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How to appropriate value in formal and informal open innovation: A perspective of strong ties and weak ties

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Abstract

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Open innovation has come to be seen as a smart way for of firms to improve their capabilities in developing new products, new processes and new services. Scholars and practitioners have emphasized the benefits of open innovation. More specifically, open innovation enables firms to gain complementary assets and competitive advantage through financial aspects like cost reduction, and improved risk sharing and commercial returns, as well as non-financial aspects like broadening the knowledge base, asset reallocation, and the setting up of technical standards. Many corporations active in open innovation undoubtedly obtain strategic and economic benefits in practice (H. W. Chesbrough, 2006). But with improved innovation outcomes a key question that comes to the fore is is how best to protect a firm's knowledge and appropriate profits from innovation. Appropriation strategies that play a pivotal role in value capture include patenting, trademarks, secrecy, and lead-time advantage (Teece, 1986).

Use of these strategies matters potentially even more in a context of open innovation, where technologies and knowledge are transferred and utilized beyond the boundaries of firms more often and more easily (Agostini & Nosella, 2017; Amara, Landry, & Traoré, 2008). Consequently, an interesting debate on the tension between openness and value appropriation has emerged, especially regarding the use of patents. One group of authors who support disclosure point out that external search openness increases the use of patents by preventing free-riders, encouraging knowledge sharing, and hindering the transfer and release (Hagedoorn & Zobel, 2015; Zobel, Lokshin, & Hagedoorn, 2016), while another group supports exclusivity, arguing that a greater scope of open innovation activities increase exposure that involves more knowledge sharing and frequent interactions, which runs contrary to patent exclusivity (Arora, Athreye, & Huang, 2016; Jensen & Webster, 2009; Norman, 2002; West, 2006). It has been shown that the use of patents not

only involves a trade-off between risk and return in specific occasions, but is also an outcome of preferences in relation to other appropriation strategies such as secrecy (Arundel, 2001; Zaby, 2010).

The essence of open innovation is the creation of new resources and capabilities through relationships. Many scholars have made a key distinction between the formal way of partnering, organized by contracts, and the informal way of building relationships, subject to flexible private ordering (Almirall & Casadesus-Masanell, 2010; Hagedoorn & Zobel, 2015; Mina, Bascavusoglu-Moreau, & Hughes, 2014). Interestingly, some evidence has emerged that firms active in the two models of open innovation show different attitudes towards the use of patenting (Mina et al., 2014). In light of the opposing nature of disclosure and different level of innovations between patent and secrecy (Hall, Helmers, Rogers, & Sena, 2014; Holgersson & Wallin, 2017), whether firms using different open innovation models adopt opposing appropriation strategies to capture value becomes a more interesting issue.

Yet there is little specific evidence of how these two ways of engaging in open innovation might affect use of patents and secrecy differentially. Moreover there do not appear to be prior conceptualizations of this either. Hence the research question of this paper is: How do formal and informal open innovation activities drive the use of patents and secrecy?

To answer this research question, we draw on the well-established distinction between strong and weak ties in relationships as an explanatory mechanism for why firms might seek to appropriate value in different ways. Specifically, we argue that firms using formal partnering, as a form of strong ties, or informal ways of collaborating, which can be seen as weak ties, have different relationship objectives and distinctive ways of working (Milesi, Verre, & Petelski, 2017).

Thus we build on recent literature using the relational perspective (Hagedoorn & Zobel, 2015; Henttonen, Hurmelinna‐Laukkanen, & Ritala, 2016) and respond to calls to develop its use further in the context of open innovation settings (Dahlander & Gann, 2010).

In short, we use the regional Tianjin Community Innovation Survey database to show that formal open innovation is associated with use of patents, while informal open innovation leads to more use of secrecy. The latter effect disappears when including an interaction effect between formal and informal open innovation. This suggests that secrecy is acceptable to informal counterparts, but when firms start to formalize relationships use of secrecy is no longer an acceptable norm to partner firms. We see the contributions of this paper in disentangling the effects of different ways of working with outside parties on the firm's own appropriation strategy, and thus taking a further step towards uncovering the black box which links open innovation to value appropriation.

Theoretical background

In order to capture large chunks of value created from innovation, patents and secrecy are among the most effective appropriation strategies. But what drives use of these these strategies? At a basic level there must be some cost-benefit analysis, i.e. whether firms patent or maintain invention secrecy depends on which of these options they see as more beneficial. Previous of studies have asserted that disclosure and technological advances matter to this equation. On the one hand, patents are used as a technical reserve to protect innovative output, as well as for strategic motives like blocking, signaling and reputation, licensing and encouraging innovators (Neuhäusler, 2012). To get exclusive usage rights, a firm needs to disclose innovation information

to the public. Disclosure required by utilization, acquisition and sharing of rights is often considered to be the main motive behind patenting (Holgersson & Wallin, 2017; Somaya, 2012). Unlike a patent, secrecy is valuable precisely because knowledge remains unknown. This may be a more appropriate strategy in the early stages of innovation, as it restrict knowledge outflow. Technological advances can make secrecy an extremely valuable means of appropriation. Some of the literatures arrives at this same conclusion, i.e. some very large and important innovations are protected through secrecy, because it brings lead time advantages, whereas relatively small innovations are protected by patents (Anton & Yao, 2004; Bos, Broekhuizen, & Faria, 2015; Hall et al., 2014; Sofka, de Faria, & Shehu, 2018). As detailed below we argue that the choice between patents and secrecy may be driven by the kind of collaboration firms engage in, formal or informal, since the different tie strength these collaboration modes represent have implications for the ways firms work together.

Formal and informal open innovation

Firms have different ways of managing openness (Dahlander & Gann, 2010; Van de Vrande, De Jong, Vanhaverbeke, & De Rochemont, 2009). To better understand this, conceptually much work has drawn on the definition of openness from resource-based view, i.e., searching broadly and deeply for sources which the firm can tap into to develop innovations (Laursen & Salter, 2006; Zobel et al., 2016). In spite of the dominance of this distinction, some other work discusses that there is another key distinction in open innovation, between formal and informal activities (Alexy, Bascavusoglu-Moreau, & Salter, 2016; Cosh & Zhang, 2011; Du, Leten, & Vanhaverbeke, 2014; Mina et al., 2014; Van de Vrande et al., 2009).

Formal and informal activities are different ways of partnering and working together. Formal

activities are generally based on explicit, and contractually underpinned collaborative agreements enforceable by law, while informal activities are based on loosely defined collaboration agreements that are perhaps enforceable by markets, and involve more generic and less well-defined network activities (Allen, James, & Gamlen, 2007; Holgersson, Granstrand, & Bogers, 2018; Van Aken & Weggeman, 2000; Van de Vrande et al., 2009). Formal activities include, but are not limited to, joint R&D, joint production, and venture capital. Meanwhile informal activities include visiting and learning, technical talks and communication and so forth, which as as common characteristics are not focused on monetary exchange in a relationship.

Both formal and informal inter-firm activities help to gain access to and subsequently transfer knowledge, as well as develop a collection of resources and capabilities that a firm cannot create independently (Lorenzoni & Lipparini, 1999). These capabilities are created through complex, resourced-based interactions among firms (Amit & Schoemaker, 1993). As firms build up a portfolio of formal and informal open innovation relations, they can eventually create novel value (Dyer & Singh, 1998).

