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The paradox of openness revisited: Open innovation and patenting by UK Innovators

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Abstract

The paradox of openness points out that on the one hand, firms are more likely to seek external collaborators if they can protect their innovation by patents, and more generally, guard against unintended knowledge spillovers to partners. On the other hand a focus on patenting and exclusivity makes a firm less efficient in developing collaborative innovations, and hence also, a less attractive partner. Thus, opening up to outside sources of knowledge to innovate may weaken the firm?s power to capture rents from that knowledge. We argue in this paper that the relationship between external sourcing (openness) and patenting is contingent on the technological ability of the firm. Firms will make different choices depending upon whether they are technically superior to their rivals and lead in the market or not. Leading firms are more vulnerable to unintended knowledge spillovers during collaboration as compared to followers, and consequently, the increase in patenting due to openness is higher for leaders than for followers. We test this conjecture by estimating whether the reduced form relationship between patenting and collaboration is stronger for leaders than for followers and find support for our arguments.

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The paradox of openness revisited:

Open innovation and patenting by UK Innovators

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Abstract:

The paradox of openness points out that on the one hand, firms are more likely to seek external collaborators if they can protect their innovation by patents, and more generally, guard against unintended knowledge spillovers to partners. On the other hand a focus on patenting and exclusivity makes a firm less efficient in developing collaborative innovations, and hence also, a less attractive partner. Thus, opening up to outside sources of knowledge to innovate may weaken the firm's power to capture rents from that knowledge. We argue in this paper that the relationship between external sourcing (openness) and patenting is contingent on the technological ability of the firm. Firms will make different choices depending upon whether they are technically superior to their rivals and lead in the market or not. Leading firms are more vulnerable to unintended knowledge spillovers during collaboration as compared to followers, and consequently, the increase in patenting due to openness is higher for leaders than for followers. We test this conjecture by estimating whether the reduced form relationship between patenting and collaboration is stronger for leaders than for followers and find support for our arguments.

1. Introduction:

Over the last quarter century two apparently contrasting trends have marked the innovation process. On the one hand, patents have become increasingly important as an appropriation tool (OECD 2004, WIPO 2007). On the other, innovators are increasingly relying upon collaboration with other firms and organizations (Chesborough, 2003). The question we address in this paper is the relationship between sourcing knowledge from the outside to develop innovations and using patents to appropriate the returns from innovation.[2]

The relationship between the reliance on external sources and the appropriability strategy of firms has been analysed extensively since the early paper by Cassiman and Veugelers (2002). This literature has converged around two conflicting points of view, which Laursen and Salter (2014) dub the "paradox of openness", namely that opening up to outside sources of knowledge to innovate may weaken the firm's power to capture rents from that knowledge. In other words, openness, or external sourcing, entails a trade-off. On the one hand, firms are more likely to seek external collaborators if they can protect their innovation by patents, and more generally, guard against unintended knowledge spillovers to partners. We call this the "spillover prevention" view. The second, which we call *"organisational openness"*, holds that a focus on patenting and exclusivity makes a firm less efficient in developing collaborative innovations, and hence also, a less attractive partner.

Our paper advances the debate on openness versus patenting in several ways. First, we argue in this paper that the relationship between external sourcing (openness) and patenting is contingent. Firms will make different choices depending upon whether they are technically superior to their rivals and lead in the market or not. Put differently, the trade-off between appropriating benefits and enhancing the efficiency of collaboration differs between leaders and followers. Leading firms are more vulnerable to unintended knowledge spillovers during collaboration as compared to followers, and consequently, the increase in patenting

[2] There is an older and even more extensive literature on the importance of patents for selling or licensing technology (Arrow, 1962; Arora, Fosfuri and Gambardella, 2001; Gans, Hsu and Stern, 2008). See also Arora and Gambardella (2010) for a survey of the literature.

due to openness is higher for leaders than for followers. We test this by estimating whether the reduced form relationship between patenting and collaboration is stronger for leaders than for followers.

Second, we point out that both patenting and openness are jointly determined, because they are both choices made by the firm. The existing literature has treated either openness as logically prior to appropriability (e.g., Laursen and Salter, 2014) or appropriability as logically prior (e.g., Zobel et al. 2013). In this paper we develop a simple framework that explains the joint determination and also provides a useful way to link the underlying theory to the observed relationship between patenting and openness, without resorting to causal assertions.

Our third contribution is to introduce new and more precise measures of the use of patents based upon a new survey, instead of relying upon perceived importance of various appropriability strategies as much of the existing literature has done. Our data are based on a survey of over 800 UK firms using the sixth wave of the Community Innovation Survey (CIS 6). We are able to augment our data by also using the responses of these firms in the CIS 6.

The remainder of this paper is organised in the following way: Section 2 surveys the relevant literature on the paradox of openness and highlights the empirical issues that limits the empirical analysis in this area. Section 3 articulates why leaders face a different tradeoff from followers, and provides a simple model of the benefits and costs of openness that links the theoretical trade-off to behaviour, which motivates our empirical analysis. Section 4 introduces the data and describes our key measures. Section 5 discusses the empirical results. Section 6 concludes.

2. Openness and Appropriability

2.1 Theoretical views

There are two dominant views on how patenting is related to use of external knowledge sources in innovation – we call these the "spillover prevention" theory and the *"organisational openness"* theory.

In the *"spillover prevention*" theory (Cassiman and Veuglers, 2002) firms engaged in outside collaboration favour the use of patents as a means of reducing spillovers of valuable knowledge to external partners. In the simplest version of the spillover theory, firms want to prevent imitation of their (focal) innovation and patent in order to protect the rents from that innovation. The likelihood of spillovers is greater if the firm is open i.e., if it collaborates with a partner, because collaboration inevitably reveals more information to others than if the innovation were entirely in-house.

