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External Knowledge and Product Innovation in Korean Firms: Interaction Between Learning and Searching Modes
외부지식이 제품혁신에 미치는 영향: 지식학습과 탐색방법의 상호작용을 중심으로

Jaegun Lee(First Author)
Ph.D. student, School of Business Administration,
Kyungpook National University
(*hl5ylz@naver.com*)
Moon-Goo Huh(Corresponding Author)
Professor, School of Business Administration,
Kyungpook National University
(*moongoo@knu.ac.kr*)

This study examines how the external knowledge affects innovation. We categorize firms' external knowledge sources into two modes: STI(science-technology-innovation) and DUI(doing-using-interacting). At the same time, we distinguish between the breadth and depth of firms' external knowledge acquisition strategies, while considering the interaction between the knowledge source and the acquisition strategy. Previous studies have considered the source and the acquisition strategy of external knowledge independently. Thus, in order to fill this gap in the literature, we identify two types of external knowledge, each with its own searching mode, suggesting a 2 × 2 acquisition strategy model of external knowledge.

Key Words: External knowledge source, Searching modes, Knowledge depth, Knowledge breadth, External knowledge acquisition strategy

Ⅰ. Introduction

In a dynamic and ever-changing industrial environment where technology and product life cycles are shortened, firms must innovate to launch new products which in turn ultimately affects the firm's survival (Teece, 2007). However, firms cannot achieve excellent performance in terms of innovation speed and novelty only through internal competence in a dynamic environment. Thus, firms should supplement this through external knowledge search (Von Hippel, 1998).

Based on this social phenomenon, many studies have tried to verify the validity of external knowledge search for innovation, and these documents emphasize that external

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knowledge search is a key factor for firms in achieving innovation in a dynamic environment.

In general, the resources of a firm are limited and the final form of innovation the firms seek to pursue also differ. Therefore, recent studies have been carried out to verify what kind and how much resources should be invested on external knowledge search according to the type of innovation, and this is generally studied in two contexts.

First and foremost, recent studies have discussed the kind of knowledge learned by the firms through external knowledge search. For example, Jensen et al. (2006) termed it either STI mode (Science-Technology-Innovation) or DUI mode (Doing-Using-Interacting) depending on whether the external knowledge search is to seek for scientific understanding or to seek experience and know-how, and verified that each method has a different impact on novelty and efficiency of innovation.

Second, it discusses how to set the scope of knowledge search in performing external knowledge search. Laursen and Salter, (2006) differentiated the breadth of external knowledge search and analyzed the differences found depending on the type of innovation and claimed that there are effective types of innovation depending on the difference in scope.

The type of knowledge gained through external knowledge search and the scope of search based on the limited resources of the firm and performing external knowledge search according to the form of innovation sought by the firm can be seen as a key factor in affecting the survival of the firm. However, existing studies have considered the type or the extent of knowledge to be learned as an independent research area and the impact of each on innovation. This is problematic as it fails to comprehensively consider the key factors that may influence innovation and therefore does not provide sufficient evidence to explain the phenomenon.

Therefore, this study divides the goal of innovation pursued by the firm into exploratory innovation and exploitative innovation and considers both the type of knowledge and the scope of the search to find out what is the most effective knowledge to search depending on the sought goal and the level of intensity in utilizing the source of external knowledge needed for learning to achieve the goal.

Based on the above discussion, the theoretical and practical contributions to be expected from this study are as follows. First, this study is expected to enable efficient and effective allocation of resources in performing external knowledge search by firms according to the goals they pursue as they perform innovation activities with limited resources. Second, even though external knowledge search is a very important factor in innovation, this study is expected to increase theoretical understanding by studying the current fragmented research from an integrated viewpoint. Lastly, this study is expected to expand the understanding in Asia, which is relatively insufficient, by setting up Korean firms with the most active innovation activities as subjects of the study.

Based on the above discussion, the following research question was derived from this study.

Research question. What are the modes of external knowledge search that are best suited to the type of innovation a firm pursues?

Ⅱ. Theoretical Background

2.1 Product Innovation Performance and Learning from External Knowledge

It is important that firms acquire information from external knowledge and use it to remain competitive (Grant, 1996). Persisting with existing knowledge does not help firms develop, but instead creates routines within firms. These routines make it difficult for firms to adapt to changing external environments (Levitt and March, 1988). Prior studies suggest that firms should actively try to adopt new knowledge externally for open innovation (Chesborough and Appleyard, 2007). Therefore, firms should aggressively apply new information and knowledge from external sources, such as other businesses or markets, in their product innovation activities. Furthermore, they should use information from a variety of sources in addition to subsidiaries, competitors, and suppliers (Yi, 2009).

Firms absorb new knowledge from external sources and apply it to product innovation as follows. They can improve an existing technology or product, or acquire new professional knowledge (Cohen and Levinthal, 1990). In addition, product innovation performance is improved by using knowledge from external sources. Because external knowledge is distributed among more fields than is internal knowledge, product innovation activities using such knowledge can effectively shorten the length of product innovation process, and can increase the probability of an innovation covering a broader technological and experimental range through the inflow of ideas (Clausen et al., 2013; Fleming and Sorenson, 2001; Katila, 2002; Katila and Ahuja, 2002; Laursen and Salter, 2006). In addition, because the number of available concepts based on existing technologies is limited, there is a greater possibility of the firm achieving effective product innovation and a broader range of technology (Katila and Ahuja, 2002).

That is, by accepting new information and knowledge from external sources, firms can prepare for risks associated with its environment, can shorten the product innovation process, and can increase the possibility of successful innovations. On the other hand, the firm is likely to spend more on managing and maintaining new knowledge as the degree of searching for external knowledge increases in terms of its transaction costs (Leiponen and Helfat, 2010). In addition, excessive knowledge searching may make it difficult to use new knowledge or to apply it to product innovation activities (Koput, 1997). Huh (2010) suggests other negative effects of excessive knowledge searching. First, uncertainty in searching for knowledge from external sources can increase the expense. Second, it can increase the importance of the knowledge to be integrated, causing technical and organizational problems. Third, it increases the breadth of choice and the management of knowledge required, causing an information overload.

