The Paradox of Openness
Appropriability and the Use of External Sources of Knowledge for Innovation

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Abstract: To innovate, firms often need to draw from a wide number of different sources of knowledge from outside their organization. At the same time as firms need to be open to external sources, they also need to be focused on capturing returns to their innovative ideas. This gives rise to a *paradox of openness* - the creation of innovations often requires openness and commercialization of innovations requires appropriability. Using an econometric analysis of the UK innovation survey, we find the openness of firms to external sources of innovation is curvilinearly (taking an inverted U-shape) related to the firm's appropriability strategy. We also find that the greater the presences of the absorptive capacity within a firm, the greater are the chances that it will be open to external sources. We explore the implications of these findings for theory and empirical research.

Keywords: Openness, innovation, appropriability strategy, absorptive capacity, technological opportunities

1. Introduction

This paper explores the factors that shape how open firms are to external sources of knowledge in their innovative activities. Many scholars have suggested that the innovation process is becoming more open, distributed and even democratic (von Hippel, 1988; Chesbrough and Teece, 1996; Chesbrough, 2003; Coombs, Harvey and Metcalfe, 2003; Jeppesen, 2005; von Hippel, 2005). At the same time, a variety of organizations have shifted their attitudes toward external sources of knowledge, developing more extensive links with universities, lead users, external consultants and suppliers. In part these attempts to open up the firm to external sources is a response to the increasing complexity of knowledge required to successfully manage the commercial introduction of new products and processes. It is also reflects the increasing division of labor within the economic system between different actors, enabling the emergence and development of more extensive markets for technology (Arora, Fosfuri and Gambardella, 2001; Brusoni, Prencipe and Pavitt, 2001).

However, previous research has made limited attempts to address the contingencies and strategies that condition the ability of firms to be open to external sources of innovation. We suggest that there are four lines of analysis that can help to develop a conceptual framework for the study of the determinants of openness. The first explores the impact of the appropriability strategy of the firm on its orientation to external sources of innovation. In order to so, we draw from a range of theories in industrial economics and management that describe strategies firms follow to appropriate the benefits of their innovations and how these strategies shape their attitude to external sources of knowledge. We suggest that at the same time as firms need to be open to external sources, they also need to be focused on capturing returns to their innovative ideas. The creation of innovations often requires openness and

commercialization of innovations requires appropriability. This may be described as the *paradox of openness*. The second examines the impact on prior investments in absorptive capacity on the propensity of firms to be open to external sources. This research builds on Cohen and Levinthal (1989; 1990) and seeks to better understand how absorptive capacity shapes the relationship between the firm and its external environment in the innovation process. The third analyses the behavior of new firms and their openness to the external environment. Here we focus on knowledge-intensive startups and how the problems of disclosure and theft shape their attitudes to external environment. Finally, we explore the impact of the richness of industry-level technological opportunities on the attitudes of managers to external sources of knowledge. We expect that in environments of high opportunities, firms will be likely to be open to external sources in order to gain access to critical external inputs and keep up to date with the latest developments in technology and markets.

Using data from sample of 2,304 UK manufacturing firms, we explore the factors that explain the openness of firms to external sources of knowledge for innovation. Using a zero-inflated negative binominal regression where the dependent variable is the openness of the firm to external sources of knowledge for innovation, we find considerable support for our conceptual framework for explaining the openness of firms to external sources of innovation. We find that overall appropriability strategy is curvilinearly (taking an inverted U-shape) related to openness. We also find that the greater the presences of the absorptive capacity within a firm, the greater are the chances that it will be open to external sources. Knowledge intensive startup firms are less likely to be open than other firms and high industry-level technological opportunities encourage firm-level openness.

The paper is organized into five sections. Section 1 reviews the theoretical empirical background to the study and section 2 outlines the hypotheses. Section 3 describes the data, method and descriptive analysis. Section 4 reports the results and Section 5 contains discussion and conclusions, including an exploration of future research challenges.

2. Theoretical and empirical background

A central part of the innovation process concerns the way firms go about organizing the search for new ideas that have commercial potential. New models of innovation have suggested that many innovative firms have changed the way they search for new ideas, adopting open search strategies that involve the use of a wide range of external actors and sources to help them achieve and sustain innovation (Schumpeter, 1942/87; Rosenberg, 1982; von Hippel, 1988; Freeman and Soete, 1997; Tidd, Bessant and Pavitt, 2000). Indeed, Chesbrough (2003) suggests that many innovative firms have shifted to an "open innovation" model, using a wide range of external actors and sources to help them achieve and sustain innovation. In this respect, innovators rarely innovate alone (Baum, Calabrese and Silverman, 2000; Lee, Kyungmook and Pennings, 2001). They tend to band together in teams and coalitions based on "swift trust", nested in communities of practice and embedded in a dense network of interactions (Scott and Brown, 1999; Brown and Duguid, 2000). To gain access to these networks and external sources, firms need the capability to absorb ideas from external sources and to integrate them with their internal processes in order to achieve an innovation (Cohen and Levinthal, 1989; Cohen and Levinthal, 1990).