It is widely recognized that using external knowledge could make it more difficult to protect the innovation. For instance, Noordhoff, et al. (2011) argue that innovations sourced from customers carry the risk that the customer may implement the invention itself, in effect becoming a competitor. Giarratana and Mariani (2014) argue that using outside sources of knowledge makes it harder to enforce secrecy within the firm, increasing the risk of imitation. Consequently, if a firm is unwilling to patent, or if patents are ineffective, it may choose to be closed. The key takeaway is that a firm has a greater incentive to patent if it is open than if it is closed. Simply put, in this view, we expect to see a positive association between patenting and openness.

Protecting the focal innovation is not the only source of association between patenting and openness. Many innovations are complex and require lots of different bits of prior knowledge or background knowledge. Crucial bits of background information can leak out to partners during collaboration. Patents can protect against that as well. Arora and Merges (2004) develop an analytical model in which the fear of knowledge spillovers may lead firms to internalize research even if internal research is less productive than external research, and how the patents condition this trade-off. Using firm-level data from Germany Buss and Pukert (2015) document a positive link between R&D outsourcing and intellectual property infringement, particularly for generic knowledge.

More broadly, scholars have argued that strong IPRs are often beneficial and potentially even necessary for open innovation (Arora and Gambardella, 1994; Chesbrough, 2003). Thus, Graham and Mowery (2006) suggest that "… IP protection creates a platform for the transfer of knowledge assets…" (p.185). Note that Arora and Gambardella (1994) and

Graham and Mowery (2006) have focused on the importance of IP protection to the agent transferring knowledge rather than sourcing it, whereas this paper is focused on firms sourcing external knowledge.

A different source of positive association between patenting and openness is that open firms may patent to signal their innovative capabilities to other firms (Alexy et al., 2009; Hagedoorn and Ridder, 2012). For instance, Hagedoorn and Ridder (2012) surveyed 86 firms which are active in open innovation and found that nearly 90% of the firms regard patent as important method for signaling the nature of their technological capabilities.

In sum, firms that rely on external sources of knowledge (open firms) will patent much more than firms that do not (closed firms) for three reasons. First, they want to protect their focal innovation produced through collaboration; second, they want to protect the background knowledge implicit in the innovation; and third, they want to send out precise signals about their value as innovation partners.

By contrast, the "organizational openness" theory, inspired partly by studies of open-source software and the literature on "collective invention" (cf. Allen, 1983; Bessen and Nuovalari, 2012), implies that firms engaged in external collaboration should be less likely to use patents. Laursen and Salter (2014) articulate the organizational perspective most clearly. They argue that although firms may wish to use patents to prevent knowledge from spilling out, a focus on patenting may make it harder to collaborate with outsiders. For instance, Foss et al. (2011) show that in order to benefit from customer interactions, firms have to delegate responsibility and increase internal communication. An unintended consequence may be that proprietary information can spill out. In other words, a focus on protecting the firm's proprietary information is likely to make it more difficult to collaborate with outsiders. Other scholars have also stressed the tension between IPR and openness to outside knowledge. Jensen and Webster (2009) contend that knowledge capture practices may impede collaborative knowledge creation process. For example, interacting with other organizations to stimulate knowledge creation relies on interdependencies and reciprocities, whereas patenting gives rise to exclusivity. The emphasis on exclusivity that a patenting intensive appropriation strategy entails can impede the efficiency of collaborative development of innovation.

Interestingly, even those who believe that open innovation is often facilitated by strong intellectual property rights (IPR), concede that firms may benefit from voluntarily waiving some of their intellectual property rights (Chesbrough and Appleyard, 2007; Pisano, 2006). The strategy that firms choose to purposefully disclose selected knowledge to general public (including competitors), instead of keeping them proprietary, is termed as “selective revealing” (Henkel, 2006; Henkel et al., 2014; Alexy et al., 2013).[3] By engaging in selective revealing, a focal firm can encourage others to participate in shared problems solving or to make complementary investments (Alexy et al., 2013). In other words, patenting and associated secrecy can make a firm a less attractive partner to potential collaborators. Thus, the organizational openness view would posit that firms that seek external knowledge for innovation are less likely to patent because patenting impedes their ability to gain from collaboration, and because they want to be attractive partners for potential collaborators.

In sum, the literature on openness and appropriability has stressed different aspects of the tradeoff, and also reached different conclusions. Some studies find a positive relationship between appropriability and openness. For instance, Cassiman and Veuglers (2002) use data on Belgian innovators from the European Community Innovation Survey (CIS) to test how firms fashion their appropriation strategy to guard against spillover of knowledge in formal R&D collaborations. They find that the reported effectiveness of “strategic appropriation” (secrecy, complexity, lead-time) is positively related to the probability of external collaboration, but also that the probability of external collaboration is not related to the effectiveness of intellectual-property protection (patents, trademarks, and copyrights). Zobel et al. (2013) find that patenting is positively associated with different types of external collaborations for a sample of solar technology start-ups in the U.S.

[3] Practices similar to selective revealing have long existed and can be found in historical accounts. Allen (1983) documented how the sharing of information among competitors in the English blast furnaces industry in 1850-1875 contributed to the innovation and development of the industry. Nuvolari (2004) also studied the collective invention settings in the Cornish mining district in the early period of industrialization, which contributed to the development of one of the key technologies of that period, steam power.

Other scholars report opposite findings. Based on the survey data of 785 Australian firms, Jensen and Webster (2009) conclude that the firms favoring internal R&D and relying upon secrecy and patenting are less likely exchange of knowledge with partners. When firms do use external knowledge, they rely on licensing, hiring other organizations' workers, and public domain sources such as patent disclosures, publications and technical meetings. Firms favoring open styles of learning operate in the opposite manner: They are less likely to use patenting and secrecy and collaborate with suppliers, customers, and other partners.. Alexy et al. (2014) do not report the direct relationship between patenting and openness, but their results indicate that patenting intensive firms are less likely to be open, particularly when they are underperforming.

