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Open innovation: a new classification and its impact on firm performance in innovative SMEs

Joon Mo Ahn, Tim Minshall, Letizia Mortara

Centre for Technology Management, Institute for Manufacturing, Department of Engineering, the University of Cambridge, Cambridge, UK

{ja494, thwm100, lm367}@cam.ac.uk

Abstract. This paper attempts to deepen understanding of the relationship between open innovation (OI) and firm performance in small and medium-sized enterprises (SMEs). Based on survey data from 306 Korean innovative SMEs, the results of this study show that: (1) broad and intensive engagement in OI and cooperation with external partners are positively associated with firm performance; (2) technology and market-oriented OI modes (Joint R&D, user involvement and open sourcing), involving relatively low level of changes, can positively contribute to performance enhancement; and (3) innovative SMEs benefit from working with non-competing partners, such as customers, consultancy/intermediaries and public research institutes. This work has broadened the evidence available on SMEs' OI adoption and has proposed a new way to study OI adoption and implementation.

Keywords. Open innovation, Innovation collaboration, Small and medium-sized enterprises, and Performance

1. Introduction

Open innovation (OI) is a distributed innovation process based on purposively managed knowledge flows across organisational boundaries (Chesbrough and Bogers, 2014), and it has become a widely known business strategy in many industries (Dahlander and Gann, 2010; Gassmann et al., 2010; Huizingh, 2011; Mortara and Minshall, 2011). The majority of studies have focused on studying OI in multinational corporations (MNCs), but our knowledge of OI in small and medium-sized enterprises (SMEs) is still fragmented (Lee et al., 2010; Schroll and Mild, 2012; Van de Vrande et al., 2009). Although recent studies have investigated SMEs in many contexts, due to the complexity and breadth of the concept of OI, encompassing various innovation activities, there have been substantial challenges in the measurement of OI (Podmetina et al., 2014; Schroll and Mild, 2012). This made it difficult for researchers to cover the full OI spectrum. Until now, research focus has been on OI proxies (rather than OI itself), such as information search breadth and depth (e.g., Laursen and Salter, 2006), technology sourcing and scouting (e.g., Parida et al., 2012) or inter-organisational networks (e.g., Lasagni, 2012; Zeng et al., 2010). These proxies are certainly important indicators of OI activities, but they represent a rather focused (and potentially limited) interpretation of OI adoption, hindering a complete understanding of OI approaches. In this regard, this paper attempted to investigate various OI modes in a single study, which is novel in the context of OI adoption in SMEs.

Theoretically, OI can be a good approach enhancing SMEs' performance. SMEs' organisational characteristics, such as flexibility (Rothwell and Dodgson, 1994) or a simple hierarchy (Teece, 1996), may represent their advantages in the implementation of OI. By opening their boundaries, SMEs can access the necessary complementary assets to deal with their inadequate research and development (R&D) capacity or

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involve end-users in their innovation process to develop marketing related capability (Lee et al., 2010; Teece et al., 1997). However, given their resource constraints, it might not be easy for SMEs to employ many OI modes at the same time. Further, owing to the heterogeneity of OI, decisions relating to its adoption might be difficult for SMEs. As each OI mode differs from others in terms of knowledge flow direction and types of change being brought in, this diverse nature of OI will raise issues of choice for SMEs who might end up with an incomplete OI approach. Yet, the literature has not fully shed light on how OI affects SMEs' performance. Along with other researchers in the OI domain, we would like to understand whether a broad or deep (intensive) OI adoption may enhance firm performance, but unsatisfied with the approaches taken to date relying on a limited number of proxies, we propose a concurrent method by interpreting OI adoption as a process involving changes and by expanding Laursen and Salter's (2006) breadth and depth concept to OI modes.

To address the research gap, survey data from 306 innovation-oriented Korean manufacturing SMEs were collected and analysed using an ordered-Probit model. Recognising the heterogeneity of SMEs, emphasis has been placed on innovation-oriented firms due to their strong internal R&D and clear focus on innovation. As, in general, SMEs are not formally engaged in R&D (Brunswicker and Vanhaverbeke, 2014), this focus on innovative SME may lead to a clear linkage between OI and firm performance.

The remainder of this paper comprises four sections. We first introduce the theoretical background and develop hypotheses about the relationship between OI and firm performance. Then, in section 3, we describe the data and method, and present the results in section 4. Section 5 covers discussion and the paper concludes with implications and possible research limitations.

2. Theoretical background and hypotheses

2.1. Open innovation

Figure 1 shows the traditional "closed" approach to innovation in firms focusing on core markets which use primarily internal resources to develop products (Mortara et al., 2011). Simplistically, a focal company has internal R&D units, each of which is pursuing innovation targeting an "existing" or "identified" key market area.

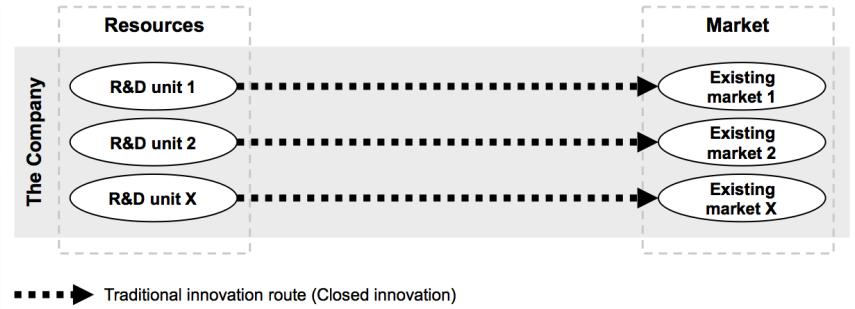

Fig. 1. Closed innovation (Mortara et al., 2011, p 294)

In contrast, OI is "the purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough et al., 2006, p.1). This means that with OI, all knowledge

(internal knowledge as well as external knowledge) can find its way to commercialisation for existing or new markets by crossing a firm's boundary.

