0.342 for collaboration/−0.012 collaboration squared). So while the cost-side of appropriability is less evident in the case of involvement of competitors (which is consistent with Hypothesis 3), across most of the distribution, the relationship between openness and appropriability is stronger if competitors are not included in the openness portfolio compared to if they are included. These results would appear to run counter to Hypothesis 3.

The difference in the findings for these two setups is that including zero search or zero collaboration firms in the group of firms with no competitors in the collaboration portfolio enhances the relationship between openness and appropriability for that group compared to the group that use competitors. However, although firms that neither search externally nor collaborate do have appropriability mechanisms in place (153 out of a total of 471 firms for external search breadth, and 1536 out of 2180 for collaboration breadth), the probability of observing low levels of openness combined with low appropriability is higher for this group of firms. For this reason, comparing firms that do and do not use competitors, but including only those with non-zero search/collaboration may be the "cleanest" test of the hypothesis. In sum, however, we find only partial support for Hypothesis 3.

4.4. Alternative explanations and robustness checks

To rule out alternative explanations and to check the robustness of our results, we specify several alternative econometric models. There might be concern that our results depend ultimately on the inclusion of squared terms in the regressions. We would argue that the squared terms need to be explicitly modeled because they are strongly significant and, hence, their exclusion would lead to biased estimations (especially for innovation collaboration breadth). However, Table 6 Models I and IV present the estimations with the squared terms excluded. These models confirm the predominantly positive relationship between strength of the appropriability strategy on the one hand, and breadth of external search and collaboration on the other.

There also might be concern that the relationship detected could be inflated due to an endogeneity problem—in particular the self-selection of appropriability and openness strategies by "high-quality" firms. In the absence of instrumental variables that would fulfill both the strength and validity requirements, we included in our two equations two proxies for "high-quality firms" in the context of innovation. Arguably, innovation is the central outcome variable related to open innovation, and the available econometric evidence demonstrates that innovative firms demonstrate higher productivity, higher profits, better export performance, higher market value, better credit ratings, larger market share and higher probability of survival in the market (Geroski et al., 1993; Banbury and Mitchell, 1995; Blundell et al., 1999; Hall, 2000; Czarnitzki and

Table 6
Seemingly unrelated fractional response regressions: The relationship between appropriability strategy and openness, Robustness Checks.

| | External search breadth | | | | | | Innovation collaboration breadth | | | | | |
| | Model I | | Model II | | Model III | | Model IV | | Model V | | Model VI | |
	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.	Coeff.	Std. err.
Appropriability strategy	0.089***	(0.004)	0.131***	(0.013)	0.143***	(0.013)	0.073***	(0.009)	0.197***	(0.030)	0.213***	(0.029)
Appropriability strategy squared			−0.003***	(0.001)	−0.003***	(0.001)			−0.008***	(0.002)	−0.008***	(0.002)
R&D intensity	0.965*	(0.379)	0.785*	(0.366)	0.918*	(0.366)	2.770***	(0.672)	2.410***	(0.622)	2.760***	(0.659)
R&D start-up	0.329***	(0.073)	0.237***	(0.072)	0.297***	(0.074)	0.737***	(0.166)	0.585***	(0.168)	0.683***	(0.169)
Number of employees (log)	0.105***	(0.016)	0.111***	(0.016)	0.106***	(0.016)	0.265***	(0.037)	0.285***	(0.036)	0.267***	(0.036)
Part of an enterprise group	−0.084†	(0.045)	−0.091*	(0.045)	−0.082†	(0.045)	0.094	(0.098)	0.097	(0.099)	0.102	(0.098)
Market size	0.010	(0.014)	0.006	(0.014)	0.003	(0.014)	0.121***	(0.032)	0.117***	(0.032)	0.103***	(0.032)
Product innovation			0.007***	(0.001)					0.012***	(0.002)		
Labor productivity			0.000	(0.000)					0.000	(0.000)		
Industry-level appropriability					−0.961*	(0.234)					0.124	0.548
Industry-level appro. squared					0.073***	(0.018)					0.004	0.039
Constant	−1.810***	(0.101)	−1.968***	(0.102)	1.049	(0.741)	−4.319***	(0.232)	−4.835***	(0.250)	−5.327**	1.800
Industry effects (14)	Yes		Yes		Yes		Yes		Yes		Yes	
Geography effects (12)	Yes		Yes		Yes		Yes		Yes		Yes	
No. of obs	2931		2930		2931		2931		2930		2931	
1 Log likelihood	−1367		−1357		−1362		−917		−894		−905	
ML (Cox–Snell) R^2:	0.23		0.28		0.27		0.13		0.16		0.15	

Model statistics are single equation statistics.

† Two-tailed test: $p < 0.10$.
* Two-tailed test: $p < 0.05$.
** Two-tailed test: $p < 0.01$.
*** Two-tailed test: $p < 0.001$.

