Journal of the Association for Information Systems

JAIS

Research Article

Complementarities and Substitutabilities Among Knowledge Sourcing Strategies and Their Impact on Firm Performance

Byounggu Choi
Kookmin University
h2choi@kookmin.ac.kr

Jae-Nam Lee
Korea University
isjnlee@korea.ac.kr

Abstract

Knowledge sourcing strategy (KSS) is regarded as a key determinant of successful Knowledge Management (KM). However, prior research on how KSSs can improve firm performance has produced inconsistent results. This may be due to inadequate consideration of complementary and substitutable relationships in KSSs. Whereas previous studies have assessed the impact of individual KSS on firm performance, in practice firms adopt several different KSSs simultaneously. Drawing on the Knowledge-based View (KBV) and the complementarity theory, this study investigates the impact of multiple KSSs, in terms of sourcing type and origin, to develop three sets of hypotheses on complementarity and substitutability. Survey data collected from 372 firms in Korea are analyzed to test the hypotheses using the supermodularity and submodularity functions. The results confirm complementary relationships between system- and external-oriented, between person- and internal-oriented, and among system-, person-, and internal-oriented strategies, as well as substitutable relationships between person- and external-oriented strategies. Interestingly, different knowledge sourcing patterns between knowledge intensive and non-knowledge intensive environments are revealed. This study expands KM research by developing a new conceptual framework of KSSs and employing advanced analytical approaches to explore the relationships between KSSs and firm performance. It also offers valuable practical suggestions for managers in selecting successful combinations of KSSs using a judicious combination of system- and external-oriented, of person- and internal-oriented, or of system-, person-, and internal-oriented strategies.

Keywords: *Knowledge Sourcing Strategies, Knowledge Management, Knowledge-based View, Complementarity Theory, Complementary, Substitutability, Knowledge Intensive Environment, Firm Performance, Supermodularity, Submodularity.*

* Kalle Lyytinen was the accepting senior editor. This article was submitted on 5th July 2010 and went through three revisions.

Volume 13, Issue 7, pp. 498-545, July 2012

1. Introduction

Regarded as the first and most important step in effective knowledge management (KM), knowledge sourcing accesses, acquires, and reuses different types of knowledge such as expertise, experience, insights, and opinions (Chen & Lin, 2004). Most firms strive to realize the benefits of KM by effectively using various knowledge sources. An appropriate knowledge sourcing strategy (KSS) enables an organization to efficiently create, acquire, and access knowledge by reducing search and transfer costs, thus resulting in better firm performance (Gray & Meister, 2004). The knowledge management literature has devoted substantial attention to the analysis of KSSs, and the associated research has identified several dimensions of KSSs at the firm level, including (1) the extent to which knowledge is accessed through a person or a system (i.e., sourcing type), and (2) whether it originates from within or outside the firms (i.e., sourcing origin) (Menon & Pfeffer, 2003; Mitchell, 2006).

While these studies have increased our knowledge of KSSs, our understanding of their roles and impact remains fragmented for several reasons. First, most previous studies exploring the performance consequences of KSSs examine only one sourcing strategy at a time (DeCarolis & Deeds, 1999; Haas & Hansen, 2005), even though KSSs are not mutually exclusive and firms actually adopt them in a combined manner. Considering a KSS as an isolated decision can lead to seriously inappropriate inferences. For example, many KM researchers have concluded that information technology (IT) exerts a limited impact on KM (Powell & Dent-Micallef, 1997), insisting that a system-oriented sourcing strategy, such as published sourcing based on IT, can result in poor predictions that do not help achieve effective KM (Gray & Meister, 2006; Lee & Choi, 2003). However, these results may differ if the synergistic impact between system-oriented KSS and other KSSs is considered. Second, although several studies have investigated the synergistic impact of KSSs on firm performance, they have generally considered the impact of a single sourcing dimension (i.e., either sourcing type or sourcing origin) without considering the synergistic impact of KSSs across different sourcing dimensions (Cassiman & Veugelers, 2006; Nevo, Wade, & Cook, 2007). It is clearly necessary to investigate the synergistic impact of KSSs across different knowledge sourcing dimensions to improve understanding of the impact of KSSs on firm performance. Finally, even recent studies emphasizing synergy employ a "reductionistic" perspective, consequently limiting the degree to which the true relationship between KSSs and firm performance can be ascertained (De Clercq & Dimov, 2008). For example, previous research examining the synergy between more than two practices or variables has frequently resorted to estimating pair-wise interaction effects (Belderbos, Carree, & Lokshin, 2006). This approach causes problems because it omits relevant terms and is likely to have an omitted variable bias, thus resulting in incorrect inferences (Lokshin, Carree, & Belderbos, 2004).