Although the ability to absorb external ideas is often seen as a dynamic capability (Eisenhardt and Martin, 2000), there are relatively few studies examine the factors

that shape why some firms are more open than others in their innovative activities. Previous research has highlighted the importance of investments in absorptive capacity in shaping orientation of the firm to its external environment (Cohen and Levinthal, 1989; Zahra and Nielsen, 2002). Yet, this research fails to account for how the openness of a firm is related to its strategy for capturing or appropriating the profits of its innovative activities (Teece, 1986; Chesbrough, 2003). Some appropriability methods require firms to strategically limit their use of external sources of ideas and they bound the exchanges between the firm and its external environment. Indeed, formal mechanisms of appropriability, such as patents, require firms to demonstrate novelty and informal mechanisms, such as secrecy, require firms to keep information hidden from competitors (Cohen, Nelson and Walsh, 2000).

The openness of firms to external sources is also profoundly shaped by the search activities of other firms in their industry and by the nature of the environment in which they operate (Cohen and Levinthal, 1990). Nelson and Winter (1982) describe how the search activities of firms are constrained or bounded by past choices, the nature of technology, and by technological trajectories. As well, the use of external sources is also influenced by the general level of technological opportunities available in the industry (Klevorick *et al.*, 1995). In this respect, the openness of individual firms to external sources of innovation is subject to a degree of managerial choice, but many of these choices are conditioned by the external environment and by their past. To paraphrase Karl Marx, it is not simply managerial choices that determine the openness of firms to its environment, but the environment that helps to determine their decision to be open.

3. Hypotheses

The role of appropriability strategy for openness

There is a complex and intimate relationship between how firms try to appropriate rents or profits from their innovations and how open a firm is to its external environment. For technology-based new firms, there are substantial hazards in being open to external firms and organizations (Gans and Stern, 2003; Shane, 2003). The most extreme danger here is outright theft. Many of these new firms are organized around the exploitation of new ideas and ideas are often leaky within communities of practice (Brown and Duguid, 2000). Given the lack of complementary assets held by new firms, the danger of leaky knowledge can act as a strong incentive to limit collaboration or openness to the external environment. A common method for protection by new firms is secrecy. Gaining formal intellectual property, such as a patent, can be a useful measure of protection, but the value of such intellectual property is limited to its defensibility in legal suits and/or the ability of the technology entrepreneur to have a credible threat of legal intervention (Teece, 1986; Gans and Stern, 2003).

However, there are considerable advantages for new firms to collaborate with existing firms and external partners in order to commercialize an idea. New firms often lack the appropriate complementary assets to successful bring the product to market (Gans and Stern, 2003). In particular, they may lack brand reputation, sales and service support, and/or manufacturing facilities. In order to bring a product to market, new firms often need to operate under the radar of incumbents with existing complementary assets and they need to quickly orchestrate a range of activities in order to gain market presence before incumbents can overcome them. Given the challenge faced by new firms, it is often necessary for them to collaborate with and/or

to work with external organizations, such as consultants, venture capitalists and suppliers (Baum, Calabrese and Silverman, 2000; Lee, Kyungmook and Pennings, 2001). Many of these organizations will have assets that new venture lacks and they may also be able to provide resources to help the new venture establish itself before it is detected and faces competition from incumbents (Shane, 2003).

Managing these external sources and linkages beset by information asymmetries. In order to gain access to and convince potential partners of the benefits of collaboration, it is necessary to negotiate formal agreements or at least informal bargains that are based on a degree of mutual understanding. External partners will require enough information about the idea in order to some belief about its eventually successful commercialization. In other words, they need to know about the idea before they buy into it and figure out best they can contribute. The difficulty here is described as Arrow's (1962) *paradox of disclosure*, whereby "when 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 may increase the power of the buyer and reduce the bargaining power of the technology entrepreneur, especially in the absence of credible threats and intellectual property rights protection.

This paradox of disclosure also applies to range of external interactions between the technology entrepreneur and the external environment beyond the commercial transaction of selling the idea. Indeed, to win the support of external parties or gain access to knowledge sources, it often necessary for firms to informally trade knowledge with competitors and other actors in the innovation system. Von Hippel (1988: 76-92) shows that many innovators have dense networks of relations with their

users, suppliers and competitors, and that trading certain ideas and secrets in strategic ways is often mutually beneficial. In part this informal knowledge trading is a response to uncertainty about markets and technology and it allows firms to share information and ideas about the future in order to better prepare themselves for future events. It also represents a strategic response to the firm to need to gain external knowledge and gaining this knowledge often requires giving up something in return. Of course, there are extreme dangers for technology entrepreneurs in such knowledge trading, but nevertheless, it is sometimes necessary for these entrepreneurs face these risks to "get in the know" and to gain access to critical external inputs.