2.2 Types of Learning from External Knowledge Sources

Product innovation can be completed by cooperating with external business partners and through internal R&D activities (Hull and Covin, 2009). Creating knowledge activities for product innovation means constant mutual communication, regardless of the technological level of the industry (Robertson and Patel, 2007), while actively applying the external knowledge improves product innovation performance more than when using internal knowledge or prior information only.

Acquiring external knowledge tends to be divided into two learning modes in the literature, namely, the STI mode and DUI mode (Jensen et al., 2007). These two modes play a role in the business strategy, and have different characteristics and effects on the product innovation process. Additionally, recent studies on the learning types suggest that a combination of the STI mode and DUI mode will perform best in product innovation activities (Parrilli and Elola, 2012; Apanasovich, 2014; González-Pernía et al., 2015).

2.3 STI Mode

Innovation requires constant R&D activities and sufficient human capital. However, innovation that focuses on internal information only will make it difficult for firms to adapt to a changing environment and can have a negative effect on a firm's survival. This problem can be solved by learning from external knowledge. Using the STI mode enables a firm to use more information technologies and to have better innovation performance, possibly even at a lower cost, using systematized knowledge (Lundvall and Lorenz, 2007). Various sources support these activities, such as private research institutes, universities, consulting firms, and academia (Isaksen and Karlsen 2012b; Jensen et al., 2007; Parrilli and Elola 2012; Fitjar and Rodríguez-Pose 2013). In summary, the STI mode of learning can be defined as studying professional, systematized, and scientific knowledge from external sources for product innovation development (Jensen et al., 2007).

Knowledge gained using the STI or DUI modes has different forms, and can be tacit knowledge or explicit knowledge (Jensen et al., 2007). While we learn explicit knowledge from workers who map out the settlements or resolutions, the STI mode also appears as a form of explicit knowledge itself (Jensen et al., 2007). Thus, there is little value in the knowledge provided by the STI mode in tacit form, which should only appear in documentation so that it can be delivered easily. This is how knowledge from external sources using the STI mode can be used when it is not protected by intellectual property rights. This is why using the STI mode is easier than using the DUI mode when working with patent applications or licenses (Lundvall and Lorenz, 2007). Additionally, knowledge learned using the STI mode is easier to document and systematize than in the case of the DUI mode, making it straightforward to deliver to members of a firm (Grant and Baden-Fuller, 2004).

In summary, using the STI mode, a firm can acquire professional, systematized, and scientific knowledge, which is predominantly explicit in form, and then easily supply this information to members of the firm. Explicit knowledge from external sources is easier to gather than is implicit knowledge (Biery et al., 2009).

2.4 DUI Mode

The main source of knowledge has been from the R&D laboratories of firms, which have been part of large-scale industry since the 20th century (Mowery and Oxley, 1995; Chandler, 1997). Although most of academic world and the knowledge industry focus on learning from external knowledge through scientific knowledge, this does not mean we should ignore the importance of tacit knowledge. Of course, the development of technology has largely been the result of scientific knowledge. However, this type of innovation is still difficult to achieve because experts often perform learning based on a partial understanding of the technology (Nelson, 2005).

The DUI mode covers the afore-mentioned vulnerability when solving problems. Some problems faced by firms are specific to a situation, rather than general problems. In this case, regardless the extent of their existing knowledge, employees find a way to solve the problem and, in the process, learn something new, which has a positive effect on product innovation performance.

Knowledge gained from the DUI mode covers tacit factors that contribute to successful product design effective to consumer demand. Furthermore, it can be acquired from external parties in the internal and external value chain, including business service suppliers, customers, and competitors. (Jensen et al., 2007).

In addition, the knowledge learned through the DUI mode is tacit knowledge, which is related to know-how, skills, and experience. That is why it is difficult to deliver the knowledge to another firm or members, and to assimilate it with existing knowledge (Kognut and Zander, 1992; Grant and Baden-Fuller, 2004). However, it is still highly valued in terms of creating a competitive advantage by preventing competitors from imitating a firm's products. In summary, learning from external knowledge using the DUI mode is difficult to apply in practice because it has tacit characteristics. However, when it is applied successfully, it can create higher value innovations.

2.5 Modes of external knowledge search

The modes of external knowledge search can be distinguished based on their breadth and depth. According to Laursen and Salter (2006), breadth relates to the number of external sources, while depth refers to the availability and importance of knowledge from external sources. The two modes have different effects on firms' product innovation activities (Laursen and Salter, 2006).

Prior studies focus on applying the knowledge gained from external parties to the product innovation process in relation to open innovation (Laursen and Salter, 2006). Accordingly, searching for knowledge may increase the probability of successful product innovation because it accumulates knowledge and experience about internal and external products, technologies, and market environments (Levinthal and March, 1993). The open innovation process is a unique source of technologies, because individual firms are affected differently by the external environment in terms of how often a technical opportunity is applicable, or how fast the environment changes (Cohen and Levinthal, 1990; Klevorick et al., 1995). The mode of knowledge search varies increasingly with the importance of the external environment, resulting in a greater variety of strategies. The knowledge search process is affected by a firm's experience and strategy for the future (Laursen and Salter, 2006). Thus, the results expected by firms facing the same opportunities can be different, depending on the mode of knowledge search they employ (Eckhardt and Shane, 2003). The chosen mode can affect the performance of a firm, which is why identifying and applying the most effective mode in terms of its breadth and depth is important (Levinthal and March, 1993).

2.5.1 The Breadth of an External Knowledge Search

The breadth of an external knowledge search refers to the number of paths or sources a firm can use to search for external knowledge for an open innovation activity (Laursen and Salter, 2006). Prior studies on product innovation argue that applying knowledge from both internal and external sources can increase the probability of successful innovations. Recent studies by Baldwin and Clark (2000, 2006) emphasize the success of product innovations derived from a variety of sources of knowledge.

The breadth of a search, especially in product innovation activities, can make it easier to accept knowledge from external sources, and can reduce the uncertainty inherent in the process (Leiponen et al., 2010). Increasing the breadth of an external knowledge search increases the probability of successful product innovation.