In-bound OI refers to innovation activities focusing on acquiring external knowledge (Spithoven et al., 2011); 'in-sourcing' (or 'licensing-in'), 'joint R&D', 'Merger and Acquisition (M&A)/strategic alliance' and 'user involvement' fall into this category. As illustrated in Figure 2, the firm can achieve new resource combinations by using competences and resources of external partners, which will focus on existing or new markets (Mortara et al., 2011). For example, firms which face the challenge of maintaining a high pace of innovation can use external resources to fuel existing pipelines with innovative products (curved line A in Figure 2), or two organisations can contribute to the formation of a new market (curved line B in Figure 2) (Mortara et al., 2011)

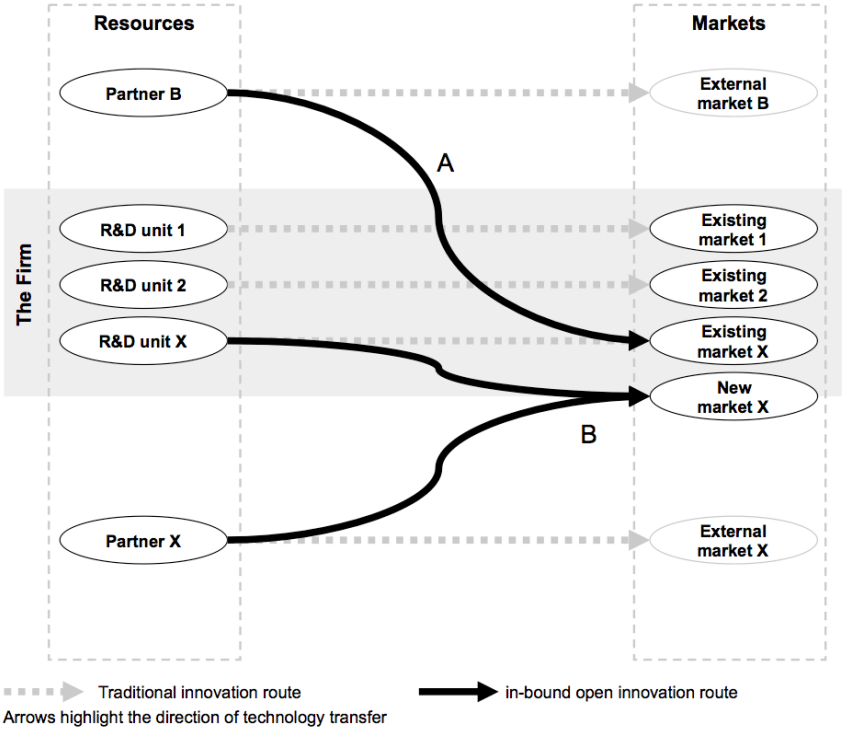

Fig. 2. In-bound open innovation (Mortara et al., 2011, p. 296)

Out-bound OI relates to the exploitation of knowledge in a variety of ways. By revealing internal knowledge via out-bound OI, innovation finds its way towards commercialisation. 'Licensing-out', 'spin-off' and 'open-sourcing' are examples. As illustrated in Figure 3, internal resources can lead to the targeting of a new market. For example, licensing-out (curved line D in Figure 3) enables an external partner to use the firm's internal knowledge and create a new market (Mortara et al., 2011).

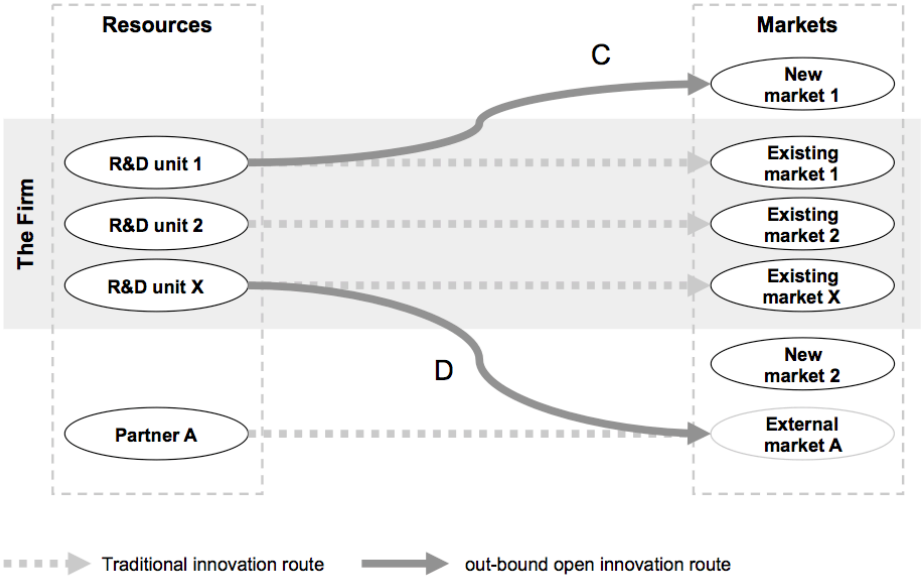

Fig. 3. Out-bound open innovation (Mortara et al., 2011, p. 295)

Although Enkel et al. (2009) suggested a 'coupled process' combining both in- and out-bound knowledge flows and Dahlander and Gann (2010) and Chesbrough and Bogers (2014) extended the coupled model definition, for the purpose of this analysis we concentrate on the main in- and out-bound knowledge flows (e.g., Chesbrough and Brunswicker, 2013), according to the flow dominance. In fact, from the viewpoint of a single partner (e.g. the focal firm), when knowledge is exchanged simultaneously in two directions (e.g., when a firm is doing a strategic alliance with another firm), it could be represented by two independent knowledge flows (i.e., two arrows) which happen concurrently. In this situation, however, for the focal firm, even though there is an out-bound flow of knowledge for the benefit of another firm, the main purpose would be the acquisition of the knowledge necessary to create new value for its own purposes. Thus, we assume that there is always a dominant direction in the knowledge flow from the perspective of the focal firm. For instance, in Figure 2, the curved line B can be an example of coupled OI process. From the firm's perspective it is in-bound OI, but it is out-bound OI when viewed from Partner X's perspective.

2.2. Open innovation in SMEs

Despite the relative scarcity of studies covering OI in SMEs (Ahn et al., 2013; Brunswicker and van de Vrande, 2014; Lee et al., 2010; Parida et al., 2012; Spithoven et al., 2013; Van de Vrande et al., 2009), a few notable ones have shown various motives for and barriers to OI adoption in SMEs. Amongst the motives, an insufficient marketing capacity has been identified as the main driver of OI adoption in SMEs (Narula, 2004). In general, most of the SMEs' weaknesses in innovation arise from their size (Freel, 2000; Narula, 2004; Teece, 1986). SMEs can adopt OI in order to react actively to market changes, to meet customer demand and/or develop new sale channels (Lee et al., 2010; Van de Vrande et al., 2009). A weak R&D capacity has also been found as an incentive for reliance on external knowledge (Kim and Park, 2010). To overcome the problem of insufficient R&D expertise, SMEs can attempt to explore a wide range of external information sources (Lee et al., 2010) or

to exploit other companies' expertise by forming alliances to access complementary assets (Ahern, 1993; Nooteboom, 1994; Teece et al., 1997; Van Dijk et al., 1997).