Yet others report intermediate findings. For instance, Arundel (2001) analyzes data 1993 European Community Innovation Survey for up to 2849 R&D-performing firms, and finds only weak evidence that that participation in cooperative R&D increases the value of patents over secrecy for product innovations. Laursen and Salter (2014), using data on over 2900 innovators from the 4th UK Innovation Survey, find that openness first increases and then decreases with an emphasis on appropriability. Huang et al. (2014) use data from a 2003 survey of over 4000 Australian firms. They too find that the degree of openness is non-linearly related to appropriability. However, when they restrict attention to formal appropriability (patents, copyrights and trademarks), they find a positive relationship between appropriability and openness. Arora, Cohen and Walsh (2014), using data on nearly 1500 American manufacturing firms, finds that there is no systematic difference on average between firms that used external inventions versus those that used internal inventions. However, they also find that firms that relied upon customers and suppliers for inventions were less likely to patent the focal invention than firms that relied upon internal invention, whereas firms that used inventions from universities, independent inventors and R&D suppliers were more likely to patent the focal invention.

2.2: Empirical Issues

The empirical literature on openness and appropriability also suffers from some shortcomings. The empirical literature has tended to use measures of appropriability in general, often because specific information on patent use is difficult to obtain.[4] Yet, the use of patents is fundamentally different from other types of appropriability strategies such as secrecy, first mover advantage or product complexity. For instance, collaboration will surely weaken the ability of the firm to keep secrets. Indeed, Arundel (2001) reports that openness is associated with a greater importance of patenting relative to secrecy. Similarly, knowledge itself is "non-rival" in use. Consequently, both partners can use it, reducing the chances of conflict, unless one partner wishes to patent it. Thus, Huang et al. (2014) find different results when they focus on formal versus informal appropriability. By focusing on a widely studied means of appropriability, namely patenting, we hope to sharpen our understanding of this complex topic.

Another empirical issue is the use of the reported effectiveness of patents as perceived by the respondent rather than actual use of appropriation methods to protect innovations. Perceived effectiveness scores are problematic. Though ordinal, they are typically treated as cardinal variables in regressions. Perhaps even more problematic is that they are not easy to compare across respondents. Many, but not all, of the studies cited above, including Arundel (2001), Cassiman and Veuglers (2002), Laursen and Salter (2014), and Huang et al. (2014), use ordinal scaled measures of the importance of appropriability mechanisms, which are then aggregated in a variety of ways.

Actual measures of patenting intensity of innovations can overcome this limitation but are rare to find.[5] Perez-Luno and Valle-Cabrera (2011); Cohen et al. (2000), Alexy et al. (2014) ask innovating firms about their use of patenting in general (specifically, the percentage of their innovations for which they had applied for patents). and Arora, Cohen and Walsh (2014), ask respondenets whether they had patented their most significant innovation -- the innovation that accounted for a plurality of their sales over the last three years. In our

[4]For instance, Laursen and Salter (2014) do not distinguish between formal appropriation mechanisms such as patents, and appropriation via secrecy or lead-time, Cassiman and Veugelers (2002) divide appropriation strategy into formal appropriation strategies (which include patents, but also trademarks and copyrights) and other types of appropriation strategies.

[5] The latest UK CIS does ask for actual share of innovations protected by the different methods of appropriability.

empirical analysis, we feature the latter measure, namely whether the firm has patented its most significant innovation. We find similar, though weaker, results using the share of innovations protected by patents.

A major problem with the empirical literature is that it has treated the trade-off between appropriability and openness as a causal relationship (e.g., Cassiman and Veuglers, 2002; Laursen and Salter, 2014; Huang et al. 2014) or patenting on openness (e.g., Alexy et al.2013; Zobel et al. 2013).[6] This is problematic because both patenting and openness are strategic choices by the firm and it is difficult to assign logical priority. Empirically, this requires instruments for the endogenous choice, a difficult task which the literature has rarely undertaken successfully. This problem can however be sidestepped because theory does not prescribe causality. Instead it prescribes patterns of association. An example of such an approach is Buss and Pukert (2015), who eschew causal estimation and instead use reduced form estimation to show that R&D outsourcing is associated with higher likelihood of product infringement.

Further, as developed more fully in the next section, the association between openness and patent use will differ in strength, and perhaps also in direction, across different types of firms. Firms have heterogeneous abilities but there is little attempt in the empirical literature to distinguish between the different types of firms- such as firms which are technology leaders and those that are technology followers. In other contexts where technological leakages may pose a strategic threat or advantage, scholars have emphasised the different costs of collaboration to leaders and followers. For example, writing about agglomeration economies, regional spillovers and MNE location, Alcacer and Chung (2014) and Chung and Alcacer (2002) find technology leaders care more about accessing scientific resources from locations while technology followers are likely to position themselves to profit from locating in areas where spillovers are prevalent. Agglomerations thus mainly attract technology

[6] In some cases, scholars (e.g., Huang et al. 2014) have compounded the problem by not distinguishing between firms that successfully innovate and those that do not. It is likely that firms that do not innovate are less likely to patent and also less likely to report external collaborations.

followers that hope to benefit from spillovers while technology leaders are more likely to pursue specialised scientific assets.

3. Leaders, followers and the paradox of openness revisited

The tradeoff between openness and appropriation is contingent upon the type of firm. Specifically, the association between patenting and openness will be stronger when the focal firm invests heavily in research and development, and relies upon product innovation, because –such a firm is more vulnerable to spillovers during collaboration. They have proprietary technical information distinguishes them from rivals. Their profits are also more sensitive to the entry of imitators, which erode innovation rents. These firm, whom we call leaders, are more likely to use patents if they are open. By contrast, followers, have less to gain from patenting, and potentially more to gain from successfully collaborating. Followers have less proprietary technical information. As followers, they also typically have less to fear that their spillovers will facilitate the entry of other competitors.