Strong and weak ties

Relational characteristics are crucial in knowledge acquisition and protection (Kale, Singh, & Perlmutter, 2000; Norman, 2002). Extant studies typically delineate the strength of ties based on their frequency, duration, closeness, trust (Granovetter, 1973; Levin & Cross, 2004), formal control, and scope of knowledge (Gilsing & Nooteboom, 2005). Kontinen and Ojala (2011) and Söderqvist and Kamala Chetty (2013) define strong ties as those which are close, on the basis of trust, mutual respect, deep knowledge and experience of each other. By contrast, weak ties are characterized as superficial ties which are lack of adequate trust, and parties embedded in weak

ties do not know well each other and are not emotionally close.

This implies that relationships in informal open innovation activities are by default weak ties although some such activities may also be undertaken with firms with which a formal collaborative agreement exists simultaneously. For example, visiting a firm and holding informal talks do not necessarily require strong and close personal and organizational relationships; instead, they are probably superficial contacts, characterized by 'friends of friends' relationships at a distance. Therefore, we assume that strong ties are associated with formal open innovation partnerships and weak ties associate with informal way of working.

Formal ways of collaborating, involving clear goals and procedures in concrete written agreements and high levels of trust, are often used in mainstream innovation (Van Aken & Weggeman, 2000). What mainstream innovations need is a steady flow of ideas, technological inventions and operational support for joint problem-solving (Capaldo, 2007; Christensen, 2013). Formal contracts explicitly stipulate the performance target and procedures that both partners should follow (Bai, Sheng, & Li, 2016). The rights to use background and foreground intellectual assets within each firm are especially well-defined in such agreements (Slowinski, Hummel, & Kumpf, 2006). In other words, contracts ensure formal controls and reduce information asymmetry between the focal firm and counterparties (Heide, Wathne, & Rokkan, 2007) and lower the level vagueness in goals and behaviors. When firms engage in many formal activities, such as joint R&D and technology investment, they know exactly what they need form their partners and in turn understand what they themselves should do during the innovation process. As such, formal contracting activities enhance the level of trust through narrowing domain and severity of risk and track record (Dekker, 2004). Trust and reciprocity lead to increased

willingness to pool assets and share knowledge with counterparties and thus produce first-class innovation (Capaldo, 2007). All in all, formal or contracting activities (1) bring a steady flow of knowledge and may deepen existing knowledge, (2) rely on formal control on the behaviors and outcomes of innovation, and (3) increase trust, and thus are regarded as strong ties (Gilsing & Nooteboom, 2005; Söderqvist & Kamala Chetty, 2013; Wang, Sung, Chen, & Huang, 2017).

By contrast, informal activities involving diverse knowledge, flexibility and low trust are regarded as weak ties, such as casual contacts and friends of friends (Chandra, Styles, & Wilkinson, 2009). A broad array of non-currency exchanges and communications is involved in informal collaboration. A key advantage of this way of working is its low set-up cost, the possibility of idea jams, and superior flexibility. Firms engage in informal activities to increase the diversity of accessible knowledge and promote innovation at the fuzzy front end (Van Aken & Weggeman, 2000). Informal activities often do not aim at actual innovation, but rather at testing ideas to provide a favorable condition for subsequent formal collaboration (Van Aken & Weggeman, 2000). This is conducive to creating and organizing spaces to produce innovative concepts by conceiving jointly with partners and therefore support proactive strategies that aim at nurturing a new philosophy (Capaldo, 2007). Informal activities are rarely controlled by contracts, and involve irregular, loose and temporary interactions with often unpredictable results, and often multiple routes to innovation success (equifinality). This nature of informal collaboration enables firms to govern these relationships through weak ties.

Hypotheses

Formal OI and patent, informal OI and secrecy

Whether firms patent or maintain invention secrecy depends on what they believe to be most beneficial. Various studies assert that disclosure and technological advances matter (Anton & Yao, 2004; Bos, Broekhuizen, & Faria, 2015; B. Hall, Helmers, Rogers, & Sena, 2014; Sofka, de Faria, & Shehu, 2018). Disclosure required by utilization, acquisition and sharing of rights is often considered to lead to prioritization of patents (Holgersson & Wallin, 2017; Somaya, 2012). Firstly, intellectual property rights are a primary consideration when firms collaborate with partners. They have more preference for using patents while involving contractual agreements, which require clarification of intellectual property rights (Dekker, 2004; B. Hall et al., 2014). In formal settings, specification and division of intellectual property rights should be explicitly brought to the surface. Patents are mainly used to prevent imitation by others and the rights that can be guaranteed by law create a clear boundary around knowledge, even if partners have complicated interactions.

Secondly, given that firms that formally partner more or less signal that they expect to generate innovation, then the most obvious and accessible output would be a patent, no matter whether it is jointly or exclusively owned. Normally both parties negotiate how to allocate and adjust rights whenever innovations are realized under formal control. Formal OI provides in-depth but overlapping and redundant information and knowledge through strong ties (McFadyen, Semadeni, & Cannella Jr, 2009), which are exploited to develop incremental innovation (Lechner & Dowling, 2003). A moderate technological lead makes outcomes of exploitation and incremental innovation (H. Chesbrough & Prencipe, 2008; Dittrich & Duysters, 2007) relatively easy to be reverse-engineered, and accordingly, the firm may favor pure patents over secrecy to

capture value (Graham, 2004; B. Hall et al., 2014).

Thirdly, engagement in formal OI activities makes firms prefer to use patents because collaboration with partners involves sharing. For example, licensing a patent offers legal protection for part of the knowledge and leaves room for selective knowledge sharing, which allows for organizational learning in open innovation (Somaya, 2012). In some cases, firms choose to be open to serve as licensors to gain licensing income, as licensees in turn receive a nonexclusive license for the use of technology (Dekker, 2004) or for cross-licensing. Besides, during the process of being open formally, patents also play an important role in creating indirect advantage, e.g., negotiation as bargaining power facilitates cooperation and participation of standards. The signaling effect of patents increases reputation, firm value and helps to attract new partners (Bos et al., 2015). Taken together, on the basis of strong ties, the creation, sharing and utilization of patent rights corresponds with the climate in formal OI. Instead, secrecy which aims at deliberately withholding knowledge, is not compatible with the mutual expectations and goal congruence of formal partnering (Bos et al., 2015).

By contrast, scenarios where secrecy trumps patent occur in informal OI. Unlike patents, secrecy has no freedom to operate and disclose. We start out by looking at the stage in which a specific strategy is more effective for protecting the inventions (Arundel, 2001; Hussinger, 2006). Generally, firms that engage in OI practices which can be organized informally aim at technology exploration, most of which help to fill in knowledge needs without spending substantial investments. Firms which pursue these informal OI activities are mostly motivated by market-related determinants such as keeping pace with market development and market share, followed by gaining knowledge and promoting innovation (Van de Vrande et al., 2009).

Conversely, firms engage in formal OI activities focus more on market and commercialization, innovation and utilization of resources, which orients towards technology exploitation. Regarding the former, informal OI activities are conducted in order to explore new approaches in the early stage of an innovation value chain, for instance the phase of idea generation, and as regards the latter, formal OI is used to exploit innovation in later stages (Love, Roper, & Bryson, 2011). Secrecy is more effective and nearly the only way to protect innovation in the early stages, providing enough time to modify existing inventions before entering the market (B. Hall et al., 2014). Patents are often preceded by secrecy to uphold the novelty and the patentability (Holgersson & Wallin, 2017). Sequentially, a patent is more suitable during the commercialization phase, even though secrecy can be used throughout the innovation value chain (B. H. Hall & Sena, 2017; Pääällysaho & Kuusisto, 2008).