2.5.2 The Depth of an External Knowledge Search

The search depth is also closely related to product innovation performance. The search depth refers to a more detailed search based on fewer external sources of knowledge (Leiponen et al., 2010). In other words, the depth of an external knowledge search reflects how strongly it concentrates on a small number of knowledge sources. Katila and Ahuja (2002) explain how the search depth affects product innovation performance from three aspects. First, it repeats the same technical factors in order to reduce errors, establishing a reliable development routine (Levinthal and March, 1981). Second, greater experience makes it easier to understand the knowledge. Third, this better understanding helps to determine whether knowledge is applicable, and makes it possible to derive new knowledge and insight.

Ⅲ. Research Model and Hypotheses

3.1 Learning from External knowledge and Product Innovation

Product innovation can be divided into exploratory innovation and exploitative innovation, based on the characteristics of the new product. These two innovation types have different sources of knowledge, capabilities, innovation goals, and characteristics, and their own approaches to completing an innovation (Park and Lee, 2008). Exploratory innovation refers to developing new products with superior functions and performance (Levinthal and March, 1993). Exploitative innovation focuses on improving existing products using existing knowledge and experience (March, 1991). As such, the two types have different modes of learning. This study categorizes the modes of learning as the STI mode and DUI mode

(Jensen et al., 2007), as described earlier.

The STI mode is effective to innovation based on scientific knowledge, which is typically explicit, systematic, and clear, and applies this knowledge to firms or members (Grant and Baden-Fuller, 2004).

Therefore, scientific knowledge gained from the STI mode can be applied more quickly and clearly than knowledge learned using the DUI mode can (Bierly et al., 2009). Furthermore, firms pursuing open innovation using technical ideas or resource from external sources have access to a wider range of technological changes and experiments than those that do not, making successful product innovation more likely (Clausen et al., 2013; Fleming and Sorenson, 2001; Katila, 2002; Katila and Ahuja, 2002; Laursen and Salter, 2006).

In summary, learning from external knowledge using the STI mode enables a firm to combine new knowledge in different ways, which is more effective than relying on existing methods only for exploratory product innovation seeking quantitative improvements of new concepts. Therefore, using the STI mode provides more variety in terms of combinations of knowledge and technologies when developing new products, and is quicker than using the DUI mode, which is more useful in exploratory product innovation.

On the other hand, in addition to learning from scientific knowledge using the STI mode, firms use accumulated experience and know-how. This is called learning using the DUI mode, which generally has tacit characteristics (Jensen et al., 2007).

Tacit knowledge is not systemized or characterized by accumulated learned knowledge, but is related to experience, skill, and know-how. Thus, it is comparably more difficult to deliver than is knowledge gained using the STI mode, because there is no documentation (Nonaka and Takeuchi, 1995). Therefore, DUI learning requires a higher cost, and is limited in terms of the speed and extent of learning (Apanasovich, 2014). In addition, DUI mode knowledge is more difficult to combine with existing knowledge and to apply in practice (Kogut and Zander, 1992). However, this knowledge can prevent competitors from imitating products, making it possible to maintain a competitive advantage. In particular, firms that use the DUI mode in open innovation perform experiential learning, and increase their productivity and effectiveness through repetition (Rosenberg, 1982). These firms also strengthen their experiment and problem-solving capabilities through constant interaction with external partners (Wuyts et al., 2004; Lorenz, 2012).

In summary, learning from external sources using the DUI mode is effective for problem-solving based on accumulated experience and constant interactions, and when improving existing technology or product quality. However, because the DUI mode has a higher cost and

〈Table 1〉 Modes of learning

Criteria	STI	DUI	STI and DUI
Dominant knowledge typology	Explicit, scientific, codified, know-why, and know-what	Tacit, synthetic, know-how, and know-who	Explicit, scientific, and tacit
Main external partners	R&D institutions, universities, research intensive firms, and R&D organizations	Competitors, value chain	Value chain, competitor, R&D institutions, universities, research intensive firms, and R&D organizations
Type of product innovation	New product and radical innovation	Incremental innovation and commercial innovation	Incremental and radical innovation

Adapted from Apanasovich, N. (2016). Modes of innovation: a grounded meta-analysis. Journal of the Knowledge Economy, 7(3), 720-737.

takes longer than does the STI mode, which is more effective for exploratory innovation that requires rapid changes and fast solutions, it is more effective in exploitative product innovation requiring product-related problem-solving and functional improvements (see Table 1).

Thus, the STI mode increases the probability of creating new knowledge using external knowledge, while the DUI mode improves product quality and problem-solving using accumulated experience and know-how. Furthermore, considering that an excessive learning from external knowledge sources increases the cost of the learning (Koput, 1997; Leiponen and Helfat, 2010; Huh, 2011), this study suggests the following hypotheses.

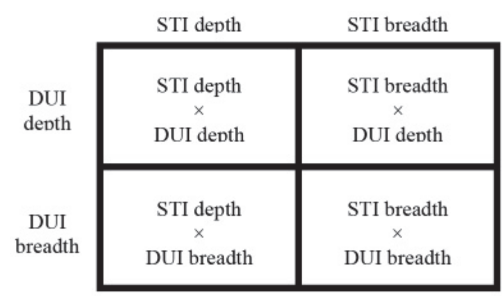
Hypothesis 1a: The inverted U-shaped relation between learning from external knowledge and exploratory product innovation is more effective to learning using the STI mode than using the DUI mode.

Hypothesis 1b: The inverted U-shaped relation between learning from external knowledge and exploitative product innovation is more effective to learning using the DUI mode than using the STI mode.