In terms of barriers, as it is not easy for SMEs to achieve economies of size and scope, they may not transfer their technologies across product lines to create new products (Teece, 1980, 1982). In fact, internal R&D often has a dual function, in the sense that it not only generates new technologies but also increases absorptive capacity (Cohen and Levinthal, 1990; Rosenberg, 1994). As this capacity development mainly depends on the level of accumulated prior knowledge (Cohen and Levinthal, 1990), SMEs with less intensive R&D capacity may not be able to exploit external knowledge efficiently (Rosenberg and Steinmueller, 1988). Also, difficulties in recruiting highly skilled workers, changing organisational cultures and problems in finding and interacting with external partners are also frequently cited as hindrances to OI (Lee et al., 2010; Van de Vrande et al., 2009). The high cost of patent management may be prohibitive for SMEs, resulting in infrequent adoption of out-bound OI modes, such as IP licensing (Spithoven et al., 2013). Further, the limited ability to barter technology assets may make it difficult for SMEs to establish symmetric relationships with large established firms (Minshall et al., 2010; Narula, 2004).

OI in SMEs seems to be different from that in large firms (Ahn et al., 2013; Lee et al., 2010). While there have been a few examples of out-bound OI modes, the in-bound mode has been actively adopted by most SMEs (Van de Vrande et al., 2009). Among various in-bound OI modes, joint R&D and user involvement have been the most frequently observed modes and this mode preference has also been observed in many subsequent studies (Laursen and Salter, 2006; Lee et al., 2010; Van de Vrande et al., 2009). Even though large firms are more widely involved in various OI activities, SMEs seem more intensely involved in a few OI activities (Spithoven et al., 2013). Since SMEs cannot invest large financial resources in internal R&D, they carefully build an innovation portfolio and use it to get maximum benefits (Alstrups, 2000). Because of this careful and intensive innovation engagement, OI can contribute more to new product development in SMEs than in large firms (Spithoven et al., 2013).

2.3. Re-defining open innovation modes according to the changes involved

Owing to the complexity and heterogeneity of OI, it has not been easy to investigate the effect of OI on firm performance. In this context, we propose to re-define the OI modes in order to include the challenges of implementation highlighted above and allow a more in-depth evaluation of OI, in particular in the SME context. The OI literature has mainly dealt with knowledge flow directions, but OI modes can also be classified according to the type of changes involved in the adoption and implementation process. In Figure 1-3 each shift represents a 'change' implying a certain level of 'corporate entrepreneurship' and some risks and hence some associated resistance to its adoption (Mortara et al. 2011). Every time an innovation is directed towards an existing market (i.e. horizontal shift), a certain degree of change (dominantly technological) is involved. However, when an OI mode which also involves a vertical shift is implemented, a firm has to face changes in both technology and market. In the OI paradigm, not only do firms have to utilize external technology, but they also have to have access to new markets to exploit their internal knowledge in different ways (e.g., IP licensing) or to make new organisations (e.g., M&A or spin-off) to absorb or examine a potentially innovative disruptive technology. Additionally, as OI can be perceived as innovating innovation (Chesbrough, 2003), if a firm is required to establish new organisational constructs to operate any of the modes, a further degree of change becomes involved. OI adoption will reform organisations, in the sense that it forces them to experiment and adopt new ways, such as new knowledge (technology), new markets and even new forms of organisations (Mortara et al. 2010).

In this context, we propose a new OI taxonomy (see Table 1) by classifying the OI modes according to the dominant changes involved. Accordingly, 'technology-oriented OI', such as 'in-sourcing' and 'joint R&D', refers to innovation activities aiming at technological innovation. As the aim of this OI is to expand the boundary of its innovation sources, the adoption of this OI brings in substantial increase in technology stock. 'In-sourcing' is the fastest way of acquiring technological knowledge, but it does not usually involve a great deal of market and organisational change. 'Joint R&D ' may occasionally involve some degree of organisational changes (e.g., Intel's Lablet, see Tennenhouse (2004)), but its focus is still on acquiring the necessary technology. 'Market-oriented OI', on the other hand, attempts to identify new market needs. Examples are 'user involvement', 'open-sourcing' and 'licensing-out'. 'User involvement' and 'open sourcing' aims to identify market needs. 'Licensing-out' may necessitate a certain level of organisational change (e.g., the creation of a new IP division), but the focus of this OI is on commercialising under-utilised knowledge by generating a new market for it (i.e., making a new commercialisation route, see a curved line D in Figure 3). Last, 'organisation-oriented OI' causes drastic changes in organisational structures and 'M&A/alliance' and 'spin-off' are examples of this OI mode. 'M&A/alliance' may aim to acquire external technology, but this kind of OI involves greater changes in a firm's organisational structure. Similarly, 'spin-off' involves substantial changes in organisational structure.

This classification is based on the type of dominant (i.e., the highest) core changes (from technological to organisational change) involved. Thus, for instance, we classified 'open-sourcing' as 'market-oriented', in the sense that it emphasizes interactions with customers/users and 'M&A' and 'spin-off' as 'organisation-oriented' because the adoption of these OI modes involves (mainly) new organisational forms and practices. Our classification relies upon dominant changes, so it suggests that a higher level of change can include a smaller one (i.e., it is an inclusive concept). For instance, market-oriented OI can include technology changes, whilst organisation-oriented OI can embrace both technological and market changes, in the sense that organisational changes are the most complicated ones involving many types of different sub-level changes.

Table 1. Open innovation classification (Note: '✓'denotes a low and'✓✓' denotes a high level change)

	Dominant knowledge flow direction	Changes involved in OI			Dominant core change
		Technology	Market	Organisational structure	
In-sourcing (Licensing-in)	In-bound	✓✓			Technology-oriented
Joint R&D		✓✓			Technology-oriented
User involvement		✓	✓✓		Market-oriented
M&A/alliance		✓	✓	✓✓	Organisation-oriented
Open sourcing	Out-bound	✓	✓✓		Market-oriented
Licensing-out		✓	✓✓	✓	Market-oriented
Spin-off		✓	✓✓	✓✓	Organisation-oriented

2.4. Open innovation and firm performance

Recent studies have investigated the influence of OI on performance using large-scale data sets (Podmetina et al., 2014), and their approaches can be grouped into the following three: 1) the degree of openness (OI proxies), 2) individual OI mode

influence and 3) collaboration influence.

