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HOW DO FIRMS SOURCE EXTERNAL KNOWLEDGE FOR INNOVATION? ANALYSING EFFECTS OF DIFFERENT KNOWLEDGE SOURCING METHODS

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In the era of "open innovation", external knowledge is a very important source for technology innovation. In this paper, we investigate the relationship between external knowledge and performance of technology innovation. The effect of external knowledge on the performance of technology innovation can vary with different external knowledge sourcing methods. We identify three ways of external knowledge sourcing: information transfer from informal network, R&D collaboration and technology acquisition. We propose three hypotheses to examine relationship between the three methods of external knowledge sourcing and the technology innovation performance. Our results show that information transfer from informal network and technology acquisition have positive relationships with the technology innovation performance. R&D collaboration, however, has an inverted-U-shape relationship with technology innovation performance. This implies that the effect of external knowledge on technology innovation varies depending on the particular external knowledge sourcing method. This research has an important implication for firms in selecting an appropriate strategy for accessing external knowledge.

Keywords: External knowledge; knowledge sourcing method; technology innovation; strategy; open innovation; information network; R&D collaboration; technology acquisition.

Introduction

Chesbrough (2003) suggests that innovation process of many technology intensive firms are changing from the "closed innovation" model to the "open innovation" model and much research has been done in this area. Open innovation's

emphasis on the importance of using external knowledge for successful innovation has been long noted by many researchers in the past (Leonard-barton, 1995; Keil, 2002). Research has focused on the extent of using external knowledge to explain firm's technology innovation performance (Levinthal and March, 1993; Katila and Ahuja, 2002; Laursen and Salter, 2006) or the relationship between particular knowledge sourcing method and technology innovation performance (Brockhoff, 1992; Goerzen, 2007).

There are various methods of external knowledge sourcing such as information transfer from informal network (Laursen and Salter, 2006); R&D collaborations (Pisano, 1990; Brockhoff, 1992; Shan *et al.*, 1994); or technology acquisition (Granstrand, 1982; Granstrand and Sjölander, 1990) and most firms source external knowledge by simultaneous utilisation of different external knowledge sourcing methods. However, previous studies explore the effect of external knowledge on technology innovation performance without considering different effects of various external knowledge sourcing methods. The effect of external knowledge on technology innovation performance can vary depending on the external knowledge sourcing methods. Therefore, it is strongly needed to study different effects of several ways of using external knowledge on technology innovation performance.

In this study, we examine the relationship between different methods of external knowledge sourcing and technology innovation performance by simultaneously incorporating various methods of external knowledge sourcing within a single empirical model. We identify three methods of external knowledge sourcing: information transfer from informal network, R&D collaboration and technology acquisition. Effects of these three external knowledge sourcing methods on technology innovation performance are analysed empirically using the negative binomial regression model. We employ the "Korea Innovation Survey" dataset covering the information transfer from informal network, R&D collaborations and technology acquisition of corporations in the manufacturing sector in South Korea. The number of firm's product innovation in 2004 is used as the dependent variable to represent firm's technology innovation performance.

We find that the effect of using external knowledge on the technology innovation performance varies depending on the external knowledge sourcing method. Our research presents important implications for firms in selecting a sourcing method for external knowledge and in determining appropriate utilisation levels of external knowledge sourcing methods.

Conceptualisation and Hypotheses

External knowledge and technology has great effect on firms' technology innovation performance in the era of open innovation. Chesbrough (2003) suggests that porosity of a firm's boundary is necessary to absorb external knowledge and

capabilities, and previous studies support Chesbrough's suggestion (Shan *et al.*, 1994; Leonard-barton, 1995; Powell *et al.*, 1996). When a firm has porosity at its boundary, then the firm can develop networks with various external knowledge sources. Researchers suggest that networks are important pathways of information, knowledge and capabilities (Granovetter, 1973; Hansen, 1999; Ahuja, 2000; Sparrowe *et al.*, 2001). Thus, firms can explore and exploit external knowledge through network.

Previous research analysing knowledge sharing and innovation performance based on network theory has focused on the effects of network properties and structure (Galaskiewicz and Zaheer, 1999). Granovetter (1973) and Hansen (1999) emphasise the efficient knowledge sharing through weak ties. Ahuja (2000) explores the relationship between network structure and firm's performance by using concepts of direct-indirect ties and structural hole. Sparrowe *et al.* (2001) suggest the effect of centrality on the performance of individuals or organisations. However, when firms pursue technology innovation through developing network with external knowledge sources and absorbing external knowledge, there exist other important factors affecting the firms' technology innovation performance — the extent of using external knowledge and the effect of particular external knowledge sourcing methods.