3.2 External Knowledge Search Mode and Learning Mode

From the perspective of organizational flexibility, exploration and exploitation have mutually complementary characteristics (March, 1991). This requires a combination of the STI mode, which is effective to exploratory product innovation, and the DUI mode, which is effective to exploitative product innovation. Recent studies on the STI and DUI modes discuss when each results in better innovation performance (Fitjar and Rodríguez-Pose, 2013; Aslesen et al., 2012; Chen et al., 2011; Parrilli and Eloa, 2012; González-Pernía et al., 2015). The common combination of STI and DUI in these studies creates more scientific knowledge, while pursuing innovation from active interactions and an exchange of calculated knowledge (Jensen et al., 2007; Isaksen and Karlsen, 2010; Parrilli and Elola, 2012; González-Pernía et al., 2015). Empirical research based on this approach (i.e., STI + DUI) focus on China and Scandinavian nations (e.g., Denmark and Norway), and some have contributed positive effects to innovation performance. However, more research is required before the findings can be generalized. Therefore, we assume that these studies did not find coherent results because they did not consider sufficient factors (i.e., depth and breadth) in terms of the learning modes (STI and DUI). Thus, we focus on Korea, where R&D investment and external cooperation are fulfilled most actively, according to the OECD (2015).

We assume that the correct choice of learning mode affects product innovation performance, and that this performance is affected differently by the two searching modes (Eckhardt and Shane, 2003). As discussed above, the correct choice of searching mode helps clarify the performance of product innovation, and contributes to better firm performance by selecting an optimal breadth and depth (Levinthal and March, 1993). Therefore, firms apply different learning modes and searching modes.



〈Figure 1〉 Combinations of external knowledge search

In particular, product innovation performance can be divided into exploratory and exploitative product innovation, as discussed in hypothesis 1. Here, the breadth and depth of the searching mode affect the diversity of knowledge and the degree of understanding (Laursen and Salter, 2006). Therefore, firms must choose an effective searching mode based on the learning mode for optimal product innovation performance. Thus, we assume that a firm has four different combinations of learning and searching modes, as shown in Figure 1.

Search breadth refers to the number of external sources of knowledge (Laursen and Salter, 2006). This increased diversity enables the firm to acquire knowledge from external parties, which improves the likelihood of innovation success (Baldwin and Clark, 2000, 2006). Search depth refers to a deeper search for knowledge among few sources (Leiponen et al., 2010), improving the firm's understanding, and enabling it to combine the knowledge with its existing knowledge.

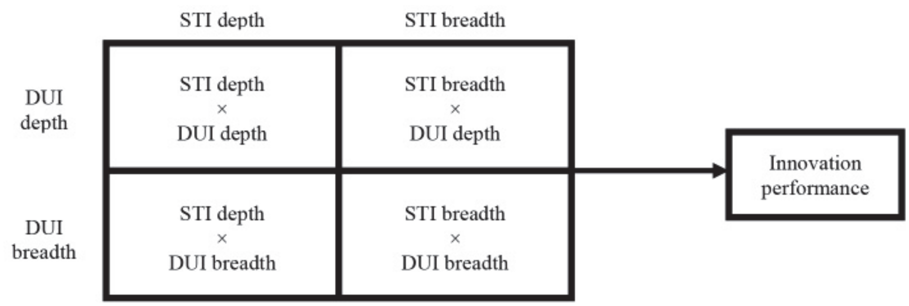
The expected effects of learning from each mode are as follows. The STI mode performs product innovation activity based on scientific knowledge, which is generally explicit. Explicit knowledge takes less time to learn and is easier to understand than is tacit knowledge. Therefore, the STI mode incurs a lower cost (Lundvall and Lorenz, 2007). Therefore, it is suggested that breadth is more effective to the STI mode than is depth.

Firms must acquire external knowledge by searching, and must invest sufficient time to apply this knowledge (Katila and Ahuja, 2002). Thus, the firm may absorb the external knowledge more quickly using the STI mode. However, knowledge from a small number of sources may decrease the range of combinations, hindering the diversity of knowledge and increasing the possibility of over-searching. Thus, using the STI mode with depth results in too much information and a higher cost. Therefore, if a firm uses the STI mode of learning, it is advisable to focus on breadth. In this way, the firm absorbs knowledge in less time and at a lower cost, resulting in an effective combination for the required technology. Therefore, we assume that search breadth is more effective to searching for external knowledge using the STI mode. However, Koput (1997) argued that this mode can have negative effects on innovation performance in terms of managing or using ideas and making decisions, given the volume of information. Thus, we verify the inverted U-shaped relation between the STI mode and search breadth.

The DUI mode of learning refers to unofficial and tacit knowledge (Jensen et al., 2007). Tacit knowledge is related to experience, technology, and know-how, making it relatively straightforward to distribute and combine with existing knowledge (Kognut and Zander, 1992; Grant and Baden-Fuller, 2004). Thus, we suggest that the DUI mode is better suited to depth than it is to breadth when searching for external knowledge.

A firm must invest a significant amount of time in acquiring such knowledge, including much trial and error, before being able to apply it to the firm (Katila and Ahuja, 2002). Tacit knowledge learned from the DUI mode is necessary, but is not useful when there are multiple search targets (Terjensen and Patel, 2015). According to the attention-based view, a firm might find knowledge acquisition more difficult if it focuses on critical external information and knowledge with too wide a search (Ocasio, 1997). Thus, focusing on the search breadth when using the DUI mode makes it more difficult to acquire knowledge and to establish effective combinations of knowledge.

On the other hand, focusing on tacit knowl-



〈Figure 2〉 Research Model

edge for innovation means the search depth makes it easier to deliver, acquire, absorb, and apply knowledge based on interaction and mutual trust (Terjensen and Patel, 2015). Likewise, Kogut and Zander (1992) claim that a deeper search contributes to knowledge acquisition by establishing a process and routine for evaluating, absorbing, and applying the required knowledge. Furthermore, according to the attention-based view, a manager focuses on limited sources to produce knowledge that is more visible than in the case of tacit knowledge (Ocasio, 1997). Thus, we suggest that search depth is more effective for the DUI mode.

In summary, the combination of the STI and DUI modes is much stronger, minimizing the uncertainty product innovation performance and the cost of searching for knowledge. Therefore, we suggest that using a combination of STI breadth and DUI depth is the most effective combination for product innovation performance. As such, we suggest the following hypotheses (see Figure 2).

Hypothesis 2: Among the combinations of STI breadth/depth and DUI breadth/depth, the combination of STI breadth and DUI depth is most influential to firms' product innovation.