Ignoring the possibility of patenting for now, let V be the value from the innovation without collaboration and (V +x) be the value with collaboration. We assume $x > 0$ which is the same as assuming collaboration creates value. When there is a potential for spillovers, the value with collaboration will include an additional term, y, where y represents leakage of knowledge. We assume that spillovers reduce value i.e., $y <0$. Thus $x+y$ represents the incremental profit from collaborating during innovation. Thus, a firm will collaborate if $x + y > 0$ and is closed otherwise.

Patenting offers firms an opportunity to reduce leakage during collaboration and, independent of collaboration, potentially also increases the value of the innovation by preventing imitation. If an open firm patents then the values of all parameters V, x, and y will change. Let V^p be the payoff from innovation with a patent, and $V' = V^p – V$ represent the change in value if firm patents, and likewise x^p be the value from collaboration if the focal firm patents, and $x' = x^p – x$ represents how the incremental value from collaboration changes if the firm patents. We similarly define y^p and y'.

In line with organisational openness theory we assume $x' < 0$ (patenting reduces the value from collaboration) but spillover theory implies $y' > 0$. The sum, $x'+ y'$ represents the difference in the incremental payoff to patenting between open and closed firms is $x'+ y'$.[7] These differences in the incremental payoffs to patenting between open and closed firms are at the heart of the paradox of openness, because they depend upon whether the firm is a leader or follower.

If we use the subscripts L and F to denote leaders and followers respectively, we argue that $x' +y'$ is greater for leaders than followers. In particular, followers may have more to gain from attracting partners to collaborate, and less to lose in terms of leakage of proprietary information. As a result, the gains in patenting for followers that collaborate compared to followers that do not, $x'_F +y'_F$, are lower than the comparable gains for leaders, i.e., we assume that $x'_L +y'_L > x'_F +y'_F$.

If $x'_L +y'_L > 0$, then spillover prevention dominates organizational openness for leaders. Similarly, if $x'_F +y'_F < 0$, then organizational openness dominates spillover prevention for followers. This is sufficient for $x'_L +y'_L > x'_F +y'_F$. However, it is not necessary. In other words, we are not specifically arguing that leaders are more likely to patent when they open rather than when they are closed, nor that followers are less. Rather, we are arguing that patents are more attractive to leaders when they are open than when they are closed, compared to the same choice made by followers.

Moving from payoffs to choices about collaboration and patent use involves some additional assumptions steps. In this setup, there are four choices for a firm – collaborate and patent, collaborate and not patent, not collaborate and patent, not collaborate and not patent. If we assume that the payoff from each choice has an additive error term that is iid and distributed

[7] The cost of patenting, ineffectiveness of patenting and other factors may mean that $V'<0$ is also possible. Note that $x'+y'$ combines two decisions – whether to be open or not, and whether to patent or not. Virtually all the existing literature tries to estimate the causal impact of one type of decision on another. Cassiman and Veuglers (2002) do instrument for their endogenous variables although the plausibility of their instruments is open to debate.

with a generalized extreme value distribution, the probability of the different choices can be written as follows[8]

Pr(no collaborate & no patent) = 1/D (1)

Pr(no collaborate & patent) = $\exp(V^p)/D$ (2)

Pr(collaborate & no patent) = $\exp(V+ x+y)/D$ (3)

Pr(collaborate & patent) = $\exp(V^p+ x^p + y^p)/D$ (4)

Where $D = 1 + \exp(V^p) + \exp(V+ x+y) + \exp(V^{p}{}' + x^p + y^p)$

The probability of patenting given collaboration,

$$\Pr(\text{patent} \mid \text{collaboration}) = \exp(V^p+ x^p + y^p - V- x-y) /(1+ \exp(V^p + x^p + y^p - V- x-y))$$

$$= \exp(V'+x'+ y')/(1+ \exp(V'+x'+ y'))$$

Similarly, for closed firms, the probability of patenting,

$\Pr(\text{patent} \mid \text{no collaboration}) = \exp(V')/(1+ \exp(V'))$.

There are two main points of this exercise. First, that patenting and openness are not randomly assigned to firms. Each choice has its costs and benefits, and these costs and benefits are inter-dependent. The second point, which follows from the first, is that the empirical analysis of the relationship between these choices must be particularly sensitive to their joint determination and, hence also, to differences across firms. In particular, one has to exercise care when moving from theoretical trade-offs to observed combinations of choices.

Consider the positive association between patenting and openness reported in the literature (e.g., Zobel et al 2014). This is equivalent to the conditional mean of patenting being higher for open than closed firms i. For binary variables, the conditional mean is the

[8] For instance, the payoff with no collaboration and no patenting is V+ ε, where ε is distributed with GEV type I distribution, and the other payoffs are analogously defined. These are the assumptions underlying the familiar multinomial logit model. We do not estimate a multinomial logit because it would imply estimating a set of parameters for each of the choices. With limited number of observations, we chose to directly estimate the expectation of patenting conditional upon openness for leaders and followers.

same as the conditional probability. Thus E(Patenting | open)–E(Patenting |closed) is positive if and only if exp(V'+ x'+ y') – exp(V') is positive. The latter is positive if and only if x'+ y' is positive. Therefore, a positive association between patenting and openness is equivalent to spillover prevention dominating organizational openness.