Previous research suggests that the extent of using external knowledge is determined by the variety of external knowledge sources used by focal firms and the strength of relationship between focal firms and external knowledge sources (Levinthal and March, 1993: 103; Katila and Ahuja, 2002; Laursen and Salter, 2006). These research are based on the concepts of exploration and exploitation. March (1991) suggests that there are optimal level of exploration and exploitation. Levinthal and March (1993) indicate that it is very difficult to determine an optimal exploration strategy and suggest two criteria such as "broader" and "deeper" to determine an optimal exploration strategy. Katila and Ahuja (2002) extend the concepts of exploration and exploitation and suggest "search scope" and "search depth" to describe the extent of using external knowledge. "Search scope" describes how broadly a firm searches new knowledge and "search depth" describes the extent of reuse of existing knowledge. They analyse the effects of these factors on technology innovation performance. Laursen and Salter (2006) define "breadth" as the variety of external knowledge sources and "depth" as the variety of important external knowledge sources. They analyse the effects of "breath" and "depth" on the firm's technology innovation performance and find the inverted U-shape relationship between two determinants and technology innovation performance. These studies analyse the exploration of external knowledge by applying the two dimensions of extent of using external knowledge (breadth and depth). However, the ultimate purpose of these studies is to explore the relationship between the extent of using external knowledge and innovation performance. Thus, in this study, we propose an

alternative method to measure the extent of using external knowledge that considers breadth and depth simultaneously.

The effect of using external knowledge on technology innovation performance varies depending on not only the extent of using external knowledge but also on the type of external knowledge sourcing method. There are various criteria to classify the methods of a firm's external knowledge sourcing. Peña (2002) classifies external knowledge sourcing methods by the extent of commitment of agreement (non-equity; majority-equity, or acquisition). Research classifying external knowledge acquisition methods by formality of agreement also exist (Hakansson and Johansson, 1992; Brockhoff, 1992). Robertson and Gatignon (1998) divide governance mode of firm's R&D into three such as internal R&D, alliance and market contracting. Granovetter (1973) and Hansen (1999) suggest the strength of tie as a criterion for classifying firm's network and categorizing firm's network into weak tie and strong tie. In this research, we synthesise previous criteria and identify three methods of external knowledge sourcing such as *information transfer from informal network, R&D collaboration and technology acquisition* (Table 1).

Information transfer from informal network does not require formal agreements or contracts and it develops no organisational interactions between focal firms and external knowledge sources (Hakansson and Johansson, 1992; Pyka, 1997). Also, informal network for information transfer has properties of a social network (Axelrod, 1984; Hakansson and Johansson, 1992; Gulati, 1995). Informal network that has the property of social network does not require large transactional, managerial and maintenance costs. Thus, firms have the motivation to develop large informal networks for information transfer for surviving.

Informal network for information transfer can be classified as a weak tie because it is for information sharing and not for organisational interaction or critical

Table 1. Three methods of external knowledge sourcing.

Methods	Formal agreement	Organisational interaction	Strength of network	Advantage	Disadvantage
Information transfer from informal network	No	No	Weak tie	Low or no cost	Relatively invaluable knowledge transfer
R&D collaboration	Yes	Strong and long term	Strong tie	Effective knowledge transfer, risk sharing	High coordination cost
Technology acquisition	Yes	Weak and short term	Weak tie	Fast acquisition of adequate knowledge	Risk of failure of commercialisation

capability sharing (Granovetter, 1973; Hansen, 1999). Because weak ties require very low cost or no cost for maintaining network, firms can develop more informal network for information transfer with various external knowledge sources. Through this advantage, firms can access external information more easily, react faster to fast changing environments or crises and innovate more easily.

Previous research, in fact, has emphasised that when firms acquire external information, there exists an inverted-U-shape relationship between the extent of using external information and technology innovation performance due to over searching problem, lack of absorptive capacity or dispersion of attention (Koput, 1997; Laursen and Salter, 2006). These days, however, due to the fast growth of IT and communication technology, the cost for searching external information has decreased and the efficiency of knowledge absorbing process has improved rapidly. Thus firms can acquire, keep and use more information under the condition of limited resource. In other words, due to the reduction of efforts and costs required to acquire and handle external information, firms can use external information for their technology innovation more efficiently.