Firstly, researchers have attempted to identify the effect of openness on firm performance. Rather than examining individual OI modes one by one, studies in this group have tried to discover the influence of the degree of openness in firms. Laursen and Salter's (2006) seminal paper employed search strategy as a proxy variable for a firm's openness by introducing the 'breadth of search' and 'depth of search' concept as two distinctive dimensions of openness. Their study showed that external search and linkages with external partners are positively associated with sales of new or improved products. The approach of Laursen and Salter (2006) has been developed further in many subsequent studies. For example, Chen et al. (2011) found that the breadth and depth of openness can improve both science-based and experience-based innovation, and Chiang and Hung (2010) found that breadth affects incremental innovation, whilst depth influences radical innovation.

Studies in the second group have focused on the individual effect of each OI mode. Brunswicker and Vanhaverbeke (2014) found that not all OI modes are always beneficial in enhancing innovation performance, and their findings are in line with the rest of the literature. Mazzola et al. (2012) examined the effect of twelve different OI modes on financial and innovation performance and found that the OI effect can be both positive and negative. In their study, acquisition, licensing-out, co-patenting and alliance were significantly associated with both innovation and financial performance, whilst university collaboration, public funding and R&D alliance were insignificantly associated with them. Also, they found that supplier collaboration, government collaboration and licensing-in were only significantly associated with innovation performance, while external technology commercialisation was only significant for financial performance. Hung and Chou (2013) investigated the influence of external technology acquisition (i.e., in-bound OI) and external technology exploitation (i.e., out-bound OI) but found that only external technology acquisition positively affects performance.

Lastly, some researchers have investigated the effect of collaboration. Almirall and Casadesus-Masanell (2010) simulated the effects of OI in two different settings: where partnerships were fixed or flexible. They showed that a high level of openness can bring better performance, particularly in a dynamic environment where firms can change their partners freely. Since one of the most important benefits of collaboration is accessing a partner's complementary assets (West and Gallagher, 2006), broad and intensive collaboration will enable firms to exploit external knowledge more efficiently. However, as the literature has shown, different types of external partners play crucial roles in different innovation modes. In Chen et al.'s (2011) study, collaboration with universities and research institutes affected science-based innovation, whilst this type of collaboration did not influence experience-based innovation. Rather, value chain partners and competitors influenced experience-based innovation performance

The above three strands of research show that the relationship between OI and firm performance is not simple. These complex (and sometimes inconsistent) results have inhibited our clear understanding of the effect of OI on performance. However, two points arise here. First, the complexity arises from diverse nature of OI (Dahlander and Gann, 2010), and second, this diversity brings about issues of choice. Firms have to make the most appropriate choice(s) from among various options, and this is more important in SMEs. Given the resource constraints it is not easy for SMEs to employ many innovation routes at the same time (Vanhaverbeke et al., 2012). Therefore, the relationships between OI and performance have to be further investigated and for this our OI classification (see Table 1) can be used in order to help SMEs to make better decisions with regard to choice of OI adoption.

2.5. Hypotheses

The literature has shown that SMEs are actively engaged in OI (Cosh and Zhang, 2011; Spithoven et al., 2013; Van de Vrande et al., 2009) and suggested many benefits they may obtain through OI (Brunswicker and van de Vrande, 2014; Lee et al., 2010). As the adoption of each OI mode represents a new managerial option, firms employing various OI modes may deal more flexibly with a fast-changing environment. By diversifying their innovation strategies, firms' knowledge will find its ways to commercialisation in existing and new markets. Hence:

H1) A broad OI adoption (i.e., adopting many modes) is positively associated with SMEs' firm performance.

However, since SMEs might not be able to focus on various managerial options simultaneously, adopting too many OI modes may bring in substantial risks. OI adoption, with its challenges, such as more managerial choices (Nelson and Winter, 1982) and difficulties in finding trustworthy partners (Dyer and Singh, 1998; Narula, 2004), will increase uncertainty levels. Thus, the intensive adoption of OI (rather than adopting too many OI approaches) may contribute to the enhancement of firm performance. Hence:

H2) A broad OI adoption will show a curvilinear relationship with firm performance.

H3) A deep (i.e., intensive) OI adoption is positively associated with SMEs' performance.

Because of the different types of innovation activities involved in OI (Dahlander and Gann, 2010; Spithoven et al., 2013), the influence of each OI mode on firm performance will be different. According to our OI classification in Table 1, we argue that the influence of OI on performance will vary according to the type of changes introduced by the adopted OI mode. Since SMEs typically lack the resources and management experience that are essential for dealing with changes and adapting themselves to a new innovation routine, they may not equally and effectively benefit from all kinds of OI. OI modes demanding substantial resources and involving high risks may not affect firm performance significantly. In this regards, we assume that OI modes involving relatively low level changes (such as technology or market-oriented OI) will affect firm performance more significantly than those involving more complex and higher changes (e.g., in organisation structure). Hence:

H4) The OI modes are differently associated with SMEs' performance according to the types of changes brought by the OI modes.

The literature has shown that different types of external partners play crucial roles in different innovation activities (Mention, 2011). Gronum et al. (2012) showed that collaboration with various partners can improve innovation in SMEs. However, the collaboration process is not simple. Absorptive capacity, which is an essential capacity in OI (Spithoven et al., 2011), depends upon good social relationship as well as strong internal R&D (Zahra and George, 2002). Therefore, in collaboration, not only do firms have to resolve differences embedded in external knowledge to integrate it with the internal (Salter et al., 2014), they also have to establish new protocols (Kitchell, 1997; Narula, 2004). Firms have to recognise that innovation clock speed varies in different organisations (Kitchell, 1997). Yet, this may not be easy for SMEs. Given their resource constraints, SMEs may not adequately deal with time consuming trust building process (Narula, 2004). Thus, even though collaborations contribute to the enhancement of firm performance, too many collaboration projects may not do so. Hence:

H5) A broad collaboration (many partners) is positively but curvilinearily related to firm performance in SMEs.

H6) An intensive collaboration is positively associated with SMEs' performance.

Despite the potential positive effects, collaborations with different partners may not contribute to performance improvement equally. For example, Lasagni (2012) suggested that innovation performance in SMEs can be higher when they strongly collaborated with users, customers and suppliers. His results also showed that SMEs can be better successful in product development when they closely work with research institutes. This suggests that there can be specific types of partners SMEs may prefer. As collaboration can bring in various risks, such as information leakage (Laursen and Salter, 2014; Oakey, 2013), SMEs may prefer to collaborate with partners which may not threaten them. Hence:

H7) The effect of collaboration on SMEs' performance is differently associated according to partners.