So far, the proceeding discussion has focused on new firms, yet established firms face many of the same problems faced by technology entrepreneurs. Incumbents also face the potential of competition from existing competitors or new entrants. Many of these competitors may have access to considerable complementary assets that may be greater or more effective than the incumbent firm own assets and capabilities. For these incumbents working with external partners — and being open to external sources of ideas — may be just as important as for technology entrepreneurs. And yet they may also operate in environments of leaky knowledge, extensive competition from skilled and experienced competitors, and the threat of entry from new entrants into their product markets. However, these established organizations may require external knowledge in order to render their internal development process effective (Laursen and Salter, 2006). For example, it is common for many software firms to release beta versions of their software to lead users. Knowledge about the new programs quickly spreads about the community of practice and — despite the best efforts of the organization — information about new products may leak out before the company is ready for this information to be made public. Indeed, before the

launch of its Mini-Mac, Apple Computers brought a suit against several of websites that offers early previews of future Apple products (Markoff, 2004). In this instance, although the firm may wish to keep something secret, its need to capture knowledge from lead users or others may lead to an unplanned disclosure.

In this context, firms appear to rely on a bundle of different appropriability mechanisms. Accordingly, such particular combinations or bundles of appropriability mechanisms used by firms, make up what Cohen et al. (2000: 8) term an "appropriability strategy". An appropriability strategy involves the use of a range of formal methods, such as patents and copyrights, and informal methods, such lead times on competitors and secrecy. Different organizations may apply different bundles of these methods according to the nature of the market they operate in, the type of technology used in the innovation and the general opportunity conditions in the industry. Formal methods often require firms to disclose some information to external sources, such as lawyers and patent authorities. They also require that firms invest resources in winning formal protection and such efforts may be time consuming and expensive. Informal methods rely on secrecy, lead times and complexity of the product. In order to render these strategies effective, at times firms must be able control or withhold critical knowledge from the external environment, as well as seeking opportunities to enter the market more quickly than their rivals.

The use of both formal and informal appropriability methods may be complementary. First, formal and informal methods may be used successfully at the same time for a given innovation, when an innovation is comprised of separately protected components or features. An example of such "parallel protection" comes from the chemical industry, where firms sometimes protect an innovation by applying for one or more patents while keeping other parts secret (Arora, 1997). Second, but

related, since product and process innovations are often complementary (Pisano, 1996), formal and informal methods may also be complementary when they are used separately for (related) product and process innovations. In that case, legal mechanisms may predominantly be used to protect product innovation, while informal mechanisms may predominantly be used to protect the complementary process innovation. Indeed, Cohen et al. find empirically, that patents are more effective for product innovation than for process innovation at the level of the industry. Finally, different appropriability mechanisms may be used at different stages of the innovation process. Firms may initially rely on secrecy prior to the commercialization of a new product, but subsequently try to retain competitive advantage through legal means, such as patents and trademarks.

The use of appropriability strategies requires firms to expend considerable efforts to render these strategies effective, and it can create an attention allocation problem. Such problems are the key element in the attention-based theory of the firm (Simon, 1947; Ocasio, 1997). This theory suggests that managerial attention is the most precious resource inside the organization and that the decision to allocate attention to particular activities is a key factor in explaining why some firms are able to both adapt to changes in their external environment and to introduce new products and processes. Central to this approach is to highlight the pool of attention inside the firm and how this attention is allocated. According to the theory, decision makers need to "concentrate their energy, effort and mindfulness on a limited number of issues" in order to achieve sustained strategic performance (Ocasio, 1997: 203). An overemphasis on protection may lead firms to a *myopia of protectiveness*, whereby efforts to appropriate dominate the process of commercialization. Instead of focusing on a wide range of activities necessary to achieve the innovation, such as the

mobilization of complementary assets, innovators may become obsessed with control, secrecy or legal protection (Laursen and Salter, 2005). The fear of theft may lead them to become inward, focusing their attention away from opportunities for collaboration. A myopia of protectiveness may also limit opportunities to trade knowledge (as analyzed by von Hippel, mentioned earlier) with suppliers, users and competitors. Such a myopia suggests that firms that are too tight in their appropriability strategies may forego opportunities for exchange (March, 1991; Levinthal and March, 1993).

Accordingly, the previous discussion suggests that the appropriability strategy of the firm plays an important role in shaping its relationship to the external environment. Although firms often need a degree of openness to external sources, they also need appropriate the profits from innovation. In order to gain from formal and informal knowledge trading, firms need to protect their knowledge and innovations to some extent. As such, using an appropriability strategy and being open to external sources of innovation go hand in hand: firms need to disclose some knowledge to be able to gain from being open to external sources of innovation, but firms also need to protect some of the knowledge to gain from the exchange. Nevertheless, at some point, a strong emphasis on appropriability will lead firms to be less open as their fear theft or leakage forces them to limit their exposure to external sources. Thus, we posit:

H1: The tightness of the overall appropriability strategy of firms is curvilinearly (taking an inverted U-shape) related to the degree of openness to external sources of innovation

The role of absorptive capacity for openness

Cohen & Levinthal (1990: 128) define absorptive capacity as "…the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends…" In continuation, Cohen and Levinthal argue that this ability is critical to firm's innovative capabilities, and moreover, that this ability is largely a function of prior related knowledge. Since openness of firms to external sources of innovation requires considerable effort and time to build up an understanding of the norms, habits and routines within different external knowledge sources (Laursen and Salter, 2006), it follows that firms are in need of absorptive capacity in order to be able to process external information and knowledge.