We have discussed so far that information transfer from informal network has an advantage for the firm's performance and that the negative effect of acquiring external information has decreased. Thus, we propose a hypothesis asserting that the extent of using informal information network has a positive relationship with technology innovation performance. This hypothesis differs from previous studies.

H1. *When a firm pursues innovation, the extent of information transfer from informal network has a positive effect on technology innovation performance.*

R&D collaboration network can be classified as a formal network because it is constructed by formal and specified agreement (Hakansson and Johansson, 1992; Pyka, 1997). It also has the properties of strong ties, since capability sharing and organisational interaction occurs through R&D collaboration network (Granovetter, 1973; Hansen, 1999). On one hand, a strong tie like R&D collaboration has the advantage of sharing resources and capabilities; on the other hand, it requires a large maintenance cost, thereby rendering it difficult for firms to build wide and various networks (Granovetter, 1973; Hansen, 1999).

Through R&D collaboration, not only the obvious limitations of a firm's resources and capabilities for technology innovation can be overcome, but also the financial and organisational risk of failure can be shared with collaboration partners. Also, firms can develop new business through technology alliances, which is a type of R&D collaboration (Narula, 2004). Thus, it should stand to reason that R&D collaboration is beneficial to firms' technological innovation.

However, because of problems such as opportunistic behaviours of R&D collaboration partners or technology leakages, R&D collaboration can have a negative

effect on technology innovation performance. High coordination cost that is required for profit from complex linkage between collaboration partners also has negative effects on performance (Narula, 2004). Therefore, firms pursue R&D collaboration for technology innovation at a moderate level. Based on the discussion above, we suggest a hypothesis asserting that an inverted-U-shape relationship exists between the extent of using R&D collaboration and technology innovation performance.

H2. *When a firm pursues technology innovation, the extent of using R&D collaboration has an inverted-U-shape relationship with technology innovation performance.*

Technology acquisition can also be classified as a formal network because it is constructed by a formal agreement (Hakansson and Johansson, 1992; Pyka, 1997). Technology acquisition causes a short-term organisational interaction for transferring technological knowledge. However, technology acquisition has the properties of a weak tie because it causes less organisational interaction in a long-term perspective. Firms do not need to maintain the network of technology acquisition when the contract is over.

Concerning the open innovation perspective, Chesbrough (2003) emphasises the importance of active technology acquisition for innovation and suggests that increase in technological uncertainty is one of the main motivations for a firm to select open innovation strategy. Under conditions of very high technological uncertainty, firms are more likely to choose technology acquisition rather than to pursue internal R&D (Walker and Weber, 1984; Balakrishnan and Wernerfelt, 1986; Harrigan, 1986). It is getting more and more difficult to maintain competitive advantage through internal R&D because the increase of knowledge, the development of technology and change of business environment are being accelerated. Global giants such as Procter & Gamble (Dodgson *et al.*, 2006), IBM (Gassmann and Enkel, 2004), Cisco (Chesbrough, 2003) also pursue innovation and growth through active acquisition of external technology. When firms have problems which cannot be solved by internal R&D, or when firms are required to invent new technology very fast, using technology acquisition renders great advantage to the firms' technology innovation and market adoption. Therefore, we hypothesise that technology acquisition has a positive effect on the firm's technology innovation.

H3. *When a firm pursues technology innovation, the extent of using technology acquisition has a positive effect on technology innovation performance.*

Data and Methods

Sample

The data for analysis are extracted from the "Korean Innovation Survey 2005: Manufacturing Sector (KIS)" collected by Science & Technology Policy Institute

(STEPI) of South Korea. Questionnaire and survey methods used in KIS are based on the third edition of the Organisation for Economic Cooperation and Development (OECD)'s Oslo Manual. KIS data are used extensively for research because of many reasons: its large set of data and many kinds of variables. The questionnaire of KIS is composed of 15 pages describing important terminology in the questions. It contains several questions on the type of external information sources, R&D collaboration partners, sources for technology acquisition and other questions related to a firm's technology innovation.