To explore these research gaps, this paper uses the knowledge-based view (KBV) to propose KSSs based on two different aspects of knowledge sourcing – namely "type" (i.e., system oriented and person oriented) and "origin" (i.e., internal oriented and external oriented) – because KSS implementation requires not only appropriate forms of knowledge sourcing but also proper organizational boundaries. This study defines KSS as a logical pattern regarding decisions of firms on knowledge sourcing type and origin to gain a sustainable competitive advantage. Then, drawing on the complementarity theory from economics literature (Milgrom & Roberts, 1995), this study theoretically explores the positive or negative synergistic patterns in the strategic usage of KSSs and their impact on firm performance. The complementarity approach can be conceptualized in terms of the notion of synergy, which holds that the valuation of a combination of agents (or forces) exceeds the sum of valuations for stand-alone agents (or forces) (Barua, Lee, & Whinston, 1996; Massini & Pettigrew, 2003). Thus, the complementarity approach helps integrate the type and origin aspects of knowledge sourcing and allows for a holistic examination of the impact of interplay among KSSs on firm performance. With an adequate theoretical foundation, this study can contribute to our understanding of whether and in what manner KSSs improve or worsen firm performance. For example, this study may help explain why many IT-focused knowledge sourcing efforts face difficulties in building effective KM environments.

This paper is motivated by the following question: "Which KSSs work well together?". If firms were aware of the complementary or substitutable relationship among KSSs, they might be able to decide, based on their current KSSs, which other KSSs should be adopted to improve performance. The present study attempts to answer this question using data collected from 372 Korean firms that have implemented enterprise-wide KM initiatives. The results of this study may be added to those of existing US-based and European studies to provide a more international perspective on KSSs.

2. Theoretical Background

2.1. Knowledge-Based View: Dimensions of KSS

The knowledge-based view (KBV) has played a critical role in examining the impact of various KSSs on firm performance. The KBV recognizes organizational knowledge as the most important resource guiding managerial decision-making (Santoro & Bierly, 2006). Included in the core assumptions of this view are the following: i) The principal function of an organization is to create, integrate, and apply knowledge; and ii) If firms possess unique knowledge bases and the capability to manage different knowledge areas, sustainable competitive advantages and performance differences eventually result (Grant, 1996). According to this theoretical perspective, managers can improve the performance of their firms by developing a narrow set of core competencies and capabilities based on unique knowledge embedded and conveyed through multiple entities, including routines, documents, systems, and employees. The principal focus of KBV is value creation (Bogner & Bansal, 2007), and thus, its core issue is to understand how knowledge sourcing is pursued in firms to create organizational capability and value.

A critical contribution of KBV is the recognition of two different KSSs from the knowledge sourcing type perspective: system-oriented and person-oriented KSSs (Haas & Hansen, 2005; Santoro & Bierly, 2006). System- and person-oriented sourcing strategies provide the mechanisms that underlie the creation, access, and acquisition of explicit and tacit knowledge. System-oriented sourcing strategy relies on explicit knowledge and attempts to improve firm performance using documents and IT, such as by organizing for content management and using portals to share knowledge (Kankanhalli, Tanudidjaja, Sutanto, & Tan, 2003). Other terms for this strategy include codification (Hansen, Nohria, & Tierney, 1999), non-relational learning (Rulke, Zaheer, & Anderson, 2000), and published sourcing (Gray & Meister, 2006). The person-oriented sourcing strategy generally deals with complex and tacit knowledge, and employs direct person-to-person contact and socialization processes to increase the efficacy of KM (Choi, Poon, & Davis, 2008). Examples include generating good practices through communities of practice and lessons learned from debriefings. Considered as parts of this strategy are several sourcing strategies, including personalization (Hansen et al., 1999), relational learning (Rulke et al., 2000), and dyadic sourcing (Gray & Meister, 2006).

Another crucial contribution of KBV is the identification of two different KSSs from the knowledge sourcing origin perspective: internal-oriented and external-oriented KSSs (Bierly & Chakrabarti, 1996; Menon & Pfeffer, 2003). An internal-oriented KSS attempts to increase firm performance by integrating knowledge within the boundary of the firm (De Clercq & Dimov, 2008; Kessler, Bierly, & Gopalakrishnan, 2000). Practical examples of internal-oriented sourcing strategy include the extraction of meaningful knowledge from the innovation process and the new product introduction process, the use of previous knowledge in generating technical and price proposals, and the fostering of the knowledge of core competence centers. Knowledge generated in a firm tends to be unique and specific, which makes it difficult for competitors to imitate, and ultimately resulting in considerable value to the firm. In contrast, external-oriented KSS attempts to bring in knowledge from outside sources through acquisition or imitation, and to then disseminate such knowledge across the organization (Prabhu, Chandy, & Ellis, 2005). Firms can obtain fresh ideas from supplier-buyer partnerships, outsourcing agreements, joint research projects, and so on, and use these fresh ideas to complement their knowledge base, thereby improving firm performance (Zack, 1999).