In the specific context of research & development (R&D), Cohen & Levinthal (1989; 1990) posit that R&D has two faces: not only does R&D generate genuinely new knowledge; it also enhances the firm's ability to assimilate and exploit existing knowledge from the external environment, both in terms of the firm's ability to imitate new processes or product innovations, and in terms of the firm's ability to exploit knowledge of a more intermediate sort that provide the basis for subsequent applied research and development. However, although R&D spending is applied widely in the literature as a measure of absorptive capacity (see for instance, Mowery, Oxley and Silverman, 1996; Lane and Lubatkin, 1998; Cassiman and Veugelers, 2002), the measure is a narrow measure of the firm's ability to assimilate external information[1], since many, in particular smaller, firms simply do not have a formal R&D department. Therefore, by definition, these firms do not perform R&D (Pavitt, 1988; Freeman and Soete, 1997). Accordingly, alternative measures of absorptive

[1] In this paper, we set aside the difficult issue of absorptive capacity being a function of prior *related* knowledge, since this aspect is very hard to measure, unless we are dealing with a very specific knowledge set (Zahra and George, 2002).

capacity have been suggested including levels of skills and human capital (Zahra and George, 2002; Zahra and Nielsen, 2002), also because there is no reason to believe that (formal) R&D staff alone embody absorptive capacity within firms. In sum, the arguments presented above leads us to hypothesize:

H2: The level of human capital of firms is positively related to its degree of open innovation applied by firms

New firms and openness

Technology entrepreneurs need to manage a wide range of external relationships and sources in order to successfully commercialize a new product (Shane, 2003). However, for those firms who new products are based on new technology or rely on unique knowledge of their employees, the openness to the external environment may be a dangerous or even counter-productive. The threat of competition from incumbents always remains in the air (Gans and Stern, 2003). Given the danger that these firms face, there are several reasons why they may less willing to be open to external sources. The danger of theft may be very high when a firm only has an idea, little or no formal intellectual property rights and little or no complementary assets. Indeed, popular management books on entrepreneurship advise technology entrepreneurs "not to disclose the value of new product or service, unless it is protected by patents" (Shane, 2005: 174). As such, working with external sources may lead to knowledge leakage and therefore managers in these organizations are often highly protective of their ideas. If these firms are entering the product market, they may wish to avoid detection from incumbents by limiting their interaction with external source who in turn might flag their presence to incumbents (Gans and Stern, 2003). Interactions with external sources, such as consultants, may leak information

about the new venture to incumbents. New firms also suffer the liability of newness and smallness and therefore they lack the resources to draw knowledge from external sources (Baum and Oliver, 1991). Indeed, attempting to draw knowledge from external sources may be highly time consuming and expensive. In sum, we posit:

H3: Startups with a high level of human capital are less open to external sources of innovation

The role of technological opportunities for openness

Technological opportunities within a given industry comprise the set of possibilities for technological advance and may be measured as the returns to R&D, given demand conditions, the current level of technology, and the appropriability regime (Klevorick *et al.*, 1995: 188). As resources are devoted to R&D and projects are completed, the pool of opportunities can be depleted. However, the pool of opportunities are refilled through the sources of opportunity, including the advance of scientific understanding; technological advance originating outside of the industry; and through new possibilities opened up by feedbacks resulting from current innovations (ibid, 1995: 189). In other words, when the pool of opportunities is replenished it is implied that the search space for new technological solutions is enlarged (Dosi, 1982). Accordingly, when opportunities emerge outside the firm itself, it needs to plug into these sources of opportunities. Moreover, when new opportunities emerge, they are often systemic, so that improvements in one component offer the possibility for — or even require — improvements in other components, which in turn lead firms to do more external search in order to solve the problem or bottleneck (Rosenberg, 1982). In sum, we conjecture:

H4: The higher the technological opportunities offered by the industry in which firms are operating, the higher the degree of openness to external sources of innovation

4. Data and method

Data

The data for the analysis is drawn from the UK innovation survey. The survey was implemented in 2001 and is based on the core Eurostat Community Innovation Survey (CIS) of innovation (Stockdale, 2002; DTI, 2003a). The method and types of questions used in innovation surveys are described in the Organization for Economic Co-operation and Development's (OECD) Olso Manual (OECD, 1997). CIS data have been used in over 60 recent academic articles, mainly in economics (for recent contributions using CIS data, see Cassiman and Veugelers, 2002; Mairesse and Mohnen, 2002; Laursen and Salter, 2006). CIS surveys of innovation are often described as "subject-oriented" because they ask individual firms directly whether they were able to produce an innovation. The interpretability, reliability and validity of the survey were established by extensive piloting and pre-testing before implementation within different European countries and across firms from a variety of industrial sectors, including services, construction and manufacturing.