Population of KIS was created by "Basic Statistical Survey 2003" of Korea National Statistical Office. STEPI selected 5,378 samples from this population by the Neyman method. Samples were created by second-order stratification. First, STEPI stratified the population on 23 categories according to the Korea Standard Industrial Classification (KSIC). Most categories of Korean manufacturing sectors except service sectors were included within the 23 categories. Second, STEPI stratified each category on five sub-categories according to the number of employees. Then, the population was stratified on 115 sub-categories and STEPI selected 5,386 sample firms from 115 sub-categories by the difference of variance between each sub-categories.

The survey was sent to 4,507 firms in South Korea in October 2005, with the exception of 879 firms who had rejected answering the survey. STEPI retrieved 2,738 answers, amounting up to a response rate of 60.7%. After sending the survey questionnaire, STEPI followed up with calls to sample firms to encourage their response. After receiving the answers, STEPI called sample firms to confirm the result of the survey. In this study, we use a sub-sample of the KIS including data from 1,353 firms that contains all the variables that this analysis examines.

Method

In this study, we use the number of product innovation in 2004 to measure performance of technology innovation. The number of product innovation is a countable integer value. When analysing some dependent variable that is an integer value, researchers can use regression models such as Poisson regression or negative binomial regression. Since the mean of our dependent variable is not equal to its variance and also greatly larger than its variance, our dependent variable violates the basic assumption of Poisson distribution and has an over-dispersion problem. Thus, negative binomial regression model which allows over-dispersion is chosen for analysis.

Dependent variable

This study focuses on the effects of three external knowledge sourcing methods and the extent of using each method on the firm's technology innovation performance.

Therefore, technology innovation performance is the dependent variable of the present analysis and it is the central problem of defining the measure of technology innovation performance. KIS data include several measures that are used in previous research, such as "perceived number of innovation", "fraction of the firm's turnover relating to innovative products" (Laursen and Salter, 2006) or "number of patents" (Kim, 2005). In the present study, we use "perceived number of product innovation in 2004" as the measurement of technology innovation performance.

Independent variables

In this study, we identify three methods of external knowledge sourcing: information transfer from informal network, R&D collaboration and technology acquisition. Thus, we introduce three new variables reflecting the extent of using each methods of external knowledge sourcing.

The extent of using information transfer from informal network (INFOR)

KIS introduces 19 external information sources and measures perceived importance of each source to a firm's technology innovation by a 5-point scale. The extent of using INFOR is measured by the sum total of perceived importance of 19 information sources. Thus, INFOR has an integer value of range from 0 to 95.

The extent of using R&D collaboration (COLLAB)

KIS introduces 10 R&D collaboration partners and measures the perceived contribution of each partner to a firm's technology innovation by a 5-point scale. In this study, the extent of using R&D collaboration (COLLAB) is measured by the sum total of perceived contribution of 10 collaboration partners. Therefore, COLLAB has an integer value of range from 0 to 50.

The extent of using technology acquisition (ACQUI)

KIS introduces 10 sources for technology acquisition and measures perceived contribution of each source to a firm's technology innovation by a 5-point scale. In the present research, the extent of using ACQUI is measured by the sum total of perceived contribution of 10 sources for technology acquisition. Therefore, ACQUI has an integer value of range from 0 to 50.

Control Variables

In this study, we include five control variables: R&D intensity, firm size, start-up, participation of user and market size.

Traditionally, firm's absorptive capacity has been regarded as an important factor affecting technology innovation. Absorptive capacity is measured by R&D intensity (Cohen and Levinthal, 1990); R&D intensity (RDINT) is measured by the firm's R&D expenditure divided by firm's sales. However, RDINT presents not only firm's absorptive capacity but also firm's internal effort for R&D and innovation. Thus, we use R&D intensity to control effects of absorptive capacity and internal R&D.

Firm size has important effects on the firm's innovativeness, and so, it is frequently used as a control variable in many studies related to the performance of innovation. Firm size is measured by logarithm of the number of total employees who work in focal firms (LOGSIZE).

Start-up firms show a tendency to innovate more actively than incumbents. Thus, we include whether or not the firm was a recent start-up. If a firm started in the period 1998–2002, then the firm is start-up (STARTUP). Simply, the variable takes the value of 1 when the focal firm started up in the period 1998–2002, and 0 otherwise.