3. Data and method

3.1. Samples

Data were collected through a survey using the database of the Korean Small and Medium Business Administration (SMBA). The SMBA is a government agency giving a government certificate to innovation-oriented SMEs (so-called 'inno-biz' program which was inspired by the Small Business Innovation Research (SBIR) of the US and aims to select and stimulate innovative SMEs) to encourage innovation activities. These firms are assessed by the SMBA according to four major criteria (innovation capacity, commercialisation ability, innovation management and innovation performance (OECD, 1997)). By the second quarter of 2013, a total of 17,295 SMEs had obtained the "inno-biz" certification, indicating their high level of innovativeness.

For the main survey, 3,000 manufacturing SMEs were randomly selected from the inno-biz database, and a structured questionnaire was delivered to CEOs via e-mail, using an on-line survey system in January 2013. 68 firms were not reached due to errors in contact details, and in total 329 responses were eventually collected. This gives an 11.3% response rate (i.e., 329/(3000-68)). However, 23 responses were excluded from the final sample as key information was missing. So, 306 responses were finally used for the analysis.

To examine any non-response bias, the extrapolation method was used, i.e., comparing early and late responding mean values of variables, whereby late respondents are likely to have similar characteristics to non-respondents (Armstrong and Overton, 1977). In terms of the number of employees, sales and firm age, no significant difference between the two groups was found.

3.2. Variables

Performance. Each firm's performance (a latent variable) was measured by three manifest variables. When investigating large established firms, measuring business performance in the traditional way (e.g., total revenue or return on investment) can be a good approach increasing the validity of the responses; so objective dependent variables have been used in many studies. However, acknowledging the following two aspects, the current paper attempted to use multiple subjective variables rather than single objective one. First, it is not easy for a single objective variable to measure a firm's performance exactly. For example, financial performance, such as revenue, is a good objective measurement, but it only reflects a part of firm

performance (i.e., only financial aspect). Similarly, some studies (e.g., Community Innovation Survey) used a binary variable to measure innovation performance by asking whether firms were successful in product development, but this binary variable cannot reflect the extent of firm performance improvement. Second, not only are SMEs typically reluctant to reveal their financial status (Fiorito and LaForge, 1986), but neither is it easy to evaluate the accuracy of reported figures (Covin and Slevin, 1989). Further, neither do low net-income or operating-losses necessarily indicate poor management in growth-oriented SMEs (Cooper, 1979), nor can their financial figures be free from influences of their business environment (Miller and Toulouse, 1986). As such, this study adopted subjective indicators as it happened in other SME studies (e.g., Akgun et al., 2007; Miller and Toulouse, 1986; Rhee et al., 2010). Questions regarding how good the firm was in terms of sales, new product development (or related service), and market share were included in the survey. Respondents were asked to indicate relative performance on a seven-point Likert scale, when compared with average-level competitors in their industry. Before the main analysis, confirmatory factor analysis (CFA) was conducted to see whether these three manifest variables could construct one performance latent variable. As shown in Table 2, the result shows good reliability and validity. The reliability of measurement was assessed by Cronbach's alpha, and the constructed latent variables satisfied the recommended level (i.e., good if it is larger than 0.7 (Field, 2009)). All standardized factor loadings on latent variables were over 0.5 and significant at the 0.001 level (two-tailed), thus verifying a convergent validity. In order to include this latent variable in a regression (Hung and Chou, 2013), we averaged these three manifest variables.

Table 2. Confirmatory factor analysis result

Factor loadings	Std. estimate	Critical ratio	Cronbach's alpha
Relative sales <--- Performance	0.624	-	0.742
Relative new product development <--- Performance	0.642	8.542***	
Relative market share <--- Performance	0.849	7.992***	

Significance: *** $p < 0.001$

Open innovation. We adapted Laursen and Salter (2006)'s 'breadth' and 'depth' concepts to quantify the degree of OI adoption breadth and depth (meaning how many OI modes were employed and how intensely). First, we asked how many times firms had adopted seven different OI modes in the last three years. These OI adoption variables were transformed into binary variables (0:not used, 1:used) to indicate the adoption of each OI mode. Then the binary variables were added up to indicate how broadly firms use OI, i.e., 'breadth of OI'. The seven OI adoption variables were also transformed into other binary variables (0: not used or low intensity (1~2 times used), 1: high intensity (used than more than 3 times)) and added up in order to quantify the 'depth of OI'.

Collaboration partners. Laursen and Salter (2006)'s concept was applied to measure how firms broadly and intensively collaborate with external partners. We asked the frequency of collaboration with seven different partners in implementing OI for the last three years as seven levels (0: not collaborated with, 1~6: six levels according to collaboration frequency). These variables were transformed into binary variables (0: no collaboration, 1: collaborated with) and added up to indicate how broadly firms collaborate with external partners (i.e., breadth of collaboration). As in the case of 'depth of OI', these seven collaboration variables were also transformed into other seven binary variables (0: not or low collaboration (1~2 times), 1: high intensity

(collaborated more than 3 times)) and then added up to quantify how firms intensely collaborate with OI partners.

Control variables. The following five variables were controlled due to their significance in the literature. First, the firms' 'R&D intensity' was included due to its importance in generating and absorbing knowledge (Cohen and Levinthal, 1990; Spithoven et al., 2011; West and Bogers, 2013). It was measured as the ratio of the expenditure on internal R&D to total revenue. Second, 'firm size' was measured as a natural logarithm of the number of employees. An abundance of resources is recognised as a critical factor for innovation (Chaney et al., 1991; Cyert and March, 1963), and the literature has showed its significance in OI adoption and implementation (Spithoven et al., 2013; Van de Vrande et al., 2009). As the scale of this variable was larger than those of other variables, a natural logarithm was applied. Third, a measure of the 'firm age' was employed. Research has shown that the age of a firm can influence innovation both positively and negatively (Mazzola et al., 2012). Fourth, 'government support' was introduced, as government funding encourages SMEs' networking and interaction with other innovation actors (Kang and Park, 2012). Also, in general, many governments provide significant funding and apply weaker regulations to SMEs in order to encourage the increase of SME competence (Nooteboom, 1994; Rothwell and Dodgson, 1991). Lastly, since a competitive market environment is also a strong driver of change (Hung and Chou, 2013; Lee et al., 2010), an exogenous factor, 'market turbulence', was examined. 'Government support' and 'market turbulence' were measured using the 7-point Likert scale, to establish how often the firms received government support (all kinds of government support, such as subsidies, tax deductions, loans, and research grants) and to what extent they felt that the market environment was competitive and hostile.