Note however that we have assumed that the error terms in the payoffs are independent. If the gains from patenting to prevent spillovers, (x'+ y'), are higher when the gains from patenting to prevent imitation, V', are also higher, the independence assumption would be violated. In this case, a positive association between openness and patenting would be observed even if (x'+ y') is not positive.[9] In other words, the positive association between patenting and openness can arise either if spillover prevention is more important than openness, or if the gains from patenting to prevent spillovers are correlated from the gains from preventing imitation.

We can use this framework to derive specific predictions of the different theories. The proofs of these propositions are given in the appendix.

(i) If spillover prevention dominates organizational openness for leaders, i.e., $x'_L + y'_L > 0$, then E(Patent | open leader) > E(Patent |closed leader).

(ii) If spillover prevention is dominated by organizational openness for followers, i.e., $x'_F + y'_F < 0$, then E(Patent | open follower) < E(Patent |closed follower).

(iii) If $V_L' > V_F'$, and $x'_L + y'_L > 0$, then $x'_L + y'_L > x'_F + y'_F$ implies that the difference in difference is positive, i.e., E(Patent | open leader) – E(Patent | closed leader) > E(Patent | open follower) – E(Patent | closed follower).

In our empirical analysis, we begin by showing the joint distribution between openness and patenting, and examine how this differs between leaders and followers. The data indicate a modest positive relationship between openness and patenting. This positive relationship is much stronger for leaders, but reversed for followers. We follow up on this

[9] Such a correlation would arise, if, as we argue, leaders have more to gain from preventing imitation, and more to gain from preventing spillovers during collaboration.

analysis with a more traditional regression analysis where we estimate the expected value of patenting conditional upon whether the firm is a leader or not, and whether it is open or not, controlling for various firm characteristics. We prefer this approach to the more obvious multinomial logit because it makes it easy to see how the increase in patenting between open and closed firms varies between leaders and followers.

4. Data, Methods and Variables

4.1. Data

We use the Survey of Innovation and Patent Use (SIPU) commissioned by the UK Intellectual Property Office in September 2012 and administered by the telephone survey team of the Office of National Statistics to test our conjectures. The survey is based on a sampling frame drawn from the sixth wave of Community Innovation Survey (CIS 6) conducted in 2006-2008 and asked questions about firms' innovation and technology in-licensing activities over 2009-2012. The advantage of this sampling frame is that it gave us information on the antecedent technological behavior of the surveyed firms.

The sample eligible for SIPU comprised of firms that agreed to be contacted again when they took part in the 2009 UK CIS (the CIS 6). In all 1,365 firms were contacted and the survey achieved 801 completed interviews and 10 partial interviews, yielding a response rate of 60.1%. 464 firms could not be contacted and 74 refused to participate in the survey. The SIPU sample yielded information on 329 innovating firms. Of these 81 firms had not reported any innovation in CIS 6.

4.2 Identifying technology leaders and followers

We classify the 329 innovative firms into open and closed innovative firms. The openness is defined according to the number of different types of the firms' external collaborators. In the CIS 6, firms are asked whether they cooperated in innovative activities with six types of organizations: suppliers of equipment, materials, services or software; clients or customers; competitors or other businesses in their industry; consultants, commercial labs, or private R&D institutes; universities or other higher education institutions; and government or public institutes. If a firm collaborated with two or more types of external partners on innovation, it is classified as an open innovative firm. Otherwise, it is considered as a closed innovative firm.

We use a k-means cluster analysis to classify firms as technology leaders or technology followers.[10] The clustering was based on two variables, viz. R&D intensity (measured the logarithm of internal R&D expenditure divided by number of employees) and the value of innovations (measured by the percentage of revenue from product innovation). Unlike openness, where we have roughly equal numbers of open and closed firms, the cluster analysis yields more followers than leaders. We expect technology leaders to show (on average) higher R&D intensity and more valuable innovations than firms in the technology follower group. This is indeed what we find in Table 1.

(Here insert Table 1)

Based on the leadership and openness measurement, we are able to further group the firms into four categories: open leader, closed leader, open follower and closed follower (Table 2).

(Here insert Table 2)

4.3 Patenting

Most of the extant literature uses a dummy variable indicating whether the firm has patented or not as an indicator of patent use. This measure of patent use does not allow us to control for the scale of innovations-larger firms will have more innovations and so will more often patent more. Moreover, firms with multiple innovations are more likely to file at least one patent than a firm, with the same patent propensity, which has few innovations because

[10] The cluster procedure begins with two initial group centers. Observations are assigned to the group with the closest center. The mean of the observations assigned to each of the groups is computed, and the process is repeated. These steps continue until all observations remain in the same group from the previous iteration (Stata, 2015).

of a smaller scale. We follow Arora et al. (2014) by measuring whether the firm had applied for a patent for their most significant innovation. Respondents were asked, “Of all the new or significantly improved goods or services or processes you brought to market since November 2009, think of the one that accounts for the most turnover”- thus, the most significant innovation is their most valuable one. Then they were asked if they applied for a patent for this innovation. Around 1/6th of the innovative firms had patented their most significant innovation (see the mean of “whether the company applied for a patent for significant innovation”, Table 3).

(Here insert Table 3)

Our second measure of patent propensity is the share of innovations patented. We follow Arundel and Kabla (1998) and Cohen et al. (2000) in the SIPU survey to ask firms what percentage of their innovations was associated with patent applications. In response, firms were asked to select one of six bands for the innovations viz. less than 10%, 10-40%, 41-60%, 61-90%, over 90%. We assume that the percentage in each band is concentrated around the midpoint. Among all respondents, the mean share of innovations patented is around 5%. For patenting firms only, the mean share of innovations patented is about 26%.

Both measures yield very similar results. We feature the results for whether the firm had patented its most significant innovation because typically firms have only a few innovations. The featured measure minimizes measurement error. As well, we can control for whether the innovation is a product innovation or not. Doing so is important because process innovations are typically less likely to be patented.