Many studies focusing on innovation suggest that the relatedness of lead user in innovation has a significant effect on performance of innovation (Rothwell *et al.*, 1974; von Hippel, 1988; Laursen and Salter, 2006). Lead users freely give the firm feedbacks of products that they have used and help firms by informing them of the problems firms have overlooked. We include USER variable to control the effect of relatedness of lead users to innovation. The variable (USER) is constructed based on the "clients or customers" source of knowledge for innovation. Simply, the variable takes the value of 1 when the firm indicates that it uses clients or customers to a degree of 4 to 5 as sources of knowledge for innovation activities, and 0 otherwise.

In addition, we control the size of the perceived product market (GEOMARKET). Products competing in the international market are more likely to be obsolete than products competing in the domestic market. So, firms competing in the international market endeavour to innovate more intensively than firms competing in the domestic market. In the present research, GEOMARKET variable takes the value 1 when corresponding to "international market" and 0 when corresponding to "domestic market".

Results

In the present study, we identify external knowledge sources that are used by Korean manufacturing firms through KIS data. Table 2 shows the kind of external knowledge sources and the average importance of each source. Firms use fairs, exhibitions, information network (e.g. Internet), expert magazines, customers and clients importantly for information transfer from informal network because they can be accessed easily. Table 2 also indicates that firms use universities or other higher education institutes as important sources for R&D collaboration. It means that Korean

Table 2. External knowledge sources classified by sourcing mode (n = 1,353).

Sourcing mode	External knowledge source	Average degree of importance (contribution)
Information transfer from informal network	Private research institutes	0.769
	Universities	1.400
	Government research organisations	1.146
	Non-profit organisations, e.g. associations	0.904
	Subsidiaries of same headquarter	1.226
	Competitors	1.922
	Other companies in same industry	1.338
	Suppliers of raw materials or software	1.607
	Suppliers of equipment	1.539
	Customers or clients	2.221
	Business service firms, e.g. consulting	1.200
	New employees	1.187
	Informal networks of CEO or CTO	1.394
	Patents	1.882
	Professional conferences, meetings	1.983
	Professional magazines	2.126
	Fairs, exhibitions	2.447
	Media, e.g. newspaper, TV	1.664
	Information network, e.g. Internet	2.393
	Average importance of all external information sources	1.597
R&D collaboration	Subsidiaries of same headquarter	1.021
	Competitors	0.970
	Other companies in same industry	1.214
	Customers or clients	1.478
	Business service firms, e.g. consulting	1.131
	Suppliers	1.300
	Private research institutes	0.764
	Universities	1.561
	Government research organisations	1.096
	Non-profit organisations, e.g. associations	0.768
	Average contribution of all collaboration partners	1.130

Table 2. (*Continued*)

Sourcing mode	External knowledge source	Average degree of importance (contribution)
Technology acquisition	Subsidiaries of same headquarter	1.281
	Competitors	1.898
	Other companies in same industry	1.507
	Customers or clients	1.903
	Business service firms, e.g. consulting	1.241
	Suppliers	1.953
	Private research institutes	0.925
	Universities	1.332
	Government research organisations	1.203
	Non-profit organisations, e.g. associations	0.945
	Average contribution of all technology acquisition sources	1.419

firms use academic-industry cooperation actively. Suppliers, customers/clients, competitors contribute largely to technology innovation when firms use technology acquisition for sourcing external knowledge. Suppliers, customers/clients or competitors have knowledge and technologies that are appropriate for an acquiring firm's knowledge base so that acquiring firms use these knowledge sources importantly.

Table 3 is a summary of descriptive statistics and correlations among variables. It shows that there are relatively high correlations between the extent of information transfer from informal network, the extent of using R&D collaboration and the extent of using technology acquisition. This result shows that firms that have an open attitude to external knowledge are likely to use a combination of the three

Table 3. Descriptive statistics and correlations.

Variables	Mean	Std. dev.	1	2	3	4	6	7	8
1. INFOR	31.61	19.44	1						
2. COLLAB	4.65	8.22	0.438	1					
3. ACQUI	6.95	10.1	0.542	0.488	1				
4. RDINT	4.79	34.22	0.010	0.030	0.002	1			
5. LOGSIZE	4.82	1.22	0.299	0.229	0.253	−0.091	1		
6. STARTUP	0.11	0.32	−0.074	−0.031	−0.049	0.132	−0.208	1	
7. USER	0.37	0.48	0.516	0.205	0.231	−0.002	0.110	−0.029	1
8. GEOMARKET	0.64	0.47	0.148	0.091	0.124	0.028	0.240	−0.046	0.102

Table 4. Negative binomial regression, explaining relation of external knowledge source and innovation.