Kraft, 2004; Cefis and Marsili, 2005; Parisi et al., 2006; Cassiman and Golovko, 2011; Hall, 2011).

To measure innovation, we use percentage of sales of products new to the firm in the previous three years. To measure quality we include labor productivity, measured as sales over number of employees. The results are presented in Table 6, Models II and V. The main finding is that the magnitudes of the appropriability variables become slightly smaller, but the signs and significance are virtually unchanged (for both dependent variables). The parameter for innovation outcome is positive and strongly significant, while that for labor productivity is significant only for search breadth. We do not report these results as our main results since innovation outcome and productivity cannot strictly be considered inputs to openness (rather openness is an input to the productivity and innovation outcome equations); we include R&D intensity as a measure of innovation inputs in our equations. We tried excluding the (744) firms that had not innovated in 2004 due to prior innovations, although this choice might give rise to sample selection bias (results not presented here for reasons of space). The results reduced the size of the appropriability parameters, but not their significance except in the case of search breadth where appropriability squared lost its significance. Thus, as such the results for the reduced sample are consistent with our main results. Arguably, our robustness checks do not provide a perfect solution, but we believe that they show that unobserved heterogeneity related to self-selection by "high-quality" firms (and parallel negative selection by "low-quality" firms) is unlikely to be driving our results to any great extent.

Another concern is the possibility that inter-industry differences in appropriability regimes (Levin et al., 1987) might be driving our results. Due to potential multicollinearity between our industry-fixed effects and an industry-level appropriability variable, it is challenging to check this. We tried two different methods to account for industry-firm differences. First, we created industry averages (for 21 different industries) for the importance of our appropriability measure and included these industry average scores in the regressions. Given that we include only 14 industry-fixed effects, we can identify the model while including an industry-level variable, created based on industry averages for the 21 different industries. The results are presented in Table 6, Models III and VI. Our main results are unchanged; the industry-level appropriability variables are not significant in the regression for collaboration breadth (whether or not we include industry dummies). However, in the regression for external search, the effect of industry-level importance on appropriability and appropriability squared, shows a significant U-shaped relationship (with a minimum value of the independent variable below the maximum range of the variable). Nevertheless, our results are unchanged by the inclusion of this variable. We also tried including individual industry-level protection mechanisms; again, the main results did not change significantly. Second, due to the possibility of multicollinearity as a result of the simultaneous inclusion of the industry-level appropriability variable and industry fixed effects, we tried a two-stage approach (see, Reitzig and Puranam, 2009). In the first stage, we estimate models similar to our main models, using the same estimator (the fractional response model), but with only regional and industry dummy variables as regressors. From these first-stage regressions, we extract the residuals, which become the dependent variables in the second-stage estimations. In the second stage, the industry-level appropriability variable and the remaining explanatory variables with the exception of the regional and industry dummy variables are included as regressors. The results of this procedure confirm the main results. A possible problem with the two-stage approach is that the (predicted) dependent variable in the second stage is estimated with errors (Hardin, 2002). However, the fact that our results are all

consistent (with and without the two-stage approach) tends to confirm their robustness. Thus, overall, given the results of the two robustness checks, differences in appropriability regimes are unlikely to be driving our results.

In addition, given that our results may have been a product of the way we treated our measure of external search, we experiment with a lower cut-off value, including the case of low-use along with medium and high use: the results are consistent. Finally, we run the models using ordered probit estimation: the results for parameters and significances are remarkably similar to those obtained from the fractional response model.

5. Implications and conclusions

In this paper, we focused on how the openness of the firm is linked to its appropriability strategy. We advanced the idea of the *paradox of openness* to understand how managerial attitudes toward appropriability methods are related to the firm's orientation to external actors in the innovation process. The theorizing and the derived results have significant implications for the literature on open innovation and appropriability. The current literature on open innovation includes mixed and often conflicting views on this relationship. Some parts of the literature emphasize the negative implications of a strong focus on appropriability for firm-level openness. Indeed, Chesbrough's (2003) book contains a strong normative statement related to the need for firms to open themselves to external actors, and to break away from an overwhelming focus on protecting their ideas. Similarly, von Hippel (2005) suggests that firms that are overly protective of their knowledge, will miss opportunities to exchange knowledge with different actors in the innovation system. Others have suggested that the formal IP system may place strict limits on the potential for open, cumulative development. Some authors argue that the current focus on appropriability is directing firms away from discovery of new products and services toward legal games over ownership of patents (Bessen and Maskin, 2009).

At the same time, the open innovation literature highlights how appropriability might also enable openness (Chesbrough, 2006). The existence and use of legal appropriability methods may give managers the confidence to engage more widely with the external environment. In other words, an emphasis on legal appropriability might reduce fears of opportunistic behavior from external actors (Teece, 2002). If the firm has no strategy in place to capture the value from its innovative efforts, it might choose to go it alone and reject other actors in the innovation system. Baum et al. (2000) suggest that such an approach could severely limit the opportunities to successfully develop and commercialize their innovations.