4.4 Control variables

To control for the influence of the codifiability of firms' knowledge on the patentability of their innovations, we create a variable codification of knowledge based on the perceived importance of information from scientific journals and trade/technical publications and importance of information from technical, industry or service standards to firms’ innovation related activities, which are recorded in the CIS 6. The CIS6 asks firms to rank on a Likert scale from 0-3 the importance of information received from various sources to a firm's innovation activities, where 0 indicates that the source is not used and 3 indicates that it is very important. The value of codification of knowledge is the highest value that a firm gave to these two sources.

We use the logarithmic employment as a measurement of a firm's size. In the regression with the dependent variable of whether the company applied for a patent for significant innovation, we add a control variable turnover from significant innovation to control for the importance of the significant innovation to the firm. In the SIPU, firms were asked to indicate what percentage of total turnover was from the significant innovation, such as 1-5%, 6-10%, 11-25%, 26-50% and more than 50%. We take the midpoint in each band as the value for the control variable. We also add a dummy variable significant innovation is a new good to control for the higher probability that a new good would be patented in comparison to the probability that a new service or process would be patented.

To control for industry characteristics, we generated 17 dummy variables at the two-digit industry level. A dummy variable is assigned to a two-digit industry as long as there are greater than 8 observations from this industry. Our results are unchanged if we use other industry controls, such as classifying industries into high, medium, and low technology intensity groups. The summary statistics and correlation matrix of the variables are presented in Table 3.

5. Empirical analysis

5.1 Descriptive Analysis

We begin with a simple descriptive analysis where we divide firms into whether they patent their most significant innovation (henceforth, patent) and whether they are open. Table 4a shows the result for the sample as a whole. The numbers in each cell are the counts of the firms in each category, and their share in the total sample. Looking first at the column totals, it is clear that less than a sixth of all innovators patent. Further, there is a modest positive association between openness and patenting. Whereas 18% (30 out of 163) of open firms patent, only 13% of closed firms patent. To relate it back to the model developed in section 3, E(patent | open) = 18% > E(patent | closed) = 13%. However, the difference is not statistically significant.

(Here insert Table 4a)

(Here insert Table 4b)

(Here insert Table 4c)

Tables 4b and 4c show the same results separately for technology leaders and followers respectively. Leaders patent at higher rates than followers, 19% compared to 14%. The difference in patenting between open and closed firms varies between leaders and followers. We see that E(patent |open leader) is 26% while E(patent |closed leader) is only 12%. Open leaders are twice as likely to patent as close leaders. Instead, E(patent | open follower) is 13% whereas E(patent | closed follower) is 14%; open followers are slightly less likely to patent than close followers, although the difference is not statistically significant.

The differences in these conditional means are consistent with our theoretical argument that leaders are more vulnerable to spillovers. Thus, when leaders collaborate in innovation they are more likely to use patents than when they innovate internally, and this difference is large and statistically significant. However, when followers collaborate in innovation, they are not more likely to patent than when they innovate internally.

5.2: Regression Analysis

The simple differences in conditional means do not control for a variety of other factors, such as scale and industry characteristics. Accordingly, we estimate the expectation of whether the firm patents its most significant innovation conditional on the firm type (e.g., open leader, closed leader, open follower, closed follower), as well as a variety of firm characteristics and industry dummies. The most straightforward way of doing so is through a linear regression specification. We do so in preference to a more conventional probit or logit specification because the estimated coefficients are the conditional means, and therefore easy to interpret. However, our results are robust to alternative specifications, for instance in a probit or a logit model.[11]

Table 5 shows that the patterns shown in Table 4a, 4b and 4c hold even after controlling for firm and technology characteristics, and industry fixed effects. Our interest is in investigating whether the difference in patenting between open and closed leaders is greater than the corresponding difference in patenting among followers. Formally, we want to test that the "difference in difference" is positive and significant and the two-tailed test of this hypothesis is reported in the last row of Table 5.

(Here insert Table 5)

In the first column of Table 5, we regress the four choices of firms against the use of patents to protect their most significant innovation and do not include any industry dummies or firm controls. Column 1 in Table 5 thus reproduces the specification implied by table 4c. As we expected, the increase in patenting for followers that collaborate compared to followers that do not, is lower than the comparable increase for leaders.i.e., $\{E(\text{patent} \mid \text{open})_L - E(\text{patent} \mid \text{closed})_L\} - \{E(\text{patent} \mid \text{open})_F - E(\text{patent} \mid \text{closed})_F\} = 15\%$, which is both large (recall that mean patenting rate is only slightly larger than 15%) and statistically significant.

Column 2 shows that including 17 industry fixed effects has only a slight effect on the differences in the conditional means. The difference in patenting rates between open and closed leaders decreases from about 14% to about 11% once industry effects are included. However, the difference in patenting rates between open and closed followers increases in absolute value, from −1.4% to about −4.7%. As a result, the "difference in difference" increase slightly from 15.4% to 16.0%. This difference in difference is statistically significant and quantitatively large, equal to the mean rate of patenting in the sample as a whole.

Columns 3 and 4 progressively add controls for firm size, codification of knowledge and percentage of turnover from significant innovation. Although the differences in conditional means remain more stable, the precision of the estimates falls as standard errors

[11] The results of probit and logit model are available from authors upon request.

increase. For instance, in Column 3, the differences in patenting rates between open and closed leaders is about 11.4%, whereas the difference between open and closed followers is nearly –5.3%. The difference in difference actually increases to 16.6% (compared to 16.0% with only industry effects). Column 5 additionally controls for whether the significant innovation is a good, rather than a service or process. In this specification, the difference in patenting rates between open and closed leaders is about 8.4%, but the difference between open and closed followers is -7.0%. The difference in difference is 15.4%, which is statistically significant as well.