Model	I		II		III	
Dep. variable	Innovation		Innovation		Innovation	
Indep. variable	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
INFOR			0.0106469***	0.003936	0.0036432	0.0105035
INFOR2					0.0000844	0.0001488
COLLAB			0.0146139	0.0091613	0.1089907***	0.0183958
COLLAB2					−0.0037512***	0.0005991
ACQUI			0.0394002***	0.0071043	−0.0166416	0.017813
ACQUI2					0.0020421***	0.0006081
RDINT	0.0015158	0.0016735	0.0017324	0.0016344	0.0018778	0.0016669
LOGSIZE	0.4856113***	0.0549039	0.3692698***	0.0532908	0.3557026***	0.0514149
STARTUP	−0.0638292	0.1961182	−0.1552728	0.1857564	−0.1676184	0.1809385
USER	0.5619677***	0.1257465	−0.0438754	0.1331848	−0.0140256	0.1299693
GEOMARKET	0.2841205	0.1271355	0.0795469	0.1240107	0.1883369	0.1218354
Industry dummies	Yes		Yes		Yes	
No. of obs.	1353		1353		1353	
Log likelihood	−3921.00		−3870.05		−3850.46	
Chi-square	408.67***		510.58***		549.75***	

*p < 0.10.
**p< 0.05.
***p < 0.01.

external knowledge sourcing methods. In other words, firms who have high openness actively use various methods of external knowledge sourcing.

Table 4 shows results of three negative binomial regression models that analyse the effect of three methods of external knowledge sourcing and the extent of using external knowledge on technology innovation performance. Each model contains control variables such as RDINT, LOGSIZE, STARTUP, USER, GEOMARKET and industry dummies. Model 1 is the basic model containing only the control variables. Model 2 shows the result of regression, analysing the effects of three external knowledge sourcing methods (INFOR, COLLAB and ACQUI) on technology innovation performance. Model 3 contains additional square terms of INFOR, COLLAB and ACQUI.

In Model 2, the parameter for INFOR is significant and positive. It supports hypothesis 1, which asserts that using information transfer from informal network has a positive effect on performance of technology. Model 2 shows that the parameter for COLLAB is not significant. However, Model 3 presents that the parameter for COLLAB is significant and positive and the parameter for COLLAB squared is

significant and negative. This results support hypothesis 2, which asserts that the extent of using R&D collaboration is curvilinearly — taking an inverted U-shape — related to technology innovation performance.

Model 2 shows that the parameter for ACQUI is significant and positive and Model 3 presents that the parameter for ACQUI squared is also positive and significant. Thus, hypothesis 3 is supported and we can assert that there is a second-order positive relationship between the extent of using technology acquisition and technology innovation performance.

Discussion

We establish that the effect of external knowledge on technology innovation performance varies depending on the particular external knowledge sourcing method. When a firm absorbs external information through information transfer from informal network, the more the firm uses information transfer from informal network, the more the firm gains technology innovation performance. This means that firms need large networks that have informality and properties of a weak tie to acquire abundant information from external information sources (Granovetter, 1973; Hansen, 1999).

Our result differs from previous studies (Katila and Ahuja, 2002; Laursen and Salter, 2006) asserting that there is an inverted-U-shape relationship between the extent of using external information and technology innovation performance. Previous research explain inverted-U-shape relationship through over-search problem and maintenance cost of network. However, our research asserts that there is a positive relationship between the extent of using information transfer from informal network and technology innovation performance. This result shows that over-search problem is decreased due to the reduction in searching cost and improvement of knowledge absorption process through the fast evolution of information and communication technology. Also, it implies that informal network for information transfer does not require a high maintenance cost and the benefit of information transfer is larger than the cost. Therefore, firms should more actively develop large informal channels for transferring information with external knowledge sources.