Secondly, activities in informal OI are flexible and there are no specific rules for firms to follow, resulting in unrestricted knowledge flows. The parties are not constrained by strict and explicit contracts when working informally, implying there is no need for reciprocity and trust. Thus, knowledge easily flows out of the firm, but is also captured from outside. In this manner, employees become the biggest threat of knowledge spillovers because they can decide whether the information should be disclosed. Patents are comparatively ineffective to inhibit the risk of knowledge transfer (Milesi et al., 2017). Then some measures of keeping secrecy will be preferred, such as fragmentation of knowledge and confidentiality agreements (Bos et al., 2015).

The third reason to use secrecy is that firms cooperating and working informally with others can generate new ideas and absorb valuable knowledge and then use secrecy for sustained competitive advantage, for instance by being first to the market and building a superior market

position (Coeurderoy & Durand, 2004; Ponce, 2011). Weak ties are more likely to produce exploratory, disruptive or radical innovations, which have more upside potential (H. Chesbrough & Prencipe, 2008; Christensen, 2013), enabling firms to rely on secrecy to prevent others from entering a race (B. Hall et al., 2014). Keeping the new technology confidential within the firm is thus used to protect valuable and sensitive knowledge against unfair means of competition (Hannah, 2005). Compared with secrecy, patents require a long time for application and the disclosure requirements may not help for obtaining a head start (Zaby, 2010). In summary, the loose and superficial ties in informal OI activities make firms cautious about knowledge disclosure, allow for lead time to enter the market, and accordingly create a context in which secrecy is effective.

Thus we propose the following hypotheses:

H1: The more open formal innovation activities are, the more likely firms are to use patent.

H2: The more open informal innovation activities are, the more likely firms are to use secrecy.

Interaction of formal OI and informal OI activities

Often, firms simultaneously make use of formal and informal OI activities to create and sustain competitive advantages. As mentioned above, firms may have gone through the phase of idea generation and move forward to the R&D, experimentation, manufacturing and commercialization phases while more and more formal OI activities occur. Importantly, on the way to pursue competitive advantage, formal and informal OI activities should show consistency. Interactions of formal and informal OI activities put firms in a network filled with strong ties and weak ties. The degree to which informal OI activities influence the use of secrecy, nevertheless, is likely to be contingent on formal OI activities, such that firms with many formal activities are more likely to

use secrecy to capture value from informal activities than firms with few formal ones. Specifically, weak ties have a greater potential for creating new ideas and strong ties help to realize these ideas (Tiwana, 2008).

Firms create numerous new ideas that are perceived as the intangible raw material of technical exchange in loose ties. They provide diverse and non-redundant resources such as background, capabilities, skills and the like, increasing the likelihood of finding novel ideas and generating new solutions, whereas strong ties deepen this existing knowledge base and facilitate knowledge flows and integration, making explicit innovation strategies and plans and improving the trust in weak ties (Levin & Cross, 2004). In practice, firms are prone to utilize some formal controls to produce substantial and predictable innovation in their core business (Christensen, 2013). Consequently, the best combination is to embed strong ties into a network of weak ties, which creates the most innovative solutions (Rost, 2011). Large innovations are maintained through secrecy in order to gain lead-time advantage and market share (Anton & Yao, 2004; B. Hall et al., 2014). We then propose that formal OI activities increase the probability of generating novel solutions and maintaining secrecy to capture value from informal OI activities. The engagement in informal OI, however, does not necessarily moderate the probability of adopting patent. Once firms engage in formal OI, they utilize strong ties to promote exploitation in some certain ways and will be less affected by diverse new ideas through exploration. As a result, we expect that formal OI will exert a higher probability of using secrecy conditional on informal OI. Then we have the following hypothesis:

H3: The relationship between informal OI activities and secrecy is positively moderated by formal OI activities.

Data and Methods

Data collection

The empirical study is based on the Tianjin Community Innovation Survey conducted in 2014. The Tianjin area is home to over 15 million people. The survey measures were created by the Tianjin Municipal Science and Technology Commission (TMSTC), after referencing the work of the Community Innovation Survey and China Innovation Survey. Questionnaires were sent to official representatives for filing information about innovative activities. Thesurvey includes firm characteristics, innovative behaviors, appropriation mechanisms, and relationships with others. Target respondents are CEOs supplemented by technology and accounting managers. The TMSTC provides a help service to guide respondents. Implemented by the regional government, the overall response rate is 80.72% (of 1250 questionnaires distributed 1009 were completed). The sample is drawn from across the regional economy. The subsample we use here covers 764 manufacturing firms and is drawn from the 28 main manufacturing industries. Podsakoff, MacKenzie, Lee, and Podsakoff (2003) suggest that concerns over common method bias are best addressed in the initial design of a data collection instrument rather than through post hoc statistics; given the use of objective questions we do not expect common method bias to materially affect the results.

Measures

The dependent variable is the firm's appropriation strategy, which is based on the questions about whether the firm has used (1) a *patent* and (2) *secrecy* to appropriate innovation. Both are binary variables, equaling 1 if the firm used the mechanism and 0 otherwise.

The independent variables, *formal OI* and *informal OI*, are calculated from different types of formal and informal activities firms can engage in with external parties to accelerate innovation

(Alexy et al., 2016; Freeman, 1991; Mina et al., 2014; Van Aken & Weggeman, 2000). Formal activities include (1) joint production, (2) obtaining raw materials or parts, (3) tenancy of equipment, (4) consultancy work on management, (5) training employees, (6) joint R&D, (7) venture capital, (8) licensing technology, (9) brand sharing, and (10) technology invested as capital stock. Informal activities include (1) acquiring comments or suggestions for new products, (2) discussing technological frontiers and trends, (3) technical talks and communication, (4) sponsoring or organizing fairs and exhibitions, (5) interpreting industrial norms, regulations and policies, (6) visiting and learning. Each of these activities is coded as a binary variable, with 1 indicating that the firm engages in the activity and 0 otherwise. We then sum these activities so that formal OI measure ranges between 0 and 10 and the informal OI measure ranges between 0 and 6.

We also include various controls for *R&D intensity, firm size, exports and industry*. R&D intensity is measured as the ratio of R&D expenses to sales income. Firm size is a categorical variable based on the number of employees: below 100; 100~300; 300~500; 500~1000; above 1000. Exports is a binary variable, taking value 1 if a firm exports and 0 otherwise. To keep the number of variables at bay we aggregate the 28 industries into 9 industry dummies, to control for differences across industries in appropriation regimes. These dummies include: Food, beverage and tobacco (*S1*, 4.97%); Textiles, wearing apparel, and leather (*S2*, 4.71%); Wood, paper, printing, and publishing (*S3*, 7.59%); Petroleum, chemicals, rubber, and plastic (*S4*, 13.87%); Metals, metallic, and non-metallic mineral (*S5* as reference, 30.37%); Computer, electric, and electronic equipment (*S6*, 17.80%); Machinery and equipment (*S7*, 11.65%); Transport (*S8*, 7.33%); other manufacturing (*S9*, 1.70%).