Table 6 shows the results when we use the share of innovations patented as the dependent variable. We use this as a robustness check. The qualitative patterns are similar, although the estimates are much noiser and the fit is poorer.[12] Column 1 includes no controls. It shows that open leaders patent a higher share of innovations than closed leaders (10.5% compared to 7%). However, now open followers patent a higher share of innovations than closed followers (3.8% compared to 2.6%), and the difference-in-difference, though positive, is no longer statistically significant. This pattern persists as we add industry fixed effects, and then controls for firm size and codification of knowledge.

(Here insert Table 6)

6. Conclusion

This paper has revisited the "paradox of openness", which describes a trade-off when firms open up to outsiders to generate knowledge may weaken the firm's power to capture knowledge. Associated with this paradox, there are two seemingly contracting theoretical hypotheses. On the one hand, firms are more likely to seek external collaborators if they can protect their innovation by patents, and more generally, can guard against unintended knowledge spillovers to partners. We call it the "spillover prevention" theory. In this view, we expect to see a positive correlation between patenting and openness. On the other hand, patenting and exclusivity makes a firm less efficient in developing collaborative innovations,

[12] For instance, the R^2 in Table 5 Column 1 is 0.18 but only 0.13 for Column 1 in Table 6.

and hence also, a less attractive partner. We dub this the *"organisational openness"* theory. It implies a negative relationship between patenting and openness.

In this paper we start from the premise that both patenting and openness are jointly determined, and therefore, one cannot use a causal inference approach, common in this literature. We therefore develop a simple empirical framework that incorporates the joint determination of both variables. We argue that the relationship between patenting and openness is contingent on the technological and innovation leadership of firms. Firms will make different choices about being open and about patenting depending upon whether they are technically superior to their rivals and lead in the market or not. We use our empirical framework to derive the empirical implications of this contingency for the relationship between patenting and openness. We test this empirically, using a novel survey of a sample of over 325 innovative firms that were also covered in the sixth wave of the UK Community Innovation Survey.

We conclude that the paradox of openness can be resolved if we recognise that not all firms are equal in their technological ability and reliance upon innovation. Leading firms are more vulnerable to unintended knowledge spillovers during collaboration as compared to followers, and consequently, we find that the increase in patenting due to openness is higher for leaders than for followers. On the other hand, our results confirm that the increment in patenting due to collaboration is much lower in firms that followers. Followers, with incremental innovations that benefit less from patenting and with little proprietary technology and knowhow may be less willing to patent because it makes them a less attractive open partner and perhaps also less able to derive value from collaboration.

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Table 1: Summary Statistics of Leader and Follower Firms

		R&D intensity	% of revenue from product innovation
Leader	Minimum	0	18
	Mean	1.03	32.39
	Maximum	4.17	75
Follower	Minimum	0	0
	Mean	.38	3.03
	Maximum	4.41	8
Total	Minimum	0	0
	Mean	.64	14.62
	Maximum	4.41	75

Table 2: Number of Firms in Four Categories by Leadership and Openness

	Leader	Follower	Total
Open	70	93	163
Closed	61	105	166
Total	131	198	329

Table 3: Summary Statistics and Correlation Matrix

	Variables	Number of Observations	Mean	Standard Deviation	Min	Max	Correlation Matrix 1	2	3	4	5	6	7	8	9	10
1	Whether the Company Applied for a Patent for Significant Innovation	328	15.85	36.58	0.00	100.00	1.00									
2	Percentage of Innovations Associated with Patent Applications	325	5.43	16.50	0.00	95.00	0.58	1.00								
3	Open leader	329	0.21	0.41	0.00	1.00	0.15	0.17	1.00							
4	Closed leader	329	0.19	0.39	0.00	1.00	-0.05	0.06	-0.25	1.00						
5	Open follower	329	0.28	0.45	0.00	1.00	-0.05	-0.05	-0.33	-0.31	1.00					
6	Closed follower	329	0.32	0.47	0.00	1.00	-0.05	-0.15	-0.35	-0.32	-0.42	1.00				
7	Log Employment	329	4.01	1.40	1.39	9.83	0.12	0.07	-0.04	-0.01	0.10	-0.06	1.00			
8	Codification of knowledge	329	1.31	1.07	0.00	3.00	0.10	0.05	0.22	-0.11	0.25	-0.35	0.09	1.00		
9	Turnover from Significant Innovation	316	0.14	0.20	0.00	0.75	-0.01	0.12	0.29	0.07	-0.17	-0.15	-0.07	0.04	1.00	
10	Significant innovation is a new good	329	0.60	0.49	0.00	1.00	0.22	0.12	0.26	0.00	-0.09	-0.14	-0.03	0.06	-0.07	1.00

Table 4a: Percentage of Innovators Patenting Their Most Significant Innovation

	Number of firms	Mean of Percentage of Innovators Patenting Their Most Significant Innovation
Open	166	18.40
		(3.04)
Closed	163	13.33
		(2.65)
Open minus Closed		5.07
		(4.04)

Table 4b: Percentage of Innovators Patenting Their Most Significant Innovation

	Number of firms	Mean of Percentage of Innovators Patenting Their Most Significant Innovation
Leader	131	19.23
		(3.45)
Follower	198	13.64
		(2.45)
Leader minus Follower		5.59
		(4.12)

Table 4c: Percentage of Innovators Patenting Their Most Significant Innovation

	Leader	Follower	Leader minus Follower
Open	25.71	12.90	12.81**
	(5.26)	(3.50)	(6.09)
Closed	11.67	14.29	-2.62
	(4.18)	(3.43)	(5.53)
Open minus Closed	14.05**	-1.38	
	(6.88)	(4.91)	

Note: The numbers in parentheses are standard errors. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.