We find that the extent of using R&D collaboration has an inverted-U-shape relationship with performance of technology innovation. Thus, firms should maintain the use of R&D collaboration to an optimal level. In other words, firms should utilise R&D collaboration for innovation within a controllable scope and pay attention to opportunistic behaviours of their collaboration partners (Williamson, 1985) and technology leakage (Kaufman *et al.*, 2000). According to previous research based on transaction cost view, repeated alliance or collaboration with same partner increase confidence level between partners and decrease behavioural uncertainty

and transaction costs (Marsden, 1981; Granovetter, 1985; Gulati, 1995). Thus, firms overcome the risk of R&D collaboration by repeated alliance. But, at the same time, research based on network view suggest opposite insight to the R&D collaboration. Non-redundant network has positive effect on profit from network (Granovetter, 1973; Burt, 1992) and repeated alliance has negative effect on innovation performance. Thus, concentrating on a particular alliance partner by repeated alliance has negative effects on performance (Goerzen, 2007). Too many or too few utilisation of same R&D collaboration partner have negative effect on focal firm's technology innovation performance. Thus, firms must keep in mind to utilise same partner moderately and also to update collaboration partners adequately.

The parameter of ACQUI squared is positive and significant. It means that increase in technology innovation performance accelerates with the increase of the extent of using technology acquisition. This finding corresponds with the core of open innovation paradigm (Chesbrough, 2003). Open innovation perspective has highlighted the importance of technology acquisition. When the firm meets problems which cannot be solved by internal R&D, or when the firm requires faster speed of technology innovation due to radical changes of market and technology, technology acquisition from external sources can help the firm's technology innovation and survival.

When firms utilise technology acquisition, some problems can occur. First, it is possible that newly acquired technology does not fit into the already existing technology and capabilities. Also, even if the newly acquired technology fits the usage of the acquiring firm, it is hard to integrate acquired technologies with existing technology bases of the acquiring firm. Because firms' existing technology bases have been developed in their unique paths, components of acquired technologies cannot fit components of their existing technology bases. Second, there exists a resource distribution problem. Because of limited resources, when a firm inputs more resource to external technology acquisition, resource for internal R&D decreases. Consequently, it causes the shrinking of internal R&D activity and the decrease of absorptive capacity. Third, there exists a possibility that firms fail to commercialise acquired technology. Because firms pay large costs for technology acquisition, a failure of commercialisation of acquired technology implies that firms may in the future, fail to acquire financial resource for sustainable technology innovation. Firms, therefore, have to consider these problems carefully when they acquire new technology from external knowledge sources.

A firm uses various methods such as information transfer from informal network, R&D collaboration and technology acquisition simultaneously to source external knowledge and technology. However, previous studies have only analysed separately the effect of a single method on technology innovation. Thus, previous research has less implication in selecting a method of external knowledge sourcing

and determining an appropriate level of using each method. We overcome this limitation by identifying three different external knowledge sourcing methods and analysing the effects of each on the performance of technology innovation.

The summary of this study is that firms should explore and exploit external information through informal network as much as possible, use R&D collaboration in moderate level and use technology acquisition actively to maximise technology innovation performance. Our research shows that the effect of external knowledge on the performance of technology innovation varies depending on the external knowledge sourcing method. It also provides important implications for firms in selecting an external knowledge sourcing method and determining the appropriate level of using each method. It also implies that firms do not have to make a religion of open innovation; rather, it is more commendable for them to exercise command over the strategies which fit in with their own external knowledge sourcing method.

Nevertheless, although analysing KIS database has an advantage because it offers a large number of samples, it is hard to find variables which fit precisely to the purpose of research. In the present research, we use the number of product innovations in 2004 as a measure of technology innovation. However, our measurement has limitations because each product innovation has different extents of innovativeness and different effects on the firm's innovation. Also, perception of innovation varies with firms. Thus, in future research, if we can collect data more narrowly fitting to our research purpose, we may obtain a more meaningful result.

Conclusion

Firms cannot innovate successfully by just using internal knowledge and cannot survive alone in this fast-moving environment. Firms have to explore and exploit external knowledge for innovation and must collaborate with other organisations for survival. When firms decide to use external knowledge, it becomes a very important matter that how they can access external knowledge and to what extent they use the external knowledge sourcing methods. The present research gives important implications for solving those questions. In this paper, we have discussed the different effects of various methods of external knowledge sourcing. Three different methods have been identified and it has been established that extents of using each method have different effects on the technology innovation performance. It is strongly expected that this research helps managers to select an appropriate method of external knowledge sourcing and to determine the extents of using each method.

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