Ⅳ. Data and Methodology

4.1 Sample and Data

The data are extracted from the Korean Innovation Survey (KIS), completed in 2012 (collection period: 2009 - 2011). The data set used in this study is taken from the Science & Technology Policy Institute (STEPI). The KIS is conducted every three years as the Eurostat Community Innovation Survey (CIS) by the Oslo Manual and EU, after being developed and propagated by the OECD. Thus, 〈Table 2〉 Overview sample by industry

Industry	Frequency	Percent
Chemicals	51	14.96
Plastic manufacturing	18	5.28
Nonmetallic products	11	3.23
Communications equipment	15	4.4
Metallic products	22	6.45
Pharmaceuticals	28	8.21
Electronic equipment	95	27.86
Machine manufacturing	81	23.75
Car manufacturing	20	5.87
Total	341	100

we can use the public CIS results to compare countries. The KIS is approved by the Korean National Statistical Office (Statistics Korea), providing reliable and suitable data for the investigation and for international comparability.

This study targets 341 Korean manufacturing firms. The distribution of the target industries is shown in Table 2. Korean firms are targeted because they have the highest intensity of R&D as a percentage of GDP, and one of highest increases in R&D expenses (OECD, 2015). Furthermore, Korea is effective for this study because the number of new product development (NPD) collaborations is increasing sharply (OECD, 2015). In addition, we chose firms founded more than five years previously in order to control for the start-up effect (Huh, 2011).

4.2 Measurement

4.2.1 Dependent Variables

The dependent variables for product innovation performance are divided into total product innovation performance, exploratory product innovation performance, and exploitative product innovation performance. Based on Laursen and Salter (2006), exploratory product innovation performance is measured using the percentage of sales in 2011 of new products released in the market from 2009 to 2011, according to the KIS data. Exploitative innovation performance is measured using the percentage of sales in 2011 of the firm's significantly improved products, released in same period. Total product innovation performance, defined in Hypothesis 2, is measured as the sum of exploratory and exploitative product innovation, excluding errors in the samples when the percentage of sales in 2011 or products is not 100% after being added to the total product innovation performance.

4.2.2 Independent Variables

The independent variables in this study are divided into the STI and DUI modes (Jensen et al., 2007). Using the method of Fitjar and Rodríguez-Pose (2013) for measuring the STI and DUI modes, we consider that a firm uses the DUI mode if it cooperates with at least one supplier, customer, consumer firm, inter-related firm, competitor, or any other firm. A firm uses the STI mode if it cooperates with at least one private laboratory (consulting), university or higher education organization, or public research firm (see Table 3).

The breadth and depth of a search follows Laursen and Salter (2006). This study is conducted based on CIS data, which are similar to the KIS data. Laursen and Salter (2006) excluded sources when the availability of a knowledge source summed to 0 in the survey (used 1, unused 0), and used a higher score for a larger breadth of knowledge search (STI mode for 0 - 3, DUI mode for 0 - 4). Search depth is measured from the importance of each question on sources of knowledge. Then, we added the number of questions that received a high value when low, mid, and high options were available. Note that we only consider the search depth for external sources of knowledge when the result is high (3 for STI, 4 for DUI).

The combination of the STI mode and DUI mode falls into one of four categories: STI depth and DUI depth, STI breadth and DUI breadth, STI depth and DUI breadth, and STI breadth and DUI depth. Based on an advanced method, we produced an interactive term for measuring each (González-Pernía et al., 2015). In order to prevent the probability of multicollinearity, we use mean-centering for each category.

〈Table 3〉 Overview sample by STI and DUI

Industry	Cooperation	Non-cooperation	Total
Within groups (DUI)	259(75.95%)	82(24.05%)	341(100%)
Suppliers (DUI)	114(33.43%)	227(66.57%)	341(100%)
Customers (DUI)	185(54.25%)	156(45.75%)	341(100%)
Competitors (DUI)	91(26.69%)	250(73.31%)	341(100%)
Consulting firms (STI)	53(15.54%)	288(84.46%)	341(100%)
Universities (STI)	64(18.77%)	277(81.23%)	341(100%)
Research Institutes (STI)	88(25.81%)	253(74.19%)	341(100%)

4.2.3 Control Variables

We also consider other effective variables in order to clarify the relations between the independent and dependent variables. We set control variables based on advanced research to control for differences in firm size, firm age, internal R&D, R&D workers, and the difference between industries (Leiponen and Helfat, 2010; Reichstein and Salter, 2006; Terjensen and Patel, 2015).

We selected the control variables as follows. First, firm size indicates differences in resource availability and can affect product innovation. Accordingly, the number of employees is converted to a natural log value and is controlled. Second, firm age is controlled because it reflects viability and know-how, which can affect performance. Third, internal R&D can have a meaningful effect on product innovation. However, our research objective is to determine the impact of external knowledge on product innovation. Thus, we measure and control for the amount invested in internal R&D. Fourth, we control for the number of R&D workers because this shows the absorptive capacity of a firm, which affects product innovation performance and learning from external knowledge. Finally, the nature of the industry seems to affect external knowledge learning. Thus, we include this as a dummy variable as a control.

〈Table 4〉 Overview of Measurement

Variables	Measurement	Reference
Exploratory innovation performance	Percentage of sales in 2011 of new products released in the market from 2009 to 2011	Laursen & Salter (2006)
Exploitative innovation performance	Percentage of sales in 2011 of the firm's significantly improved products, released in the market from 2009 to 2011	Laursen & Salter (2006)
STI depth	Importance of each question on sources of STI	Fitjar & Rodríguez-Pose (2013) Laursen & Salter (2006)
STI breadth	Sum of STI sources	Fitjar & Rodríguez-Pose (2013) Laursen & Salter (2006)
DUI depth	Importance of each question on sources of DUI	Fitjar & Rodríguez-Pose (2013) Laursen & Salter (2006)
DUI breadth	Sum of DUI sources	Fitjar & Rodríguez-Pose (2013) Laursen & Salter (2006)