The CIS questionnaire draws from a long tradition of research on innovation, including the Yale survey and the SPRU innovation database (for examples, see Levin *et al.*, 1987; Pavitt, Robson and Townsend, 1987; Pavitt, Robson and Townsend, 1989; Cohen and Levinthal, 1990; Klevorick *et al.*, 1995). CIS data provides a useful complement to the traditional measures of innovation output, such as patent statistics (Kaiser, 2002; Mairesse and Mohnen, 2002). CIS data offers "a direct measure of

success in commercializing innovations for a broad range of industries…that more traditional measures may not capture" (Leiponen and Helfat, 2003). The questionnaire asks firms to indicate whether the firm has been able to achieve a product innovation. Product innovation is defined as:

> ...goods and services introduced to the market which are either new or significantly improved with respect to fundamental characteristics. The innovations should be based on the results of new technological developments, new combinations of existing technology or utilization of other knowledge by your firm (DTI, 2003b).

Firms are then asked to state what share of their sales can be ascribed to different types of innovations, such as innovations new to the world. Alongside these performance questions, there are number of questions about the sources of knowledge for innovation, the effects of innovation, intellectual property strategies and expenditures on R&D and other innovative activities.

The UK innovation survey is 12 pages long and includes a page of definitions. The sample of respondents was created by the Office of National Statistics (ONS). It was sent to the firm's official representative for filling in information on the firm's activities, such as surveys for calculating the UK Gross Domestic Product and R&D expenditures. It was normally completed by the Managing Director, the Chief Financial Officer or by the R&D manager of the firm. The implementation of the survey was administered by the ONS and to guide respondents a help service was provided (Stockdale, 2002).

The survey was sent to 13,315 business units in the UK in April 2001 and a supplementary sample of 6,287 was posted the survey in November 2001. It received a response rate of 41.7% (Stockdale, 2002). The second mail out was designed to top-

up the number of regional responses to the survey. The responses were voluntary and respondents were promised confidentiality and that the survey would be used to shape government policy. The sample was stratified by twelve Standard Industrial Classification (SIC) classes and includes all main sectors of the UK economy, excluding public bodies, retail, and hotels and restaurants. The response rates for different sectors, regions and size is largely consistent with the overall response pattern (Stockdale, 2002). Our sub-sample of the survey includes 2304 manufacturing firms and draw from the entire UK manufacturing sector.

Descriptive results

Using UK innovation survey, we explore the knowledge sources for innovation in the UK. Table 1 lists all 16 external sources listed in the UK survey. Each firm is asked to indicate on a 0-1-2-3 scale the degree of use for each source. On the survey, the sources are grouped together under four different headings (market, institutional, other, and specialized). Table 1 presents the results for the entire range of sources for UK manufacturing firms. Overall, the results indicate that the most important source is suppliers of equipment, materials and components, followed closely by clients and customers (or "users"). Alongside customers and suppliers, a range of standards, such as health and safety standards, are among key sources of innovation. As might be expected (see von Hippel, 1988), the results indicate that UK firms' innovation activities are strongly determined by relations between themselves and their suppliers and customers.

[Table 1, just about here]

Table 2 explores levels of openness by industry. The results indicate that industries with high levels of technological opportunities and where firms have a high

degree of absorptive capacity are most open to external sources of innovation. These sectors include some of the leading science-based sectors, such as chemicals (including pharmaceuticals) and electrical products. As expected, low technology industries such as textiles and fabricated metal products, are also industries with limited openness. The interesting finding from this exercise is that industries with high levels of appropriability are also industries with high levels of openness and technological opportunities. However, there are some industries with relatively low use of appropriability methods and medium levels of absorptive capacity and openness, such as paper and printing products. The overall number of startups is low given the restricted nature of the sample and they appear to spread out in across a range of industries.

[Table 2, just about here]

Measures

Dependent variable. The dependent variable, measuring the *degree of openness*, is the number of external sources of knowledge or information used by the firm in its innovative activities. The survey lists 16 possible external sources and each firm was asked to indicate the importance (on a 0-1-2-3 scale) of each of these sources. As a starting point, each of the 16 sources are coded as a binary variable, 0 being no or low use and 1 being medium or high of the given knowledge source. Subsequently, the 16 sources are simply added up so that each firm gets a 0 when no knowledge sources are used, while the firm gets the value of 16, when all knowledge sources are used. In other words, it is assumed that firms that use of higher numbers of sources are more "open", than firms that are not.