2.2. Adoption Patterns of KSS: Depth and Breadth

According to KBV, firms' efforts toward successful KSS implementation can vary depending on the depth and the breadth of knowledge sourcing (Katila & Ahuja, 2002). The importance of the ability of a firm to decide on an appropriate level of knowledge sourcing depth has long been acknowledged as an important step toward successful KSS implementation (Lin, Chen, & Wu, 2006). Knowledge sourcing depth is defined as the degree of sophistication and complexity of the knowledge sources a firm uses (Ryu, Kim, Chaudhury, & Rao, 2005). Depending on how a firm uses person- or system-oriented KSS, the depth of knowledge sourcing can vary. If the knowledge sourcing efforts of a firm through person- and/or system-oriented strategies increase, the amount of accumulated knowledge stock in a firm increases as well. Once the accumulated knowledge stock of a firm increases, the ability to draw new conclusions and identify new links among the accumulated knowledge stocks may be improved. The improved ability enables the firm to use more sophisticated and complex knowledge sources, eventually resulting in a deeper knowledge base (Ryu et al., 2005).

Knowledge sourcing breadth is defined as the degree of variety or diversity of knowledge sources utilized by a firm (Leiponen & Helfat, 2010; Ryu et al., 2005). Knowledge a firm exploits may be sourced either internally through organizational learning (De Clercq & Dimov, 2008) or externally via inter-firm relationships (Hoang & Rothaermel, 2010). Accordingly, how widely a firm employs internal- or external-oriented KSS may determine the breadth of knowledge sourcing. Knowledge sourcing efforts of a firm conducted through internal- and/or external-oriented KSS facilitate knowledge flow within and/or across its boundaries. Sequentially, this action necessarily increases the likelihood of exposure to various and diverse knowledge sources, thereby leading to a broad range of knowledge bases (Zahra & Nielsen, 2002).

Figure 1 presents all possible combinations of KSSs based on the depth of knowledge sourcing type and the breadth of knowledge sourcing origin.