4. Results

4.1. Descriptive statistics

Table 3 shows the descriptive statistics with minimum and maximum values, mean and standard deviations of the respondents. The sample's average number of employees per company was 28.81, and the average firm age was 11.42 years. As their average R&D intensity (11.60) indicates, the sample firms were highly involved in innovation. For comparison, the average R&D intensity across all Korean firms in 2007 was just 2.43 (KOITA, 2009). Before the regression, multicollinearity was examined. A variance inflation factor (VIF) greater than 10 can cause a serious multicollinearity problem (Myers, 1990), but for all the tested variables, VIF values were between 1.039 and 2.039, confirming that there was no serious collinearity issue in the sample.

Figure 4 illustrates the distribution of the OI adoption of the respondent firms. The results show that in-bound OI was more favoured than out-bound OI. Particularly three OI modes, in-sourcing, joint R&D and user involvement, were actively implemented by the sample firms. Interestingly, for M&A/alliance and spin-off, there were very few examples of these modes, and when reported they only occurred one or twice. For other OI modes, the frequency of adoption showed a gradual decline.

Table 3. Descriptive statistics

Variables	Min.	Max.	Mean	St. deviation
Performance	1.00	7.00	3.897	1.097
OI breadth	0.00	7.00	1.759	1.406
OI depth	0.00	6.00	0.452	0.779
Collaboration breadth	0.00	7.00	4.261	1.909
Collaboration depth	0.00	7.00	1.958	1.864
R&D intensity (%)	0.00	80.00	11.602	10.156
Firm age (year)	3	40	11.420	7.126
Firm size (the number of employee)	3	300	28.810	36.852
Government support	1.00	7.00	2.380	1.235
Market turbulence	1.00	7.00	5.390	1.184

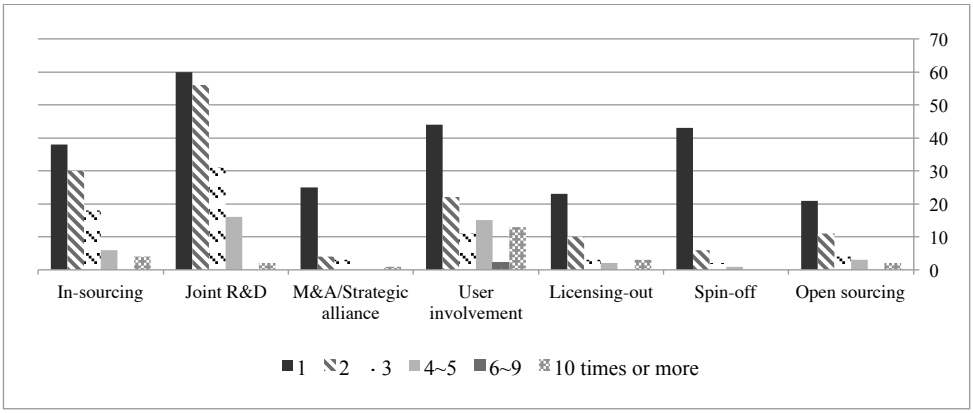

Fig. 4. Open innovation adoption (Unit of the vertical axis: the number of firms)

Figure 4 showed that in-bound OI, especially joint R&D and user involvement, were the most frequently adopted OI modes. This is in line with other studies that investigated Korean SMEs (Abulrub and Lee, 2012; Kim and Park, 2010), but this OI preference is also identified in the context of other countries. For example, Van de Vrande et al. (2009), who investigated Dutch SMEs, found that their sample firms preferred in-bound OI and meeting customer demands was the most important driver of OI. Cosh and Zhang (2011) who investigated British SMEs also found that their sample firms were actively collaborating with customers and suppliers and implementing joint R&D or joint marketing.

4.2. Open innovation modes

The latent variable (performance) is a mean value of three manifest variables and has an ordered value between 1 and 7 with interval 0.33. Considering this, an ordered-Probit regression model was employed and a normality assumption was verified by the Wilks W test. As shown in Table 4, three different models were examined in order to see the influence of the OI adoption on performance. First,

Model 1 includes only control variables (a baseline model), whilst the 'breadth of OI', its square term and 'depth of OI' were added in Model 2 to identify the relationship between the extent of OI adoption and firm performance. The robust method was used to estimate a marginal effects of square terms in a non-linear model (Norton et al., 2004). In Model 3 the effect of individual OI adoption was examined in order to see which OI mode could have contributed to firm performance.

Table 4. OI adoption and firm performance

Variables	Model 1	Model 2	Model 3
(***Controls***)			
Firm size	0.034(0.074)	0.023(0.077)	0.041(0.078)
R&D intensity	-0.004(0.006)	-0.002(0.007)	0.001(0.007)
Firm age	0.004(0.009)	0.001(0.009)	0.005(0.009)
Market turbulence	-0.109(0.050)*	-0.133(0.052)*	-0.155(0.052)**
Government support	0.124(0.049)*	0.043(0.053)	0.040(0.060)
(***OI breadth and depth***)			
Breadth of OI		0.179(0.950)$^{+}$	-
(Breadth of OI)^2		-0.020(0.021)	-
Depth of OI		0.240(0.088)**	
(***OI adoption***)			
In-sourcing			-0.032(0.055)
Joint R&D			0.125(0.058)*
M&A/alliance			-0.080(0.117)
User involvement			0.133(0.041)***
Licencing-out			0.120(0.079)
Spin-off			-0.138(0.116)
Open sourcing			0.244(0.082)**
(Model fit)			
Cox and Snell R^2	0.044	0.102	0.157
Nagelkerke R^2	0.045	0.103	0.158
McFadden R^2	0.009	0.021	0.033
Δ (-2LogLikelihood)[a]	13.521***	29.869***	48.037***

Note: Estimates are beta coefficient and robust standard errors are in parentheses.
$^{***}p<0.001$, $^{**}p<0.01$, $^{*}p<0.05$, $^{+}p<0.1$ / [a] difference with intercept only model

The results suggest that OI adoption can be positively associated with firm performance. Model 2 confirms that both broad and intensive OI adoption can contribute to performance. The square term of 'OI breadth' showed a negative association but it was statistically insignificant. Thus, hypothesis 1 and 3 were supported, whilst hypothesis 2 was rejected.

The results of Model 3 showed that only OI modes introducing relatively low levels of change, such as joint R&D (technology-oriented), user involvement and open sourcing (market-oriented), are positively associated with performance. The other OI (i.e., organisation-oriented) introducing high levels of change had no impact on performance. This partially validates hypothesis 4. Also, it was found that the coefficient of market-oriented OI was larger than that of technology-oriented OI, conjecturing high importance of market-oriented OI in SMEs.