Although the list of sources on the questionnaire is not fully comprehensive, it is extensive and the items are not mutually exclusive. It reflects a wide range of sources of innovation, including suppliers, clients and competitors as well as general institutions operating inside the innovation system, such as regulations and standards. The sources listed in the survey overlap with the resources and institutions that are considered part of the national innovation system (Lundvall, 1992; Nelson, 1993; Spencer, 2001).

Explanatory variables. To gain insight about the role of appropriability methods at the firm level, we draw from question on the survey about the importance of different methods of protection of the firm. The survey question is similar to those used in previous studies of appropriability methods (Levin *et al.*, 1987; Cohen, Nelson and Walsh, 2000). Drawing form this question, we created a measure the overall tightness *appropriability strategy* of the firm by adding up use of six key measures of protection listed on the survey, combining formal and informal methods of protection. The survey lists six different items, including "registration of design", "trademarks", "patents", "secrecy", "complexity of design", and "lead-time advantage on competitors". The set of items appear to measure a single unidimensional latent construct (Cronbach's Alpha Coefficient = 0.88).

In order to assess the importance of *absorptive capacity*, we use two measures that reflect the presence of absorptive capacity. First, we used the share of the number of employees with a university degree out of total employment in the firm. These figures were calculated from two different questions of the survey — one on the number of full-time equivalent staff with degrees and a second on the total employment in the firm in 2000. The second measure of absorptive capacity is firm-level expenditures on R&D intensity (R&D expenditure divided by sales) of the firm (Cohen and Levinthal,

1990). The numerator is taken from the UK innovation survey, while the denominator firm turnover or sales is based on Office of National Statistics register data, supplied with the survey data, for the same year (2000).

In order to explore the openness of startups, we include a measure of whether or not the firm was a startup in the period 1998-2000. It is based on a question on the survey concerning whether or not the firms was established during that period, conditional on the firms having 250 employees or less. In addition, we interact this startup variable with the percentage of scientists and engineers of total employment and R&D intensity to examine the behavior of new technology-based firms. However, since our sample is restricted to firms with 10 or more employees our sample of startups is a partial and incomplete. We do not have records on small startups (with under 10 employees) nor do we have information on firms that do not survive. As well, the sample of startups only covers those firms that we established during the period of the survey and therefore it excludes firms older than three years. In other words, the startups in our sample are relatively fast growing, successful organizations, and are not representative of the entire range of new ventures.

To explore the role of the technological opportunities in shaping the openness of firms to their external environments, we apply a measure of industry-level technological opportunities by using the average R&D intensity of the industry at the 2-digit SIC-level.

In addition to these measures, we control for firm size: firm size (expressed in logarithms) is measured as the number of employees. The numbers of employees are based on Office of National Statistics register data, supplied with the survey data, for year 2000. Finally, we include 13 industry dummies to account for different propensities to be open for innovation across industries.

Table 2 displays descriptive statistics or simple correlations among our variables. None of the correlations are sufficiently strong to demand further examination of potential multicollinearity problems. Moreover, it is noteworthy that there is a strongly significant correlation between industry average R&D intensity (our measure of technological opportunities) and the share of employees with a degree within each firm (our measure of absorptive capacity).

[Table 3, just about here]

Statistical method and regression results

Since the dependent variable (the degree of openness) is a count of scores and contains a large number of zeros, the means of estimation is a zero-inflated negative binomial regression.

The results of the zero-inflated negative binomial regression can be found in Table 4. When looking at Model 1 and Model 2, we find strong support for the hypothesis asserting that the tightness of the overall appropriability strategy of firms is curvilinearly — taking an inverted U-shape — related to the degree of openness to external sources of innovation (H1). First, the parameter for the variable representing the strength of each firm's appropriability strategy is positive and significant at the 0.1 per cent level, showing that having a stronger appropriability strategy allows firms to be more open. Second, the parameter for appropriability strategy squared is significant as well (but has a negative sign), showing that when firms use a very strong appropriability strategy they become less open in their innovative processes.

[Table 4, just about here]

The results obtained in Model 1 are also consistent with the hypothesis stating that the level of human capital of firms is positively related to its degree of open

innovation applied by firms (H2), since our human capital measure (share of employees with a degree) is positively related to the degree of openness to external sources of innovation. We also experimented with the subset of employees with a science and engineering degree (the results are not shown for reasons of space). The results of this analysis show that this measure has a positive and significant impact as well, although the impact is slightly weaker as compared to the results obtained when using all employees with a degree. From these finding, we infer that absorptive capacity enhances the ability of a firm to be open to external sources of innovation. However, when looking at Model 2, we find that R&D intensity appears to be unrelated to the degree of openness of firms. Accordingly, only a broader measure of absorptive capacity is related to how open firms are able to be in their innovative efforts. In other words, firms with a high degree of knowledge intensity are able to be more open, but openness is not conditional on the extent to which the firm carries out formal research and development.