Methods

We run a bivariate probit model (BVP) alongside two separate probit models. We have two reasons for this approach. Firstly, the BVP model allows for two binary dependent variables that may be correlated. The model takes correlations among error terms into account that will serve to examine complementary or substitute effects, rather than assuming them to be zero or constant. That means firms can simultaneously choose among different appropriation strategies, i.e., patent and secrecy. If the correlation is significant, it turns out to be efficient not to use the separate univariate probit models (Amara et al., 2008; Santamar á, Nieto, & Miles, 2012). Otherwise, BVP is not appropriate and instead a univariate probit model should be adopted (Nieto & Santamar á, 2007). Specifically, the positive and significant correlation among the error terms stands for a complementarity between patent and secrecy whereas a negative correlation stands for substitutability. Secondly, the BVP model is used because we cannot rule out the possibility that there exists endogeneity in this data (Keupp & Al, 2009). There may be a causal loop between the independent variables and dependent variables. The BVP model controls for this source of possible endogeneity by estimating both models simultaneously. Correlation is stated in this study instead of causation as previous studies do (Amara et al., 2008; Zobel et al., 2016). The BVP model is written as follows:

$$\mathrm{Y}=\beta\mathrm{X}+\sum \qquad (1)$$

Where:

$$\mathrm{Y}=\left[y_1, y_2\right]^{-1};\ \ \beta=\begin{bmatrix} b_{1_0}, b_{1_1}, b_{1_2}, ..., b_{1_6} \\ b_{2_0}, b_{2_1}, b_{2_2}, ..., b_{2_6} \end{bmatrix};\ \ \mathrm{X}=\left[1, x_1, x_2, ..., x_6\right]^{-1};\ \ \sum=\left[\varepsilon_1, \varepsilon_2\right]^{-1}$$

with Y being the vector of two binary dependent variables and X the vector of independent variables for two equations. β is the matrix of the coefficients to be estimated and ∑ is the vector

of error terms of these equations.

Results

Table 1 shows descriptive results and correlations. Overall, 61.23% of firms rely on patents and 9.97% of firms use secrecy; 4.74% of firms use both patents and secrecy while 34.56% of firms adopt neither patents nor secrecy. Regarding open innovation, 70.38% of firms engage in formal activities and 66.52% engage in informal activities. Among these, firms with low formal and informal activities account for most of the sample. Still 13.98% of firms do not engage in either set of activities. Most of the bivariate coefficients between variables are low. Only the correlation between formal and informal open innovation is a little high. But we test the variance inflation factors and find these are far lower than 10 (maximal VIF value amounts 1.46), indicating that there is no multicollinearity concern.

Insert Table 1 here

The empirical results are presented in Table 2. Model 1 contains the control variables only. In Model 2, we enter formal OI and informal OI. The former has a positive and significant effect on patent (beta=0.164, $p<0.01$), and the latter has a positive and significant effect (beta=0.201, $p<0.01$) on secrecy. H1 and H2 are thus supported. We then proceed to add the interaction between formal OI and informal OI (*Formal*Informal*) into Model 3. The interaction has a positively significant effect on secrecy (beta=0.089, $p<0.05$), supporting H3. As expected, the interaction does not exert a significant effect on patenting (beta=-0.013, $p>0.1$). As articulated in the methods

section, rho is negative and significant, suggesting that patenting and secrecy are substitutes. However, this effect is only marginally significant in Model 2 and Model 3. We then run two separate probit models, as shown in Model 4 to Model 9 in Table 3. Apart from the relationship between patent and secrecy, in line with the BVP model, the results remain stable and all hypotheses are supported. The main effects of formal and informal OI are shown in Figure 2 and Figure 3.

Insert Tables 2, Table 3, Figure 2 and Figure 3 here

Despite finding support for the hypotheses, we notice some interesting results. As Model 9 illustrates, the data does not support the main effect of informal OI on secrecy after the introduction of the interaction variable (beta=0.029, $p>0.1$). Nevertheless, we apparently can see the main effect of informal OI on secrecy from Figure 4, which shows the change in probability of the use of secrecy associated with one unit change in informal OI with a high and low level of formal OI. The actual outcome of the main effect of informal OI has undoubtedly been distorted because it is obtained by averaging all different levels of formal OI, which may not accurately describe results of any of individual effects (Gravetter & Forzano, 2018). As a result, averaging results produces zero value for the effect of informal OI on secrecy. Additionally, the effect of formal OI on secrecy is significant and negative (beta=-0.226, $p<0.1$).

We can speculate that strong ties in formal OI activities contribute to reciprocity and trust so that secrecy is not encouraged in formal settings. This to some degree also undermines the effect of informal OI, demonstrating a weaker association than the direct role of informal OI on secrecy

in Model 7 (beta=0.195, p<0.01). More importantly, unlike the constant slope in the linear moderating effect, we find that the change of probability of using secrecy varies with formal OI across all levels of informal OI. Yet interpretations of interactions with limited dependent variables are complex. The first and second derivatives of functions with respect to the probit model are nonlinear, and therefore we need to test the secondary moderating effect which is the difference between the total moderating effect arising in the model that includes the interaction and structural moderating effect arising in the model that excludes the interaction (Bowen, 2012; Monteiro, Mol, & Birkinshaw, 2017). The computing value of total moderating effect is 0.0068096 (se=0.0055289, p>0.1), the structural moderating effect is -0.0009926 (se=0.0039857, p>0.1), and the secondary moderating effect is 0.0078023 (se=0.0022354, p<0.01). Hence, the coefficient is extremely small, though the secondary moderating effect is positive and significant at 1% level, supporting H3, as shown in Figure 5. We can confirm that a high level of formal OI increases the effect of informal OI on secrecy for firms with high level of informal OI activities; however, it has the opposite effect for firms with low levels of informal OI activities.

Insert Figure 4 and Figure 5 here

Among the control variables, R&D intensity is positive and significant to use of patenting in all models. Firm size has a positive and significant effect on patenting and secrecy. However, the results also suggest that large firms value secrecy more than patent. This may be because that the more employees know key technologies, the more likely the firm keeps them secret (Bos et al., 2015). In addition, large firms can make use of marketing power to create a lead time advantage so

that use of secrecy makes more sense for them (Neuhäusler, 2012). As a result for a large number of SMEs[i] in our sample, informal mechanisms such as secrecy are favored over patenting (Agostini, Nosella, & Soranzo, 2015). Exporting has a significantly positive effect on secrecy, highlighting that exporting firms are prone to capture value through secrecy (Neuhäusler, 2012).

Robustness check

The consistency of the results across the different estimations suggests a high robustness, especially in strict BVP model. Still, we use alternative proxies for the independent and dependent variables to assess the robustness. With regard to the dependent variable, 'patent personnel' is introduced, assuming that firms probably have patents if they invest specialized personnel into patent management. For the independent variable, we replace some formal and informal activities to change elements of portfolios, such as consultancy work on technology. Finally, we introduce two control variables which affect patenting and secrecy, i.e. product innovation and process innovation (Arora et al., 2016). Then we run all the regressions again and the results are basically consistent and supportive, although there are minor changes in coefficients. Results are available upon request.

Discussions

Theoretical implications

This paper addresses the question how firms appropriate value when using formal and informal open innovation activities. The contribution of this study is threefold. The first contribution is to the increasing body of knowledge on the relationship between openness and appropriation, especially the classification between formal and informal open innovation. We make a

contribution to the empirical literature, which lacks alternative expressions of openness. We investigate conditions that different models of openness combine as complements and provide a new theoretical angle on this (Dahlander & Gann, 2010).