In terms of control variables, only the 'market turbulence' was significantly associated with performance. As expected, a competitive and hostile market environment negatively influenced firm performance. However, the other control variables did not show any significance in our sample.

4.3. Collaboration partners

To see the effects of collaboration on firm performance, three models were examined as shown in Table 5.

Table 5. OI partners and firm performance

Variables	Model 4	Model 5	Model 6
(***Controls***)			
Firm size	-0.037(0.085)	0.002(0.088)	-0.003(0.088)
R&D intensity	-0.008(0.007)	-0.005(0.007)	-0.008(0.007)
Firm age	-0.001(0.011)	0.001(0.011)	-0.006(0.011)
Market turbulence	-0.109(0.055)*	-0.124(0.056)*	-0.127(0.057)*
Government support	0.070(0.062)	0.065(0.066)	-0.016(0.065)
(***OI breadth and depth***)			
Breadth of OI			0.080(0.044)+
Depth of OI			0.322(0.102)**
(Collaboration breadth and depth)			
Breadth of collaboration	0.253(0.151)+	-	0.090(0.059)
(Breadth of collaboration)^2	-0.022(0.019)		-
Depth of collaboration	0.102(0.049)*	-	0.056(0.031)+
(***Collaboration partner***)			-
Other firms		-0.120(0.148)	-
Suppliers		0.188(0.199)	-
Customers/clients		0.519(0.190)**	-
Affiliated firms		-0.212(0.154)	-
Consultancy/intermediaries		0.358(0.161)*	-
Universities		-0.009(0.163)	-
Research Institutes		0.379(0.170)*	-
Cox and Snell R^2	0.130	0.166	0.190
Nagelkerke R^2	0.131	0.167	0.191
McFadden R^2	0.027	0.035	0.041
Δ (-2LogLikelihood)[a]	32.451***	42.369***	47.493***

Note: Estimates are beta coefficient and robust standard errors are in parentheses.
***p<0.001, **p<0.01, *p<0.05, +p<0.1 / [a] difference with intercept only model

Model 4 included two aggregated collaboration variables, breadth and depth of collaboration, whilst Model 5 showed the effect of individual OI partners. As in the case of OI adoption, the aggregated collaboration variables (i.e., breadth and depth) were positively associated with performance. The results of Model 4 showed that both broad and intensive collaboration can contribute to the enhancement of performance. However, the square term of collaboration breadth did not show its statistical significance, even though it showed a negative association with firm performance. In model 5, the effect of each individual OI partner on performance was examined. The results showed that external collaboration with customers, consulting firms/intermediaries and public research institutes can contribute positively to performance. We ran an additional model (Model 6) including all aggregated variables. The results showed that wide and intensive OI adoption with intensive collaboration can enhance firm performance, which is in line with the finding of

Spithoven et al. (2013) that SMEs benefit from intensive OI engagement.

5. Discussion

This paper has investigated the influence of OI on firm performance. Based on survey data on innovative manufacturing SMEs, we found that OI can be a good approach enhancing firm performance in SMEs. The following findings are drawn from the analysis.

First, we found that both broad and intensive OI adoption can positively contribute to the enhancement of firm performance. OI adoption can be perceived as a process of introducing a new innovation route that may not previously be provided by internal R&D. In this regard, broad OI adoption can diversify firms' managerial options that will be useful when firms deal with a fast-changing market environment. Also, intensive OI adoption, which indicates how deeply firms are engaged in specific OI modes, helps firms to examine and select efficient and most suitable innovation routes among diverse choices, which in turn could enhance performance. However, as noted by Laursen and Salter (2006), too much openness may make it difficult for firms to benefit from their innovation. So, an inverted U-shaped curvilinear relationship between OI breadth and firm performance was assumed, but the square term of OI breadth showed no significant association, which rejects our conjecture. This may be interpreted by recognising the nature of OI implementation and the changes involved. Since OI adoption is, in fact, the development of new innovation routes, its influence may be different from that of external information search that simply consumes organisational resources. As OI provides new opportunities for commercialisation by diversifying innovation routes (see Figure 2 and 3), adopting many OI modes may not harm firm performance. This finding is important for SMEs, in the sense that given the resource constraints they typically hesitate to change their innovation routes.

Second, our results also indicate that not all OI modes affect performance positively. As shown in Table 1, OI adoption involves different types of changes in technology, market and organisational structure. Our results suggest that the OI modes involving technology (joint R&D) and market level changes (user involvement and open sourcing) contribute to firm performance positively. This might be interpreted in two ways. First, this phenomenon may reflect the characteristics of SMEs that generally focus on technological development and implement market-oriented innovation (Brunswicker and Vanhaverbeke, 2014; Lee et al., 2010; Oakey, 2013). Technology is an essential source of innovation (Dosi, 1982) and innovative SMEs which do an application-oriented search perceive OI as a beneficial complement of internal R&D (Brunswicker and Vanhaverbeke, 2014). Also, most SMEs implement market-oriented, demand-driven OI (Brunswicker and van de Vrande, 2014; Lee et al., 2010; Van de Vrande et al., 2009) because they generally lack the capability to identify market trends and access new marketing channels (Narula, 2004). The fact that 'open sourcing' significantly affected performance despite its low adoption frequency (see Figure 4) may also support this explanation. As 'open sourcing' is market-oriented OI and at the same time it aims to exploit external technology (Henkel, 2006), it may satisfy SMEs' needs. The next interpretation is based on the types of changes introduced by each OI mode. Due to their insufficient resources and weak managerial capacity, they cannot deal with every kind of risk and change involved in OI (Ahn et al., 2014). They have to implement innovation discreetly according to circumstances (Alstrups, 2000). However, OI adoption results in an innovation routine modification that brings with it various changes, such as new technology, new market and new organisational structure (Mortara et al., 2011). Therefore, only when SMEs have the necessary managerial resources in dealing with

these changes can they have benefit from OI. Yet, as the advantage that most innovative SMEs have lies in technology rather than managerial resources (Narula, 2004; Oakey, 2013), they are not likely to cope with the higher level changes (e.g., building a new business model and setting up a new organisation) that require systematic resource reallocation. Thus, complex OI requiring substantial organisational changes (M&A and spin-off) or IP management (licensing-out) may be infrequently adopted compared to other OI modes and not significantly contribute to performance improvement.