With respect to startups and openness to external sources of innovation our results suggest that whether or not the firm is a startup is unrelated to the openness as the startup variable is strongly insignificant (in both models). However, the evidence of this paper supports the claim that startups with a high level of human capital are less open to external sources of innovation (H3), since the interaction term between the human capital measure and whether or not the firm is a startup has a parameter with a negative sign and is significant at the 5 per cent level (Model 1). In model 2, the parameter for the interaction term between R&D intensity and startup has a negative sign as well (significant at the 10 per cent level), further strengthening the claim that knowledge intensive startups are able to be less open, when compared to other firms.

The average R&D intensity within the industry, appear to be influencing the degree of firms' openness positively, as the parameter for the variable is positive and significant at the 1 per cent level (Model 1). Consequently, our findings are consistent with the hypothesis inferring that the higher the technological opportunities offered by the industry in which firms are operating, the higher the degree of openness to external sources of innovation (H4).

Finally we, find that larger firms are more likely to be open. An explanation for this may be that smaller firms are constrained in terms of available resources, and they may therefore not be able to do as much external search across different sources of knowledge. It may also be that innovations introduced by smaller firms are less complex in nature and that the benefits of searching broadly among many sources of innovation may be limited accordingly.

6. Conclusions

The openness of firms to external sources of knowledge remains central issue in recent debates about how to manage innovation. However, the need to open to external knowledge sources in order to innovate always needs to be combined with a strategic effort to capture the returns to the innovation. In this respect, firms face paradox — they need to open to external sources at the same time as they are focused on capturing returns to their innovative ideas. The creation of innovations often requires openness and commercialization of innovations requires appropriability. Hence the relationship between openness and appropriability is an intimate one and on-going tension that each organization must carefully balance over time.

In this paper, we have examined the nature of this relationship by examining the factors that explain why some firms are more open to external source of knowledge

than other firms. In doing so, we developed a conceptual framework that combined firm-level strategic management decision-making with industry level environmental conditions. Our approach attempts to integrate the micro and macro to better understand how each of these different levels shapes decision-making. We first found that the use of appropriability was curvilinearly related to openness. In other words, a focus on appropriability within a firm increases the chances it will be open to external sources. In this respect, attention to appropriability gives the firm the confidence to be more open to external sources. However, at some point, a strong emphasis on appropriability will limit openness and at this point the focus on capturing the rents from an innovation become greater than the benefits of being open to external knowledge.

We also found that firms with high levels of absorptive capacity are likely to be more open. Retaining skills and expert staff enables firms to access wider networks of external relations and sources. In particular, the employment of scientists may allow firms to gain a ticket to an information network (Rosenberg, 1990). As well, the existence of internal resources signals the firm is able to assimilate, use and transform external knowledge for use in internal development processes.

Knowledge intensive small firms were less likely to be open, however. These firms are often based on the exploitation of a new idea and given the danger they face from leakage of their ideas they limit the nature and scope of their external interaction. They also extremely resource constrained and may therefore lack the time and attention necessary to work capture knowledge from external sources.

In addition, we found that technological opportunities at the industry level matter for openness. Firms operating in industries characterized by high opportunities were more likely to be open. In industries with high opportunities, firms need to capture

new knowledge from a range of sources to stay in the know about developments in the market and technology. In doing so, they often need to work with many external partners, drawing knowledge from universities, consultants and suppliers. In this respect, the openness of a firm to its external environment is, in part, shaped the industrial context it operates with in and the search activities of other firms in the industry.

There are several limitations to this study. One limitation of the framework proposed here is that it does not allow for the analysis of the importance of openness of external search within each individual knowledge channel (such as users, suppliers, universities etc.). Future research should examine this issue by developing several fine-grained items for each of the knowledge sources. It also remains unclear how the complexity of an innovation shapes the way firms search for new innovation opportunities. Past research suggests that firms producing simple or discrete technologies that are artefactually simple, that is, they involve relatively few components and clear interfaces between modules, or that rely on a small number of knowledge bases, will tend to search more narrowly than firms involved in the design and development of complex technologies (Nelson and Winter, 1982). Complex technologies, such as aeroengines, often require firms to master a wide number of different knowledge bases and to understand the interfaces and integration of a range of different components (Brusoni, Prencipe and Pavitt, 2001). As well, the literature on architectural innovation suggests that changes in the integration and interfaces between modules may require firms to change their search strategies given that their past search activities are ill suited to understanding the new product architecture (Henderson and Clark, 1990). Future research on the relationship between innovative search and complexity could yield a new understanding of the cognitive and

managerial challenges of organizational responses to significant technological change. In addition, our measure of openness does not provide information about the motivations influencing why managers choose draw knowledge from a particular source or range of sources. Nor does it explore the type of knowledge drawn from each source.