The second contribution is the notion of strong and weak ties in the area of innovation and appropriation, which helps to disentangle different types of relations. Rather than using the RBV which focuses on resources (Dyer & Singh, 1998), we interpret formal and informal OI activities as strong ties and weak ties, confirming and extending Monteiro et al. (2017)'s viewpoint that the relational view enables firms to develop capabilities to profit from open innovation. Use of strong ties and weak ties represents a relational capability, which requires different appropriation strategies to protect innovation. These results seem to answer the call of several authors, and are consistent with some studies but not others.

In line with Mina et al. (2014) who point out that patenting is positively associated with formal rather than informal open innovation practices, our findings add empirical evidence indicating that firms use patenting to appropriate value from formal OI activities. With regard to informal OI, we find that informal activities consisting of a large number of weak ties have an influence on secrecy, which runs counter to Rost (2011), who argues that weak ties alone have no value. But Rost (2011) only used patent data. Our study also adds to the understanding of how to combine strong ties and weak ties to create innovations. The interaction effect may provide new insights in the literature on networks and governance where this has not been fully explained (Michelfelder & Kratzer, 2013). The results show that the probability of keeping new technology secret in an informal OI environment will grow slightly when firms engage in more formal open innovation.

The effect of informal OI on secrecy is amplified by implementing more formal OI activities. Increasing implementation of formal OI activities implies that the firm has already moved from an early stage to the next phase in the innovation value chain. One explanation would be knowledge flows. It demonstrates that strong ties help realize the new ideas and knowledge from weak ties as a complement and auxiliary, whose combination eventually results in the highest innovation capacity (Capaldo, 2007; Levin & Cross, 2004; Rost, 2011; Tiwana, 2008). This may confirm that secrecy is seen as a means of capturing highly valuable knowledge, not merely a protection mechanism, which has been mentioned in some research (B. Hall et al., 2014; James, Leiblein, & Lu, 2013). It also responds to Sofka et al. (2018) who conclude that the fact that secrecy is attached more importance depends on how visible the focal firm is. With increasing formal OI, a patent that is legally obliged to disclose information makes the focal firm more visible and riskier, reinforcing the importance of secrecy. With our rationale around moderate and large innovations, the empirical findings simultaneously echo best to previous literature based on mathematical modeling (Anton & Yao, 2004; B. Hall et al., 2014; Schneider, 2008; Zaby, 2010), conveying little patent and big secrets.

The third contribution is that we extend the application of secondary moderating effect in the probit model, whose concept has been analyzed in Tobit and logit models (Bowen, 2012; Monteiro et al., 2017). This reminds scholars to look at moderating effects in limited dependent variables.

Practical implications

This study provides suggestions on how to protect knowledge when firms are situated in an open innovation environment. For managers who make appropriation strategies, patents should be given ample investments when firms manage relationships using various formal activities. On the other

hand, firms can take steps to maintain their innovations secret when they take part in many informal open innovation activities. In practice, firms embrace open innovation formally and informally, and this interaction has a positive influence on generating innovation outcomes and creating competitive advantage. If firms have had mature thoughts on innovation from formal open innovation activities, they do not necessarily explore new ideas from informal activities because it will not increase the probability of patenting. If firms who devote attention to informal open innovation activities begin to pay more attention to formal activities, they can utilize intense relationships to realize innovation from some new ideas, and eventually keep the valuable knowledge secret.

Limitations and future work

There are some limitations and underexplored topics. Firstly, we ran a robustness check by adding and changing different activities to the formal and informal category. It can be measured in a wide spectrum not merely by changing other items of formal and informal open innovation. To verify the logic and rationale behind our arguments, more evidence is required in future studies. Secondly, we examine relations rather than being able to make a causal inference. Thirdly, notwithstanding highly valuable innovations is one of the explanations, the novelty of knowledge embedded in secrets should be further explored and calls for more empirical evidence. Moreover, in some circumstances knowledge can be protected modularly. Firms can collaborate with partners to solve a problem, only a small part of which is given to partners and then returned to constitute the whole solution, but the key technologies will be kept secret (Henkel, Baldwin, & Shih, 2013; Keupp, Beckenbauer, & Gassmann, 2009). We predict that if a patent is a complement or substitute to secrecy, or even has no interplay is contingent on some factors, which need to be

solved in future work.

Conclusions

To conclude, this paper analyzes how firms utilize their strong ties and weak ties in formal and informal OI activities to appropriate value. The major finding is that patenting plays an important role in appropriating value from formal OI activities, and that secrecy performs well in appropriating value from informal OI activities and combinations with formal ones. Hopefully this paper provides a new perspective and encourages scholars to integrate and explore more in the area of open innovation, appropriation and relationships.

References

Agostini, L., & Nosella, A. (2017). A dual knowledge perspective on the determinants of SME patenting: Results of an empirical investigation. *Management Decision, 55*(6), 1226-1247.

Agostini, L., Nosella, A., & Soranzo, B. (2015). The impact of formal and informal appropriability regimes on SME profitability in medium high-tech industries. *Technology Analysis & Strategic Management, 27*(4), 405-419.

Alexy, O., Bascavusoglu-Moreau, E., & Salter, A. J. (2016). Toward an aspiration-level theory of open innovation. *Industrial and corporate change, 25*(2), 289-306.

Allen, J., James, A. D., & Gamlen, P. (2007). Formal versus informal knowledge networks in R&D: a case study using social network analysis. *R&d Management, 37*(3), 179-196.

Almirall, E., & Casadesus-Masanell, R. (2010). Open versus closed innovation: A model of discovery and divergence. *Academy of management review, 35*(1), 27-47.

Amara, N., Landry, R., & Traoré, N. (2008). Managing the protection of innovations in knowledge-intensive business services. *Research Policy, 37*(9), 1530-1547.

Amit, R., & Schoemaker, P. J. (1993). Strategic assets and organizational rent. *Strategic management journal, 14*(1), 33-46.

Anton, J. J., & Yao, D. A. (2004). Little patents and big secrets: managing intellectual property. *RAND Journal of Economics*, 1-22.

Arora, A., Athreye, S., & Huang, C. (2016). The paradox of openness revisited: Collaborative innovation and patenting by UK innovators. *Research Policy, 45*(7), 1352-1361.

Arundel, A. (2001). The relative effectiveness of patents and secrecy for appropriation. *Research Policy, 30*(4), 611-624.

Bai, X., Sheng, S., & Li, J. J. (2016). Contract governance and buyer–supplier conflict: The moderating role of institutions. *Journal of Operations Management, 41*, 12-24.

Bos, B., Broekhuizen, T. L. J., & Faria, P. D. (2015). A dynamic view on secrecy management. *Journal of*

Business Research, 68(12), 2619-2627.

Bowen, H. P. (2012). Testing moderating hypotheses in limited dependent variable and other nonlinear models: Secondary versus total interactions. *Journal of Management, 38*(3), 860-889.

Capaldo, A. (2007). Network structure and innovation: The leveraging of a dual network as a distinctive relational capability. *Strategic management journal, 28*(6), 585-608.

Chandra, Y., Styles, C., & Wilkinson, I. (2009). The recognition of first time international entrepreneurial opportunities: Evidence from firms in knowledge-based industries. *International Marketing Review, 26*(1), 30-61.