Table 5: Regression Results

	Dependent Variable				
	Whether the Company Applied for a Patent for Significant Innovation				
	(1)	(2)	(3)	(4)	(5)
Open Leader	25.71***	22.01***	13.54	12.64	2.66
	(5.26)	(8.10)	(9.94)	(10.70)	(11.29)
Closed Leader	11.67***	10.75	2.19	2.05	-5.73
	(4.17)	(6.98)	(9.52)	(9.99)	(9.97)
Open Follower	12.90***	10.08	1.41	-0.80	-7.26
	(3.50)	(7.04)	(8.88)	(9.75)	(10.15)
Closed Follower	14.29***	14.78**	6.69	6.14	-0.26
	(3.44)	(6.59)	(9.01)	(9.69)	(9.69)
Log Employment			2.20	2.29	2.54
			(1.67)	(1.73)	(1.70)
Codification of Knowledge				2.00	2.10
				(2.27)	(2.23)
Turnover from Significant Innovation				-3.85	-0.28
				(10.92)	(10.82)
Significant innovation is a new good					10.33**
					(4.14)
17 Industry Dummies	Not Included	Included	Included	Included	Included
Number of Observations	328	328	328	316	316
R^2	0.18	0.26	0.26	0.27	0.28
F-statistic (H0: coefficient of open leader – coefficient of closed leader = coefficient of open follower – coefficient of closed follower)	3.45*	3.95**	4.34**	4.52**	3.47*

Note: The numbers in parentheses are robust standard errors. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.

Table 6: Regression Results

	Dependent Variable			
	Percentage of Innovations Associated with Patent Applications			
	(1)	(2)	(3)	(4)
Open Leader	10.51***	7.01**	5.08	4.71
	(-2.43)	(3.27)	(3.84)	(4.39)
Closed Leader	6.97***	4.36	2.37	2.19
	(-2.33)	(3.11)	(4.06)	(4.16)
Open Follower	3.80**	1.29	-0.69	-1.06
	(-1.52)	(3.37)	(4.04)	(4.20)
Closed Follower	2.57*	1.08	-0.78	-0.91
	(-1.32)	(2.43)	(3.36)	(3.21)
Log Employment			0.51	0.50
			(0.73)	(0.73)
Codification of Knowledge				0.25
				(1.17)
17 Industry Dummies	Note Included	Included	Included	Included
Number of Observations	325	325	325	325
R^2	0.13	0.17	0.17	0.17
F-statistic (H0: coefficient of open leader – coefficient of closed leader = coefficient of open follower – coefficient of closed follower)	0.35	0.39	0.46	0.47

Note: The numbers in parentheses are robust standard errors. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.

<u>The paradox of openness revisited: Appendix</u>

The following relationships are useful, and have been derived in the text.

E(Patent |open)$_L$ = exp($V_L' + x'_L + y'_L$)/(1+ exp($V_L' + x'_L + y'_L$))

E(Patent |closed)$_L$= exp(V_L')/(1+ exp(V_L')

E(Patent |open)$_F$ = exp($V_F' + x'_F + y'_F$)/(1+ exp($V_F' + x'_F + y'_F$))

E(Patent |closed)$_F$ = exp(V_F')/(1+ exp(V_F')

<u>Proof of Proposition 1</u>: E(Patent |open)$_L$ – E(Patent |closed)$_L$

= {exp($V_L' + x'_L + y'_L$) – exp(V_L')}/{(1+ exp($V_F' + x'_F + y'_F$) (1+ exp(V_L')}

={exp(V_L')(exp($x'_L + y'_L$) –1)}/ {(1+ exp($V_F' + x'_F + y'_F$) (1+ exp(V_L')}

> 0 iff exp($x'_L + y'_L$) > 1 iff $x'_L + y'_L > 0$

Therefore, E(Patent |open)$_L$ – E(Patent |closed)$_L$ >0 iff $x'_L + y'_L > 0$

<u>Proof of proposition 2:</u> The proof follows similarly to the proof for 1.

<u>Proof of proposition 3:</u>

[E(Patent |open)$_L$ – E(Patent |closed)$_L$]– [E(Patent |open)$_F$ – E(Patent |closed)$_F$] >0 iff

$(a_L - b_L) - (a_F - b_F) > (a_F b_L - a_L b_F)(1+ a_L+1+ b_F)$

where

$a_L = \exp(V_L' + x'_L + y'_L)$, $b_L = \exp(V_L')$

$a_F = \exp(V_F' + x'_F + y'_F)$, $b_F = \exp(V_F')$

Note that $b_L/b_F < a_L/a_F$ if $x'_L + y'_L > x'_F + y'_F$ because $b_L/b_F = \exp(x'_F + y'_F)$, and $a_L/a_F = \exp(x'_L + y'_L)$. If so,

$x'_L + y'_L > x'_F + y'_F$ implies that $(a_F b_L - a_L b_F)(1+ a_L+1+ b_F) < 0$ ……………………(A1)

Therefore $(a_L - b_L) - (a_F - b_F) > 0$ is sufficient for proposition 3.

$a_L - b_L = \exp(V_L')(\exp(x'_L + y'_L) - 1)$ and $a_F - b_F = \exp(V_F')(\exp(x'_F + y'_F) - 1)$ (A2)

$(a_L - b_L) - (a_F - b_F) = \exp(V_L')(\exp(x'_L + y'_L) - 1) - \exp(V_F')(\exp(x'_F + y'_F) - 1)$ (A3)

A sufficient condition for $\exp(V_L')(\exp(x'_L + y'_L) - 1) - \exp(V_F')(\exp(x'_F + y'_F) - 1)$ to be non-negative is $V_L' > V_F'$ and $x'_L + y'_L > 0$, and $x'_L + y'_L > x'_F + y'_F$.