〈Table 5〉 Descriptive statistics and correlations

	Mean	SD	Firm size	Firm age	Internal R&D	R&D workers	Industry	STI	DUI	STI depth × DUI depth	STI breadth × DUI breadth	STI depth × DUI breadth	STI breadth × DUI depth	Exploratory innovation	Exploitative innovation	Innovation performance
Firm size	4.01	1.23	1													
Firm age	16.85	10.12	.4570***	1												
Internal R&D	19.89	2.01	.6074***	.3072*	1											
R&D workers	1.98	1.21	.7815***	-.1049	.6257***	1										
Industry	26.22	3.31	.0631	.1305	.0867	.1260*	1									
STI	.601	.92	.2046***	-.0594	.2005***	.2576***	-.1497**	1								
DUI	1.90	1.27	-.0540***	-.0240	.0088	.0116	-.1108*	.3212***	1							
STI depth × DUI depth	.21	098	.0954	.0820	.1179*	.1223*	0.0593	.3095***	.2704***	1						
STI breadth × DUI breadth	1.18	3.00	.1161*	.0820	.1314*	.1816***	-.1638**	.5480***	.5818***	.3503***	1					
STI depth × DUI breadth	.31	1.19	.0678	.0010	.1247*	.1108*	.0382	.3922***	.3336***	.9038***	.4466***	1				
STI breadth × DUI depth	.51	1.51	.1037	.0484	.1690**	.1805***	-.0951	.4006***	.4881***	.6869***	.7134***	.6630***	1			
Exploratory innovation	16.06	30.65	-.0468	-.0518	-.0985	.0222	.0304	.0158*	-.0187	-.0138	.0294	-.0252	.0403*	1		
Exploitative innovation	26.82	34.0	-.0228	-.0194	-.0585	-.0389	-.0044	-.0783	-.0721	-.0224	.0221	-.0402	.0391***	-.3267***	1	
Innovation performance	43.88	37.61	-.0642	-.0649	-.1331*	-.0171	.0209	.0837*	.0804*	-.0315	.0439***	.0569**	.0682**	.5195***	0.6378***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Ⅴ. Results

5.1 Analysis

Table 5 shows the descriptive statistics and the Pearson correlations between the variables. Two exploratory and exploitative product innovation dependent variables have negative relations. Thus, It appears to be due to the trade-off between exploratory and exploitative product innovation.

We use a Tobit regression to analyze our hypotheses so as not to overestimate the coefficients, which can occur in a regression analysis if cut-off values of 0 - 100 are not considered for the independent variables. The results of the Tobit regression for Hypothesis 1a are shown in Table 6. Here, we analyze how the control variables affect the product innovation performance in model 1, and demonstrate that internal R&D and R&D workers have significant effects on exploratory innovation. Then, we analyze how the STI mode affects exploratory product innovation in model 2. The STI mode is related ($p < 0.05$) to exploratory

〈Table 6〉 Tobit regression for learning modes and exploratory innovation

	Model 1	Model 2	Model 3	Model 4
Firm size	-7.61 (5.66)	-6.45 (5.66)	-7.53 (5.65)	-6.53 (5.66)
Firm age	-.10 (.415)	-.12 (.414)	-.098 (.414)	-.133 (.412)
Internal R&D	-5.84* (2.42)	-6.02* (2.41)	-5.75* (2.41)	-5.91* (2.40)
R&D workers	16.46** (5.65)	15.06** (5.67)	16.45** (5.64)	14.80** (5.65)
Industry dummy	Included			
STI		20.76* (11.90)		21.69* (11.93)
STI^2		-6.49* (4.43)		-6.19* (4.41)
DUI			0.61* (9.61)	8.16* (9.79)
DUI^2			-.59** (2.30)	-2.26 (2.43)
Log likelihood	-871.9171	-870.2846	-871.7288	-869.8472
X^2 (pr 〉 X^2)	24.53*	27.79*	24.91*	28.67*
Pseudo R^2	.0139	.0157	0.0141	0.0162
N	341	341	341	341

Unstandardized path coefficients are reported, standard error between brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

product innovation performance, while the squared term has a negative relation ($p < 0.05$). Thus, the hypothesis of an inverted U-shaped relation is supported. Next, we analyze how the DUI mode affects exploratory product innovation in model 3. Here, the squared term has a positive relation ($p < 0.05$), once again indicating an inverted U-shaped relation.

We assume that the STI mode is superior to the DUI mode in the case of exploratory product innovation. To verify this, we converted each variable to a Fisher's z-score and tested whether the z-scores were significantly different. The Z-score is 2.66($p < 0.01$), which means that the STI mode is superior to the DUI mode for exploratory product innovation. Thus, Hypothesis 1a is supported.

Table 7 shows the results of the Tobit regression for Hypothesis 1b. Both the STI and DUI modes and the squared terms have significant results ($p < 0.05$), proving the inverted U-shaped relations. Thus, Hypothesis 1b is verified, indicating that the STI mode has less effect than does the DUI mode for exploitative innovation, based on the z-score

〈Table 7〉 Tobit regression for learning modes and exploitative innovation

	Model 1	Model 2	Model 3	Model 4
Firm size	-.321 (3.701)	-1.131 (3.697)	-.37 (3.71)	-1.228 (3.708)
Firm age	-.023 (.289)	-.0177 (.1.666)	-.019 (.289)	-.005 (.288)
Internal R&D	.906 (1.671)	1.022 (1.663)	.901 (1.673)	1.035 (1.664)
R&D workers	-1.001 (3.715)	-.276 (3.741)	-1.01 (3.721)	-.064 (3.751)
Industry dummy	Included			
STI		17.36* (8.402)		18.362* (8.498)
STI^2		-5.925* (3.141)		-5.845* (3.143)
DUI			22.06* (6.684)	23.758* (6.83)
DUI^2			-.583* (1.586)	-1.196 (1.681)
Log likelihood	-320.1493	-317.9983	-320.0719	-317.6641
X^2 (pr > X^2)	14.87*	19.17*	15.02**	19.84*
Pseudo R^2	.056	.072	.057	0.075
N	341	341	341	341

Unstandardized path coefficients are reported, standard error between brackets. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(-0.64) after converting each variable to a Fisher's z-score but it was insignificant. Thus, Hypothesis 1b is rejected.