Chesbrough, H., & Prencipe, A. (2008). Networks of innovation and modularity: a dynamic perspective. *International Journal of Technology Management, 42*(4), 414-425.

Chesbrough, H. W. (2006). *Open innovation: The new imperative for creating and profiting from technology*: Harvard Business Press.

Christensen, C. (2013). *The innovator's dilemma: when new technologies cause great firms to fail*: Harvard Business Review Press.

Coeurderoy, R., & Durand, R. (2004). Leveraging the advantage of early entry: proprietary technologies versus cost leadership. *Journal of Business Research, 57*(6), 583-590.

Cosh, A., & Zhang, J. J. (2011). Open innovation choices–What is British Enterprise doing?

Dahlander, L., & Gann, D. M. (2010). How open is innovation? *Research Policy, 39*(6), 699-709.

Dekker, H. C. (2004). Control of inter-organizational relationships: evidence on appropriation concerns and coordination requirements. *Accounting, Organizations and Society, 29*(1), 27-49.

Dittrich, K., & Duysters, G. (2007). Networking as a means to strategy change: the case of open innovation in mobile telephony. *Journal of Product Innovation Management, 24*(6), 510-521.

Du, J., Leten, B., & Vanhaverbeke, W. (2014). Managing open innovation projects with science-based and market-based partners. *Research Policy, 43*(5), 828-840.

Dyer, J. H., & Singh, H. (1998). The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of management review, 23*(4), 660-679.

Freeman, C. (1991). Networks of innovators: a synthesis of research issues. *Research Policy, 20*(5), 499-514.

Gilsing, V., & Nooteboom, B. (2005). Density and strength of ties in innovation networks: an analysis of multimedia and biotechnology. *European Management Review, 2*(3), 179-197.

Graham, S. J. (2004). Hiding in the Patent's Shadow: Firms' Uses of Secrecy to Capture Value from New Discoveries.

Granovetter, M. S. (1973). The Strength of Weak Ties. *American journal of sociology, 78*(6), 1360-1380.

Gravetter, F. J., & Forzano, L.-A. B. (2018). *Research methods for the behavioral sciences*: Cengage Learning.

Hagedoorn, J., & Zobel, A.-K. (2015). The role of contracts and intellectual property rights in open innovation. *Technology Analysis & Strategic Management, 27*(9), 1050-1067.

Hall, B., Helmers, C., Rogers, M., & Sena, V. (2014). The choice between formal and informal intellectual property: a review. *Journal of Economic Literature, 52*(2), 375-423.

Hall, B. H., & Sena, V. (2017). Appropriability mechanisms, innovation, and productivity: evidence from the UK. *Economics of Innovation and New Technology, 26*(1-2), 42-62.

Hannah, D. R. (2005). Should I keep a secret? The effects of trade secret protection procedures on employees' obligations to protect trade secrets. *Organization science, 16*(1), 71-84.

Heide, J. B., Wathne, K. H., & Rokkan, A. I. (2007). Interfirm monitoring, social contracts, and

relationship outcomes. *Journal of marketing Research, 44*(3), 425-433.

Henkel, J., Baldwin, C. Y., & Shih, W. (2013). IP modularity: Profiting from innovation by aligning product architecture with intellectual property. *California management review, 55*(4), 65-82.

Henttonen, K., Hurmelinna‐Laukkanen, P., & Ritala, P. (2016). Managing the appropriability of R&D collaboration. *R&d Management, 46*(1), 145-158.

Holgersson, M., Granstrand, O., & Bogers, M. (2018). The evolution of intellectual property strategy in innovation ecosystems: uncovering complementary and substitute appropriability regimes. *Long Range Planning, 51*(2), 303-319.

Holgersson, M., & Wallin, M. W. (2017). The patent management trichotomy: Patenting, publishing, and secrecy. *Management Decision, 55*(6), 1087-1099.

Hussinger, K. (2006). Is silence golden? Patents versus secrecy at the firm level. *Economics of Innovation and New Technology, 15*(8), 735-752.

James, S. D., Leiblein, M. J., & Lu, S. (2013). How Firms Capture Value From Their Innovations. *Journal of Management, 39*(5), 1123-1155. doi:10.1177/0149206313488211

Jensen, P. H., & Webster, E. (2009). Knowledge management: does capture impede creation? *Industrial and corporate change, 18*(4), 701-727.

Kale, P., Singh, H., & Perlmutter, H. (2000). Learning and protection of proprietary assets in strategic alliances: Building relational capital. *Strategic management journal*, 217-237.

Keupp, M. M., & Al, E. (2009). Economic Focus Study on SMEs and Intellectual Property in Switzerland. *Swiss Federal Institute of Intellectual Property*.

Keupp, M. M., Beckenbauer, A., & Gassmann, O. (2009). How managers protect intellectual property rights in China using de facto strategies. *R&d Management, 39*(2), 211-224.

Kontinen, T., & Ojala, A. (2011). Network ties in the international opportunity recognition of family SMEs. *International Business Review, 20*(4), 440-453.

Laursen, K., & Salter, A. (2006). Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. *Strategic management journal, 27*(2), 131-150.

Lechner, C., & Dowling, M. (2003). Firm networks: external relationships as sources for the growth and competitiveness of entrepreneurial firms. *Entrepreneurship & regional development, 15*(1), 1-26.

Levin, D. Z., & Cross, R. (2004). The strength of weak ties you can trust: The mediating role of trust in effective knowledge transfer. *Management science, 50*(11), 1477-1490.

Lorenzoni, G., & Lipparini, A. (1999). The leveraging of interfirm relationships as a distinctive organizational capability: a longitudinal study. *Strategic management journal, 20*(4), 317-338.

Love, J. H., Roper, S., & Bryson, J. R. (2011). Openness, knowledge, innovation and growth in UK business services. *Research Policy, 40*(10), 1438-1452.

McFadyen, M. A., Semadeni, M., & Cannella Jr, A. A. (2009). Value of strong ties to disconnected others: Examining knowledge creation in biomedicine. *Organization science, 20*(3), 552-564.

Michelfelder, I., & Kratzer, J. (2013). Why and how combining strong and weak ties within a single interorganizational R&D collaboration outperforms other collaboration structures. *Journal of Product Innovation Management, 30*(6), 1159-1177.

Milesi, D., Verre, V., & Petelski, N. (2017). Science-industry R & D cooperation effects on firm's appropriation strategy: the case of Argentine biopharma. *European Journal of Innovation Management, 20*(3), 372-391.

Mina, A., Bascavusoglu-Moreau, E., & Hughes, A. (2014). Open service innovation and the firm's

search for external knowledge. *Research Policy, 43*(5), 853-866.

Monteiro, F., Mol, M., & Birkinshaw, J. (2017). Ready to be open? Explaining the firm level barriers to benefiting from openness to external knowledge. *Long Range Planning, 50*(2), 282-295.

Neuhäusler, P. (2012). The use of patents and informal appropriation mechanisms—Differences between sectors and among companies. *Technovation, 32*(12), 681-693.

Nieto, M. J., & Santamaría, L. (2007). The importance of diverse collaborative networks for the novelty of product innovation. *Technovation, 27*(6-7), 367-377.

Norman, P. M. (2002). Protecting knowledge in strategic alliances: Resource and relational characteristics. *The Journal of High Technology Management Research, 13*(2), 177-202.

Päällysaho, S., & Kuusisto, J. (2008). Intellectual property protection in service sector. *International Chamber of Commerce, Paris*.

Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of applied psychology, 88*(5), 879.

Ponce, C. J. (2011). Knowledge disclosure as intellectual property rights protection. *Journal of Economic Behavior & Organization, 80*(3), 418-434.

Rost, K. (2011). The strength of strong ties in the creation of innovation. *Research Policy, 40*(4), 588-604.

Santamaría, L., Nieto, M. J., & Miles, I. (2012). Service innovation in manufacturing firms: Evidence from Spain. *Technovation, 32*(2), 144-155.

Schneider, C. (2008). Fences and competition in patent races. *International Journal of Industrial Organization, 26*(6), 1348-1364.

Slowinski, G., Hummel, E., & Kumpf, R. J. (2006). Protecting Know-How And Trade Secrets In Collaborative R&D Relationships. *Research Technology Management, 49*(4), 30-38.

Söderqvist, A., & Kamala Chetty, S. (2013). Strength of ties involved in international new ventures. *European Business Review, 25*(6), 536-552.

Sofka, W., de Faria, P., & Shehu, E. (2018). Protecting knowledge: How legal requirements to reveal information affect the importance of secrecy. *Research Policy, 47*(3), 558-572.

Somaya, D. (2012). Patent strategy and management: An integrative review and research agenda. *Journal of Management, 38*(4), 1084-1114.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy, 15*(6), 285-305.

Tiwana, A. (2008). Do bridging ties complement strong ties? An empirical examination of alliance ambidexterity. *Strategic management journal, 29*(3), 251-272.

Van Aken, J. E., & Weggeman, M. P. (2000). Managing learning in informal innovation networks: overcoming the Daphne‐dilemma. *R&d Management, 30*(2), 139-150.

Van de Vrande, V., De Jong, J. P., Vanhaverbeke, W., & De Rochemont, M. (2009). Open innovation in SMEs: Trends, motives and management challenges. *Technovation, 29*(6-7), 423-437.

Wang, C.-C., Sung, H.-Y., Chen, D.-Z., & Huang, M.-H. (2017). Strong ties and weak ties of the knowledge spillover network in the semiconductor industry. *Technological Forecasting and Social Change, 118*, 114-127.

West, J. (2006). Does appropriability enable or retard open innovation. *Open Innovation: Researching a New Paradigm*, 109-133.

Zaby, A. K. (2010). Losing the lead: the patenting decision in the light of the disclosure requirement.

Economics of Innovation and New Technology, 19(2), 147-164.

Zobel, A. K., Lokshin, B., & Hagedoorn, J. (2016). Formal and informal appropriation mechanisms: The role of openness and innovativeness. *Technovation, 59*.

Table 1. Descriptive statistics and correlations

		Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Patent	0.61	0.48														
	Tenure	12	8														
		2	8														
2	Secrecy	0.13	0.34	-0.08													
		0	0	1*													
		0	0	*													
3	Formal	1.49	1.52	0.235**	0.044*												
	OI	2	5	*													
4	Informal	1.17	1.14	0.143**	0.127**	0.523**											
	OI	7	4	*	*	*											

5	R & D int en sit y	2. 2 5 0 4	1. 2 8 0 1	0.0 99 **	0.0 15	0.0 45	0.1 40 ** *				
6	Fir m siz e	3. 8 4 1	1. 0 5 9	0.0 67 *	0.1 84 ** *	0.1 39 ** *	0.1 37 ** *	0.1 63 ** *			
7	Ex po rt	0. 4 1	0. 4 9 1 2	0.0 93 **	0.1 88 ** *	0.0 73 *	-0. 01 8	0.0 48	0.2 28 ** *		
8	S1	0. 0 5 0	0. 2 1 8	0.0 58	-0. 05 5	0.0 35	0.0 08	0.0 17	0.0 84 **	-0. 07 9* *	
9	S2	0. 0 4	0. 2 1	0.0 00	0.0 30	-0. 05 1	-0. 01 3	0.0 58	0.1 16 **	0.0 62	-0. 05 1

		7	2						*									
1		0.	0.				-0.											
				0.0	-0.	-0.			-0.	-0.	-0.	-0.						
0		0	2				10	0.0										
	S3			82	05	04			04	00	06	06						
		7	6				2*	04										
				**	4	0			0	6	6*	4*						
		6	5				**											
1		0.	0.								-0.	-0.	-0.					
				-0.		-0.	0.0		-0.	-0.								
1		1	3		0.0			0.0			09	08	11					
	S4			01		00	88		05	03								
		3	4		52			23			2*	9*	5*					
				0		6	**		5	8								
		9	6								*	*	**					
1		0.	0.								-0.	-0.	-0.	-0.				
				-0.				0.0	0.0	0.0								
2		1	3		0.0	0.0	0.0				10	10	13	18				
	S6			02				93	63	90								
		7	8		00	18	21				6*	3*	3*	7*				
				1				**	*	**								
		8	3								**	**	**	**				
1		0.	0.		0.1						-0.	-0.	-0.	-0.	-0.			
				-0.		0.0		-0.	0.0	0.0								
3		1	3		08		0.0				08	08	10	14	16			
	S7			01		65		03	71	84								
		1	2		**		53				3*	1*	4*	6*	9*			
				7		*		9	*	**								
		6	1		*						*	*	**	**	**			
1		0.	0.			-0.	-0.						-0.	-0.	-0.	-0.		
				-0.				-0.		-0.	-0.	-0.						
4		0	2		0.0	08	08		0.0				08	11	13	10		
	S8			02				02		00	06	06						
		7	6		06	1*	2*		25				1*	3*	1*	2*		
				6				3		9	4*	3*						
		3	1			*	*						*	**	**	**		
1	S9	0.	0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0.	-0	

5	0	1	03	04	04	05	05	06	06	03	02	03	05	06	04	.0
	1	2	1	5	4	0	2	0	8*	0	9	8	3	1*	8	3
	7	9														7

* Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level.

Table 2. Bivariate Probit Regression Results

Variable	Model1		Model2		Model3	
	Patent	Secrecy	Patent	Secrecy	Patent	Secrecy
	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)
R&D	0.133***	0.013	0.119**	-0.002	0.112**	0.017
intensity	(0.048)	(0.064)	(0.049)	(0.067)	(0.050)	(0.068)
Firm size	0.111*	0.217***	0.115*	0.207***	0.112*	0.218***
	(0.057)	(0.072)	(0.061)	(0.074)	(0.061)	(0.075)
Export	0.084	0.405**	0.009	0.434**	0.018	0.451**
	(0.123)	(0.175)	(0.129)	(0.182)	(0.129)	(0.184)
S1	-0.032	-0.268	0.058	-0.310	0.080	-0.353
	(0.279)	(0.503)	(0.294)	(0.535)	(0.294)	(0.533)
S2	-0.514*	0.324	-0.411	0.339	-0.407	0.280
	(0.282)	(0.363)	(0.285)	(0.365)	(0.286)	(0.367)
S3	0.314	-0.332	0.504*	-0.257	0.537*	-0.435
	(0.272)	(0.484)	(0.291)	(0.487)	(0.294)	(0.518)
S4	-0.002	0.322	0.011	0.239	0.009	0.171
	(0.187)	(0.262)	(0.195)	(0.274)	(0.197)	(0.277)
S6	-0.303*	0.137	-0.255	0.122	-0.245	0.051
	(0.170)	(0.254)	(0.174)	(0.258)	(0.175)	(0.263)
S7	-0.056	0.361	-0.111	0.299	-0.117	0.311