Our study contributes to this discussion. We find that managerial attitudes to openness and appropriability are very closely connected. This suggests that a firm's inbound open innovation, which Dahlander and Gann (2010) describe as often having a "non-pecuniary" logic, may in fact be strongly influenced by that firm's "pecuniary" logic, manifested by its appropriability strategy. We found evidence also that an overly strong emphasis on appropriability may be associated with reduced efforts to draw in knowledge from many different external actors in formal collaborations for innovation. Our results relate to both these perspectives in the literature discussed above, and highlight the positive and negative aspect of appropriability for openness.

Our study also draws attention to how different forms of openness might be connected to appropriability concerns. We found that the negative side of appropriability (a concave rather than a linear relationship) and its link to openness is greater for formal collaboration than for external search breadth, supporting the hypothesis that the "scaring off" effect is stronger for direct collaboration than

for external search which involves less two-way interaction. We also examined the particular case of innovation partner portfolios including or excluding competitors; although our results are not conclusive, it seems possible that excluding competitors weakens the link between appropriability and openness.

The present study also advances out understanding of absorptive capacity (Cohen and Levinthal, 1990) by pointing to the importance of appropriability strategies in this context. The literature on absorptive capacity focuses on important aspects such as firms' ability to transform and exploit ("realized absorptive capacity"), or to acquire and explore ("potential absorptive capacity") external knowledge (Zahra and George, 2002; Jansen et al., 2005). This research highlights the knowledge transformation process (related to exploiting external knowledge) within the receiving firm. However, the possibility that the utilization of absorptive capacity may involve the firm in formal and informal knowledge trading has not been considered in the literature. In the prevailing models of absorptive capacity, appropriability concerns are often represented as a second order conditioning factor rather than a central determining element shaping the firm's external knowledge absorption efforts (see Lane et al., 2006; Todorova and Durisin, 2007). Our theoretical and empirical contribution suggests that potential absorptive capacity needs to be accompanied by a strategy for protecting the firm's knowledge in order for the firm to be able to exploit the new combinations. Our analysis implies that these aspects of knowledge exploration and exploitation are connected.

Our study has important implications for research on appropriability. As Pisano (2006) suggests, research on appropriability largely focuses on the industry-level environment and how the presence of tight or weak appropriability regimes shapes individual firm behavior (Levin et al., 1987; Cohen et al., 2000; Arora and Merges, 2004), and downplays the role of managerial choice in relation to protecting innovations. In the literature on external collaboration and appropriability researchers often rely on industry- rather than firm-level measures of appropriability, suggesting that managers' have little scope to alter the level of their legal appropriability in the face of industry level patterns (Cassiman and Veugelers, 2002). In contrast, our approach looks at how firm-level choices concerning the strength of the appropriability strategy are connected to firms' relationships to external actors in the innovation system.

6. Limitations and future research

There are several limitations to this study. First, it draws on a rich and detailed cross-section of UK manufacturing firms' innovative activities, but these data make it difficult to draw strong causal inferences about the relationship between appropriability and openness. As noted in the introduction, our analysis does not provide any direct evidence of causality. It would be useful to have panel data or experimental data for analysis to better understand the direction of the relationship. However, even with panel data, identifying the precise direction of causality and the strength of each direction would be difficult (a Granger causality test is likely to show a bi-directional causality). Second, we do not have a direct measure of firm scope, that is, whether the firm is engaged across a range of industries or products in our dataset. For this reason we are unable to control directly for firm scope; however, this limitation applies to all studies that use Community Innovation Survey-type data. In addition, many of firms in our dataset are small firms and, therefore, are likely to be active in a small number of markets. Third, we have no information on stocks of IP held by each firm; it is possible that IP stock shapes the firm's approach to engaging with external actors. Given the small average size of the firms in

our sample and that we measure directly the importance that firms attached to these formal methods, we do not think that this limitation undermines our study. However, it would be useful to examine the relationships among appropriability strategy, openness, and stock of IP. Third, like Cohen et al. (2000), our approach is based on relatively simple addition of the importance that firms attach to different protection mechanisms. However, firms can choose among different combinations of protection mechanisms (Fischer and Henkel, 2013) and this choice might be related to its openness to external actors. Future research could explore the link between this choice among different protection mechanisms, and different types of openness.

The issue of how appropriability strategies enable and constrain managerial behavior in other parts of the organization appears also to be an interesting area for future research. In the paper, we have on two different forms of openness—external search and formal collaboration, but appropriability choices might also be related to other open innovation decisions, such as corporate venture capital investments by large firms, and interactions between new firms and incumbents. We need more knowledge about how choices about appropriability and openness shape the firm's performance, perhaps especially in the case of young, small firms. The insights from new research on these issues could give additional help to guide managers confronted by the paradox of openness.

Acknowledgements

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