Table 8 shows the results for Hypothesis 2. After adding the control variables to model 1, we verified the effect of product innovation, and found that internal R&D has a negative relation ($p < 0.05$), but that R&D workers has a positive relation ($p < 0.01$). Model 2 shows that the valid combination of STI depth and DUI depth has an inverted U-shaped relation by proving the correlations between STI depth and DUI depth and product innovation ($p < 0.05$). Similarly, the relation between the STI with DUI combination and product innovation performance is verified as having an inverted U-shape in model 3 ($p < 0.05$).

Model 4 shows the relations between STI depth and DUI breadth and product innovation performance, indicating a negative relation, even affecting product innovation when an ineffective searching mode or learning mode has a negative effect. Lastly, the relation between the combination of STI breadth and DUI depth and product innovation performance is verified as having an inverted U-shape in model 5 ($p < 0.05$). Hypothesis 2 suggests that the combination of STI breadth and DUI depth is the most effective for product innovation performance. Thus, we convert the variables of each mode to Fisher's z-scores to determine the gap between STI breadth and DUI depth. However, we ignore the difference in the influence of the combination of STI depth with DUI breadth because this has a negative relation with product innovation performance. The results show that the combination of STI depth and DUI depth has less of an effect (3.07; $p < 0.001$), as does the combination of STI breadth and DUI breadth (6.69; $p < 0.001$). In other words, the most effective combination is one of STI breadth and DUI depth, as assumed by Hypothesis 2.

5.2 Additional Analysis

We have proved that the combination of STI breadth and DUI depth has the strongest effect on product innovation performance. However, most studies emphasize the role of sales in product innovation because it can be measured in a commercial setting, unlike other methods such as patents (Collins and Smith, 2006; Guan et al., 2009). Nevertheless, we analyzed the robustness of the results by counting the number of patents as a further measure of product innovation performance. Using a Poisson distribution for the dependent variables added to the analysis, we limit the target to 203 firms for which we can count the number of patents earned. The results are shown in Table 9.

Based on the additional analysis, we find that no combination has an inverted U-shape, although STI-breadth and DUI-depth have a positive relation (see model 5). This result

〈Table 8〉 Tobit regression for H2

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Firm size	-4.238 (3.181)	-4.339 (3.184)	-4.123 (3.217)	-4.419 (3.18)	-4.471 (3.182)	-4.239 (3.23)
Firm age	-.231 (.248)	-.236 (.249)	-.232 (.238)	-.243 (.248)	-.202 (.25)	-.177 (.253)
Internal R&D	-.2.747* (1.424)	-2.654* (1.432)	-2.775* (1.673)	-2.599 (1.429)	-2.553 (1.433)	-2.468 (1.431)
R&D workers	8.067** (3.191)	8.024** (3.19)	8.087* (3.23)	8.126** (3.19)	8.095* (3.201)	7.61* (3.231)
Industry dummy			Included			
STI depth × DUI depth		3.162* (5.062)				19.829 (14.344)
(STI depth × DUI depth) ^{2}		-.628* (.882)				-2.677 (2.868)
STI breadth × DUI breadth			.487* (2.105)			5.385* (3.258)
(STI breadth × DUI breadth) ^{2}			-.072* (.213)			-.397 (.274)
STI depth × DUI breadth				-4.621* (4.437)		16.929 (12.937)
(STI depth × DUI breadth)^2				-.782 (.841)		2.232 (2.775)
STI breadth × DUI depth					5.109* (3.695)	10.669* (6.178)
(STI breadth × DUI depth) ^{2}					-.674* (.667)	1.336 (.974)
Log likelihood	-612.1482	-611.894	-612.0628	-611.6057	-611.5308	-609.4608
X^2 (pr 〉 X^2)	25.06*	25.57*	25.23*	26.15*	26.30*	30.44*
Pseudo R^2	.077	.079	.078	0.080	.081	.094
N	341	341	341	341	341	341

Unstandardized path coefficients are reported, standard error between brackets. * p〈0.05, ** p〈0.01, *** p〈0.001

〈Table 9〉 Additional analysis for H2

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Firm size	-.0285*** (.002)	-.0239*** (.0024)	-.0265*** (.002)	-.0252*** (.002)	-.0226*** (.002)	-.0217*** (.002)
Firm age	.5124*** (.035)	.5046*** (.036)	.5721*** (.038)	.5084*** (.036)	.5526*** (.035)	.5567*** (.040)
Internal R&D	.0441** (.0164)	.0187 (.0171)	.0043 (.0174)	.0182 (.0173)	.0049 (.0172)	-.0086 (.0185)
R&D workers	.133** (.032)	.1461*** (.032)	.0834* (.032)	.1484*** (.032)	.1106*** (.032)	.0947** (034)
Industry dummy	Included					
STI depth × DUI depth		.2453*** (.041)				.4288** (.164)
(STI depth × DUI depth)^2		-.0169** (.882)				-.0587* (.029)
STI breadth × DUI breadth			.1788*** (.021)			.1270*** (.033)
(STI breadth × DUI breadth)^2			-.0132*** (.002)			-.0091*** (.002)
STI depth × DUI breadth				.1702 (.037)		-.2801 (.152)
(STI depth × DUI breadth)^2				-.0067 (.006)		.037 (.029)
STI breadth × DUI depth					.0793* (.035)	.0905* (.053)
(STI breadth × DUI depth)^2					-.0077 (.005)	-.022 (.006)
Log likelihood	-1301.6063	-1256.6641	-1255.0567	-1260.4266	-1244.6801	-1233.6087
X^2(pr 〉 X^2)	1454.04***	1543.92***	1547.14***	1536.40***	1567.89***	1590.03***
Pseudo R^2	.3584	.3805	.3813	.3787	.3864	.3919
N	203	203	203	203	203	203

Unstandardized path coefficients are reported, standard error between brackets. * p〈0.05, ** p〈0.01, *** p〈0.001

strengthens the purpose of this study, supporting that the combination of STI-breadth and DUI-depth is the most effective, even though it does not follow an inverted U-shaped relations.