Another future research challenge is to understand changes in innovative search over time. Our approach focuses on the determinants of innovative search in one period and this remains a severe limitation of the study. However, with future innovation surveys, it will be possible to examine whether the search behavior of innovative firms has changed over time as suggested by Chesbrough. It may be that the ability of the firm to reconfigure its search strategies over time as a result of changes in the external environment — such as changes in appropriability and opportunity conditions — is the key managerial challenge faced by "open innovators". Until more research is undertaken on the evolution of search for innovation over time, the full implications of the possible movement towards "open innovation" will not be fully understood.

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Table 1: Sources of information and knowledge for innovation activities in UK manufacturing firms, year 2000 (n=2304).

Type	Knowledge source	Not used/ low use	Medium use/ High use
		Percentages	
Market	Suppliers of equipment, materials, components or software	51	49
	Clients or customers	55	45
	Competitors	73	27
	Consultants	84	16
	Commercial laboratories/ R&D enterprises	91	9
Institutional	Universities or other higher education institutes	89	11
	Government research organizations	96	4
	Other public sector e.g. business links, Government Offices	92	8
	Private research institutes	96	4
Other	Professional conferences, meetings	85	15
	Trade associations	79	21
	Technical/trade press, computer databases	73	27
	Fairs, exhibitions	70	30
Specialized	Technical standards	64	36
	Health and safety standards and regulations	61	39
	Environmental standards and regulations	65	35
Average		77	22

Table 2: Openness by industry

	No. of firms	No. of startups w. less than 250 employees	Openness mean	Degree/ employee mean	Tech. opp. Mean	Appropriability mean
Food, drink & tobacco	180	6	3.69	7.22	0.13	3.28
Textiles	135	13	2.64	5.47	0.10	3.56
Wood	128	7	3.23	4.08	0.10	3.70
Paper and printing	203	12	3.43	14.73	0.47	2.03
Chemicals	101	3	4.81	24.50	3.00	7.84
Plastics	120	1	3.62	7.41	0.63	5.52
Non-metallic minerals	62	4	3.61	6.56	0.21	5.00
Basic metals	51	0	3.88	5.12	0.15	3.29
Fabric. metal products	249	11	2.90	7.51	0.12	2.31
Machinery	183	6	4.70	11.89	0.68	5.85
Electrical	393	14	4.49	16.29	1.41	6.00
Transport	223	13	4.23	9.65	0.36	4.96
Other	276	27	3.26	6.70	0.33	4.12
Average			3.73	9.78	0.59	4.42
Total number	2304	117				

Table 3: Descriptive statistics and simple correlations (n=2304)

Variable	Mean	Std. Dev.	Min	Max	1.	2.	3.	4.	5.
1. Openness	3.76	3.63	0	16					
2. Appropriability strategy	4.40	5.12	0	18	0.464 ***				
3. Share employees with a degree	10.43	18.31	0	100	0.158 ***	0.200 ***			
4. Small startups	0.05	0.22	0	1	-0.071 ***	-0.058 **	0.026		
5. Industry average R&D intensity	0.62	0.77	0.05	6.13	0.139 ***	0.194 ***	0.240 ***	-0.023	
6. Number of employees (log)	4.17	1.39	0	8.97	0.270 ***	0.343 ***	0.056 **	-0.146 ***	0.093 ***

† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$

Table 4: Zero-inflated negative binomial regression, explaining external Openness to sources of innovation across UK manufacturing firms

Independent variables	Model 1		Model 2	
	Coeff.	Std. Err.	Coeff.	Std. Err.
Appropriability strategy	0.063 ***	0.011	0.071 ***	0.011
Appropriability strategy squared	-0.001 †	0.001	-0.002 **	0.001
Share of employees with a degree	0.003 **	0.001		
R&D intensity			-0.001	0.004
Startup	0.011	0.103	-0.030	0.082
Startup x Degree/employees	-0.010 *	0.004		
Startups x R&D intensity			-0.051 †	0.028
Industry average R&D intensity	0.134 **	0.044	0.109 *	0.043
Number of employees (log)	0.064 ***	0.013	0.063 ***	0.012
Food, drink & tobacco	0.222 **	0.080	0.175 *	0.077
Textiles	-0.092	0.094	-0.069	0.090
Wood	0.152	0.093	0.147 †	0.086
Paper and printing	0.216 **	0.079	0.273 ***	0.074
Chemicals	-0.248 †	0.147	-0.132	0.141
Plastics	0.028	0.093	0.077	0.089
Non-metallic minerals	0.096	0.119	0.040	0.117
Basic metals	0.293 *	0.122	0.313 **	0.119
Fabric. metal products	0.147 †	0.078	0.147 *	0.074
Machinery	0.203 **	0.076	0.207 **	0.073
Electrical	0.018	0.081	0.077	0.077
Transport	0.198 **	0.073	0.195 **	0.068
Other	Benchmark		Benchmark	
Constant	0.769 ***	0.083	0.775 ***	0.079
No. of obs	2304		2706	
Zero obs	633		775	
Log likelihood	-5318.96		-6213.57	
Chi-square	328.72 ***		351.33 ***	

† $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$