	(0.200)	(0.265)	(0.210)	(0.275)	(0.210)	(0.278)
S8	-0.313	0.193	-0.293	0.252	-0.294	0.260
	(0.248)	(0.346)	(0.260)	(0.353)	(0.259)	(0.352)
S9	-0.482	-4.489	-0.366	-4.306	-0.359	-4.363
	(0.434)	(1292.367)	(0.432)	(1620.530)	(0.432)	(1479.649)
Formal OI			0.164***		0.169**	-0.239**
			(0.044)		(0.078)	(0.120)
Informal OI				0.201***	0.079	0.027
				(0.069)	(0.091)	(0.120)
Formal*Informal					-0.013	0.089**
					(0.033)	(0.040)
Constant	-0.274	-2.626***	-0.494**	-2.819***	-0.542**	-2.563***
	(0.237)	(0.336)	(0.249)	(0.356)	(0.260)	(0.371)
Wald test of full model	50.61***		73.13***		78.67***	
LR~χ^2:ρ=0	1.83499		2.90025*		3.14858*	
Log pseudo-likelihood	-457.42414***		-427.60216***		-424.62014***	
Rho	-0.147		-0.194*		-0.204*	
Observations	514		491		491	

Notes: rho is correlation coefficient of equation patent with secrecy.

* Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level.

Table 3. Probit Regression Results

Variables	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
	Patent	Secrecy	Patent	Secrecy	Patent	Secrecy
	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)	Coeff.(Std. error)
R&D	0.139***	0.005	0.119**	-0.001	0.112**	0.016
intensity	(0.047)	(0.064)	(0.049)	(0.068)	(0.050)	(0.069)
Firm size	0.099*	0.204***	0.116*	0.202***	0.112*	0.211***
	(0.056)	(0.072)	(0.061)	(0.074)	(0.061)	(0.076)
Export	0.101	0.439**	0.011	0.444**	0.021	0.457**
	(0.121)	(0.173)	(0.129)	(0.181)	(0.129)	(0.184)
S1	-0.047	-0.274	0.058	-0.253	0.079	-0.303
	(0.278)	(0.492)	(0.293)	(0.523)	(0.293)	(0.522)
S2	-0.379	0.273	-0.402	0.336	-0.399	0.279
	(0.268)	(0.360)	(0.285)	(0.365)	(0.286)	(0.366)
S3	0.321	-0.372	0.499*	-0.246	0.531*	-0.413
	(0.267)	(0.475)	(0.289)	(0.479)	(0.292)	(0.507)
S4	0.002	0.251	0.022	0.198	0.020	0.137
	(0.186)	(0.259)	(0.195)	(0.273)	(0.198)	(0.277)
S6	-0.299*	0.075	-0.249	0.101	-0.240	0.025
	(0.169)	(0.250)	(0.174)	(0.258)	(0.175)	(0.263)
S7	-0.074	0.299	-0.110	0.284	-0.115	0.289

	(0.199)	(0.261)	(0.210)	(0.275)	(0.210)	(0.278)
S8	-0.328	0.133	-0.288	0.241	-0.288	0.236
	(0.248)	(0.342)	(0.260)	(0.352)	(0.260)	(0.351)
S9	-0.393	0.000	-0.361	0.000	-0.356	0.000
	(0.413)	(.)	(0.432)	(.)	(0.432)	(.)
Formal OI			0.167***		0.171**	-0.226*
			(0.045)		(0.078)	(0.119)
Informal OI				0.195***	0.081	0.029
				(0.069)	(0.091)	(0.119)
Formal*Informal					-0.014	0.085**
					(0.033)	(0.039)
Constant	-0.228	-2.514***	-0.504**	2.785***	-0.552**	-2.531***
	(0.234)	(0.329)	(0.249)	(0.356)	(0.260)	(0.371)
Pseudo R2	0.0342	0.0891	0.0641	0.1211	0.0655	0.1371
LR chi2	23.15**	27.51***	40.76***	36.30***	41.65***	41.07***
Log pseudo-likelihood	-326.54787	-140.67449	-297.60661	-131.77755	-297.16258	-129.29542
Observations	528	509	491	486	491	485

* Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level.

Figure 2. Main effect of formal OI on patent.

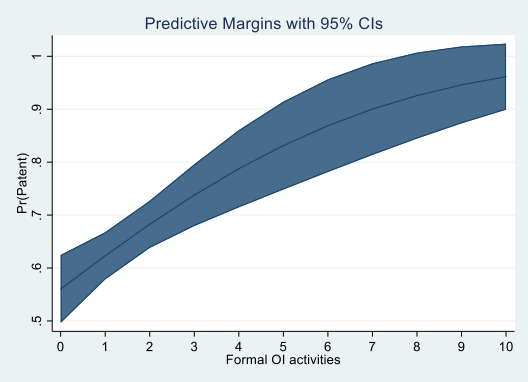


Figure 3. Main effect of informal OI on secrecy.

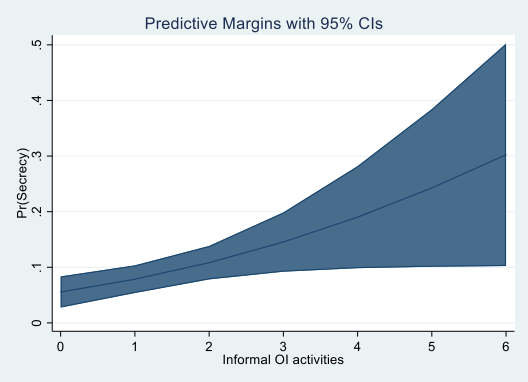


Figure 4. Moderating effect of formal OI.

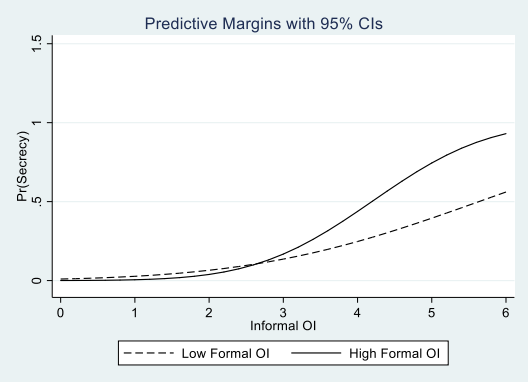
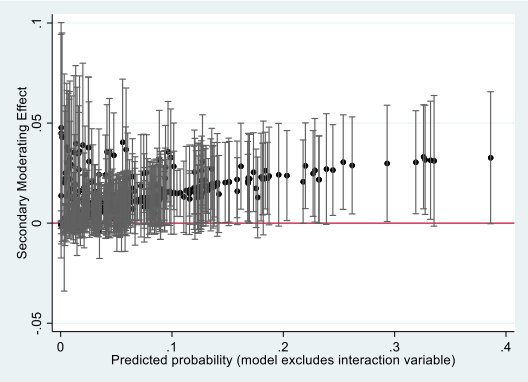


Figure 5. Secondary moderating effect for probit analysis of interaction between formal OI and informal OI.



[i] SMEs and micro-firms are firms having less than 1000 employees and less than 400 million yuan turnover in China, which has a similar standard in OECD that defines them as firms having less than 50M€ turnover. We compared them in order to show the generalisability and applicability of their results.