Ⅵ. Conclusion

6.1 Comprehensive Summary of the Study

The objectives of this study are to understand how learning from external knowledge affects the product innovation performance of a firm and how each learning mode affects product innovation by calculating the most effective combination of searching mode and learning mode. The results are as follows. First, the expected performance of product innovation is different for each learning mode. Additional sources that extend the breadth of knowledge in the STI mode, based on scientific knowledge, provide more possible exploratory product innovations. There are no significantly difference in the effect of DUI mode and STI mode on exploitative product innovation, but it is theoretically proven that the roles of each are different. Hypothesis 2 suggests that search breadth is more important for acquisition of scientific knowledge and search depth is more important for acquisition of tacit knowledge. Lastly, we show that choosing an ineffective knowledge search combination between STI and DUI negatively affects product innovation performance.

6.2 Implications for Management Practice and Theory

The resources available to firms pursuing product innovation are limited. Thus, in order to achieve successful product innovation, a firm must differentiate its knowledge learning according to the types of product innovation performance, and a manager should choose the best strategy from the combination. Therefore, a manager requires insight to make a correct choice.

In this study, the types of product innovation that a firm can pursue are classified into exploratory innovation and exploitative innovation. And further, knowledge types and acquisition modes are classified. This study provides a combination of knowledge acquisition to be pursued according to the type of innovation.

The academic contribution of this research is as follows. Prior studies separate the types of external knowledge and identify their effects on product innovation.

In addition, they determine the effect of an acquisition strategy for external knowledge on product innovation performance. However, few studies consider both elements. We examine both empirically.

This study distinguishes the knowledge

types of STI and DUI, and further divides the knowledge acquisition modes into depth and breadth. This is meaningful in that the existing research did not consider the type of knowledge and the modes of acquisition at the same time. Furthermore, this study contributes to the development of open innovation research by defining each combination as a knowledge acquisition strategy and analyzing the differential effects of each on exploratory innovation and exploitative innovation.

In addition, this study focuses on Korea. In recent years, external knowledge research has been actively conducted in Korea(Lee, Park and Bae, 2016). However it still most active in terms of learning and exchanging knowledge, unlike other studies that focus on Western countries. Furthermore, this study contributes to finding an effective combination of knowledge searching (i.e., search breadth and search depth) for each mode of learning from external knowledge (i.e., STI mode and DUI mode), which is another driving force behind Korea's rapid growth during the last 30 years. Then, we compare the figures by country using the KIS database, which is based on the CIS database, when choosing the source of the data.

6.3 Limitations and Future Research Directions

Nevertheless, our research has limitations. Even though the data sources in this research are verified by the KIS, we could not control the survey process. For example, in enterprise-level research, a respondent should represent a firm, but it is extremely difficult to verify this. In addition, it is highly likely that a respondent in one survey can answer all the questions. Thus, there may be a common method bias in this research. In addition, because the data are cross-sectional, an investigation of the causal relationship is extremely difficult. Moreover, to compare the influence of the various coefficients, the most common method is to do so using standardized coefficients. However, additional statistical methods are required for a clearer comparison.

To complement and improve this research, the following are recommended. In this study, innovation performance is limited to product innovation. However, firms pursue other types of innovation, and external knowledge sources have different effects on each type. Thus, future research should consider this. In addition, depending on the type of innovation, the types of strategy seem to be more diverse. Thus, future research should diversify the desirable acquisition strategies of external knowledge. Finally, exploratory innovation refers to the first innovation by a firm in a market. Therefore, future research should consider the novelty of innovation.

In this study, Fisher's Z-score was used to test the hypothesis. However, this is not an optimal method to clearly distinguish differences between independent statistical models. Fisher's Z-score is one of the most effective ways to compare the magnitudes of two values by standardizing the coefficient values of each model, but it does not have statistical rigor depending on the characteristics of regression analysis. Therefore, future research needs to be improved and researched.

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• The author Jaegun Lee is an Ph.D. student at the School of Business Administration, Kyungpook National University, Korea. He earned his MA in strategy and organization from the School of Business Administration, Kyungpook National University, Korea. His research interests include failure experience, and R&D cooperation.

• The author Moon-Goo Huh, (Ph.D. Korea University) is a professor of strategy and organization at the School of Business Administration, Kyungpook National University, Korea. His current research interests include dynamic capability, competitive strategy, ambidextrous organization, knowledge and innovation, and social capital.

〈Appendix I〉 Fisher's Z-score transformation

To compare the coefficients of the other models, the Z-score was transformed using the following equation. At this time, since the coefficient is larger than 1, the value is multiplied by 0.01.

$$z_1 = \frac{\ln\left(\frac{1+b_1}{1-b_1}\right)}{2} = \frac{\ln\left(\frac{1+0.2076}{1-0.2076}\right)}{2} = 0.2106$$

z_1 is transformation equation for STI coefficient.

$$z_1 = \frac{\ln\left(\frac{1+b_2}{1-b_2}\right)}{2} = \frac{\ln\left(\frac{1+0.0061}{1-0.0.061}\right)}{2} = 0.0061$$

z_2 is transformation equation for DUI coefficient.

$$z = \frac{z_1 - z_2}{\sqrt{\frac{1}{n_1-3}+\frac{1}{n_2-3}}} = \frac{0.2106-0.0061}{\sqrt{\frac{1}{341-3}+\frac{1}{341-3}}} = 2.66$$

p-value of 2.66 is 0.0039 in one-tailed test.

$$z_1 = \frac{0.5639-0.3274}{\sqrt{\frac{1}{341-3}+\frac{1}{341-3}}} = 3.07$$

z_1 is a difference between [STI breadth and DUI depth] and [STI depth and DUI depth]
p-value of 3.07 is 0.0011 in standard normal distribution.

$$z_2 = \frac{0.5639-0.0487}{\sqrt{\frac{1}{341-3}+\frac{1}{341-3}}} = 6.67$$

z_2 is a difference between [STI breadth and DUI depth] and [STI breadth and DUI breadth]
p-value of 6.69 is 0.0001 in standard normal distribution.