Third, we investigated the relationship between collaboration partners in OI implementation and firm performance, and as in the case of OI adoption we found that broad and intensive engagement with partners can affect performance positively. We presumed an inverted U-shaped curvilinear relationship between collaboration breadth and firm performance, in the sense that collaboration is a time-consuming process requiring an establishment of new protocols (Kitchell, 1997; Narula, 2004). Yet, in our results no evidence was found with regard to such a relationship. This may suggest that collaboration partners can also be perceived as providing important paths leading to new innovation routes. Certainly, building a new relationship demands resources, but as this newly established relationship can contribute to the diversification of firms' innovation routes, collaborating with many partners may not harm performance improvement. Our results also showed that non-competing partners, such as customers, consultancy/intermediaries and public research institutes, can positively affect firm performance. This is in line with the literature (e.g., Cosh and Zhang, 2011; Lee et al., 2010; Van de Vrande et al., 2009). As SMEs choose to open their firm boundaries to survive fierce competition, they may prefer OI partners who do not threaten their business.

Last, with regards to control variables, many of them did not show direct influence on performance. Despite what previous literature found (e.g., Laursen and Salter, 2006; Spithoven et al., 2011), for our sample of SMEs, internal R&D did not directly affect performance. This discrepancy might spring from our sample characteristics. As we investigated innovative SMEs with high levels of internal R&D intensity, they may already be at a high technology level, thus difficult to improve upon only by virtue of internal R&D. Just as 'over search' can be detrimental to firm performance (Laursen and Salter, 2006), too much investment in internal R&D may result in failure to allocate the limited resources elsewhere, in turn resulting in insignificant contribution to performance improvement. Rather, as our results show, broadening managerial options by opening firm boundaries will be a winning approach for highly innovative SMEs. Further, although government support did not directly contribute to the improvement of firm performance, as our correlation matrix shows (see Appendix), it was significantly related with many OI modes and innovation partners, such as in-sourcing, joint R&D, M&A/alliance, other firms and suppliers. In this respect, it can be said that government support stimulates collaboration among innovation actors and encourages OI adoption. Its importance in the OI context must not be overlooked.

6. Implications and limitations

Our study has some theoretical and practical implications. First, a possible theoretical contribution of the paper lies in the suggested OI taxonomy that classifies OI according to the type of changes involved in it (see Table 1). We used this classification to interpret our analysis results, but it can also be applied in other contexts (e.g., large firms) to enrich our understanding of OI.

Second, for practical implications, senior managers and policy makers should be aware of the importance of OI in enhancing SME performance. The findings of the

study have provided further empirical evidence that SMEs can benefit from OI by broadly and intensively engaging in OI modes and collaborating with external partners. This can be a useful guideline for mangers and policy makers who are interested in the promotion of SME OI. Given their resource limitations, SMEs may hesitate to engage in many OI modes and collaborate with many partners. However, as our results indicate, it is recommended for them to do so, as broad OI adoption and collaboration does not harm performance improvement. Since newly adopted OI and established collaboration relationships can provide firms with new innovation routes which might not be achieved through closed innovation approach, an increase in openness will contribute to the enhancement of firm performance by diversifying innovation strategies. Thus, when facing OI mode choice issues, it is indeed necessary for SME managers to broaden their OI strategies.

However, despite the above potential contributions, this paper has some research limitations. First, the sample concerns only innovative manufacturing SMEs with high R&D intensity. Thus, our findings may be affected by the sample characteristics and might not be easily generalised to other sub-populations of SMEs, such as service firms or non-innovative small firms. Second, as innovation can be different in a different national innovation system (NIS), our results from a single country context might have been influenced by national context, such as economic fundamentals and culture. As noted by Edwards et al. (2005), a higher level of understanding is achieved when considering the complex linkage between an SME and its socio-cultural context. Thus, future studies may obtain better understanding by including variables reflecting socio-cultural contexts or conducting comparative studies of two or more countries. Last, since this study did not deal with longitudinal data, any discrepancies with the literature could not be not fully investigated. For example, even though the performance variable this study used was a three-year average value, a possible delay effect may exist. Thus, it was not possible to examine whether the insignificant effect of internal R&D was caused by a delay effect. Improved results might be obtained by future studies addressing these research limitations.

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Appendix: Pearson correlation table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. In-sourcing	1																		
2. Joint R&D	.227**	1																	
3. M&A/Strategic alliance	.278**	.264**	1																
4. User involvement	.084	.076	.117	1															
5. Licensing-out	.199**	.044	.387**	.154*	1														
6. Spin-off	.099	.093	.220**	.179**	.192**	1													
7. Open-sourcing	.213**	.077	.311**	.277**	.320**	.246**	1												
8. Other firms	.080	.189**	.098	.154*	.077	.233**	.235**	1											
9. Suppliers	.116	.213**	.170**	.260**	.045	.108	.161*	.391**	1										
10. Customers/client	.124	.105	.111	.343**	.096	.170**	.201**	.363**	.514**	1									
11. Affiliated firms	.101	.215**	.193**	.045	.096	.291**	.157*	.299**	.245**	.267**	1								
12. Consultancy/intermediary	.127	.215**	.082	.113	.044	.069	.064	.389**	.425**	.327**	.334**	1							
13. Universities	.102	.523**	.166*	-.058	.148*	.056	.046	.368**	.237**	.185**	.212**	.379**	1						
14. Research institutes	.221**	.516**	.140*	.121	.046	.162*	.042	.361**	.311**	.330**	.221**	.434**	.562**	1					
15. Firm size	.105*	.069	.121	-.008	.053	.080*	.133*	.010	.021	.024	.123	.025	-.140*	-.023	1				
16. R&D intensity	.123*	.028	.134+	-.041*	.097*	.088	.036	.126	.094	.076	-.035	.111	.143*	.064	.318**	1			
17. Firm age	.047	-.105	.020	-.001	.071	.028	-.013	-.050	-.107	-.067	-.038	-.065	-.128	-.071	.382**	.223**	1		
18. Market turbulence	-.063	-.093	-.056	.015+	-.005	.049	.026	-.071	-.119	-.115	-.068	-.138*	-.126	-.167*	.013	-.068	.089	1	
19.Government support	.243**	.547**	.197**	.086	.013	.100	.164*	.278**	.186**	.151*	.188**	.220**	.403**	.430**	.024	.069	-.152*	-.122	1

** Correlation is significant at the 0.001 level (2-tailed) / * Correlation is significant at the 0.05 level (2-tailed) / + Correlation is significant at the 0.1 level (2-tailed) / Bootstrap results are based on 1,000 bootstrap samples.

Variables: (2~7) the adoption frequency of each open innovation mode / (8~14) the frequency of collaboration with each partner