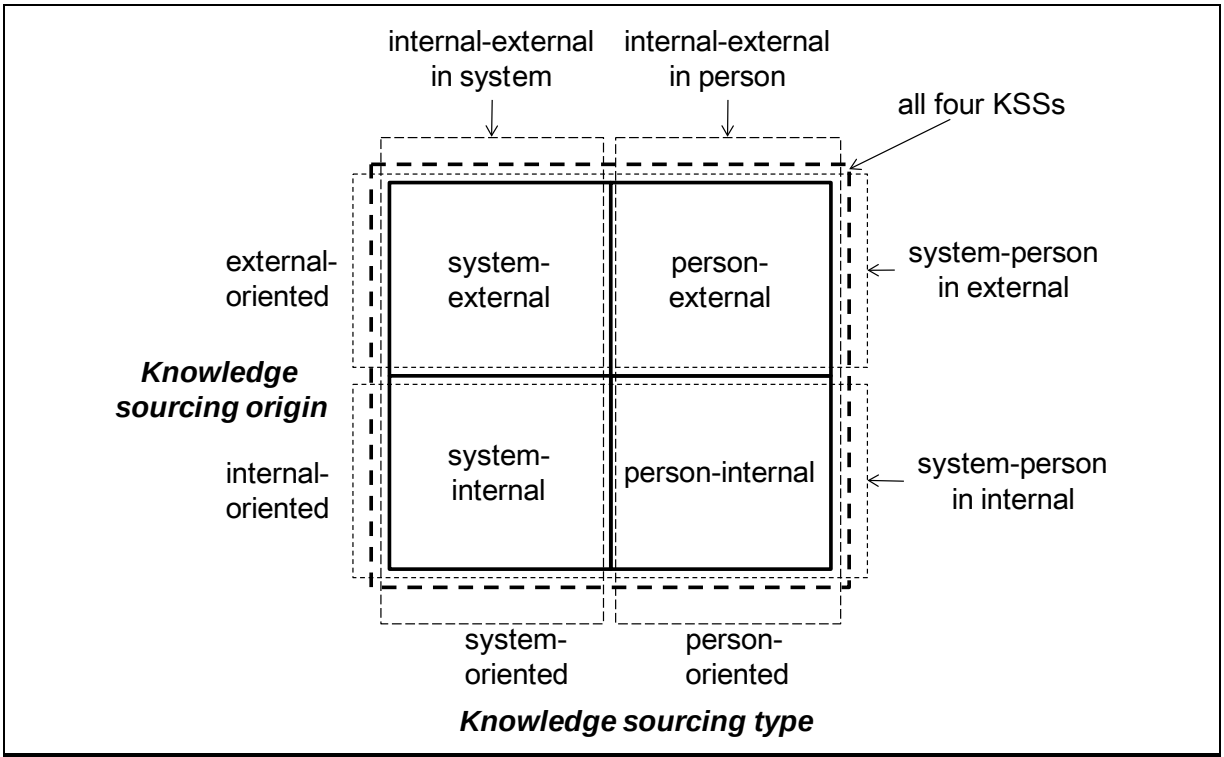


Figure 1. KSS Combinations

Whether a firm pursues all four possible KSSs (i.e., system-, person-, internal-, and external-oriented), referred to as high-depth and wide-breadth KSSs, or the two selected KSSs from each dimension, referred to as low-depth and narrow-breadth KSSs, directly affects how well specific KSSs work together to improve firm performance[1]. KSSs incur significant costs and require numerous resources; hence, understanding which KSS combinations create a positive synergistic impact on firm performance is essential. Appendix A summarizes known arguments about various combinations of KSSs.

2.3. Complementarity and Substitutability in KSS

"Complementarity" between activities can be viewed as existing if, and only if, increasing the level of any one activity leads to a higher marginal return for the other activities (Barua et al., 1996; Milgrom & Roberts, 1995). By the same token, "substitutability" exists if increasing the level of any one activity reduces the marginal or incremental returns of the other activities (Lokshin et al., 2004). In the differentiable framework, complementarities correspond to positive mixed partial derivatives of certain payoff functions (Mohnen & Roller, 2005). However, standard assumptions of the payoff function, such as concavity and divisibility, are unnatural or extremely restrictive to the many organizational or economic problems one intends to address (Massini & Pettigrew, 2003). To overcome these restrictive assumptions, Milgrom and Roberts (1995) developed mathematics for complementarities by drawing on the lattice theory and supermodularity without referring to standard assumptions. Supermodularity helps clarify complementarity; thus, it is useful for testing the existence of the latter (Cassiman & Veugelers, 2006).

Despite its importance, complementarity has not been properly addressed in previous literature on knowledge sourcing (see Appendix A). First, only a few studies have investigated the synergistic effects of KSSs on firm performance. That is, previous studies have explored the manner in which individual KSSs influence firm performance (DeCarolis & Deeds, 1999). Mitchell (2006), for example, considered internal and external knowledge sourcing as isolated decisions, and individually examined the relationship between timely project completion and internal knowledge sourcing, and between timely project completion and external knowledge sourcing. Second, little attention has been paid to potential complementarities and substitutabilities between knowledge sourcing types and origins (DeCarolis & Deeds, 1999; Dierickx & Cool, 1989). Previous studies that have dealt with the synergistic impacts of KSSs on firm performance have focused primarily on the complementarities and substitutabilities within either knowledge sourcing type or sourcing origin (see depth-focused or breadth-focused studies in Appendix A) rather than those between them. However, the ability of the firm to achieve superior performance is a function of the flow of selected valuable knowledge across its boundary (Dierickx & Cool, 1989). To understand this function, it is essential to understand the relationship between sourcing type (i.e., the selection of appropriated knowledge) and origin (i.e., the flow of knowledge) dimensions. Third, no previous study has assessed complementarity or substitutability with more than two KSSs based on knowledge sourcing type and origin dimensions. Although several studies have considered the four sourcing strategies (Zahra & Nielsen, 2002), they simply estimated pair-wise interaction effects and ignored the interaction with others (see depth- and breadth-focused studies in Appendix A). For example, Kyriakopoulos and Ruyter (2004) examined complementarity between person- and internal-oriented strategies by simply estimating their interaction effects, ignoring the interaction of person- and internal-oriented strategies with system- or external-oriented strategies. However, such testing schemes cannot fully reflect a true complementary relationship, because a proper complementarity or substitutability test requires testing for multiple inequality restrictions imposed by all possible combinations of KSSs (Lokshin et al., 2004).

While KSSs are significant to firm performance in general, little is currently known regarding which combinations of sourcing strategies matter, and why they matter. Limited information is currently available on whether the adoption of knowledge sourcing type and origin dimensions is complementary or substitutable. This insufficiency in the KM literature should be carefully considered, with an eye toward a more detailed comprehension of KSS.

[1] Although a firm may pursue only one KSS, this paper excludes this situation because our focus is on the synergistic impacts of two or more KSSs on firm performance.

3. Development of Hypotheses

3.1. Low-Depth and Narrow-Breadth KSSs

3.1.1. System-Oriented Strategy and Origin Dimension

The efforts of a firm to source knowledge residing in internal information systems or documents, namely, a combination of system- and internal-oriented knowledge (e.g., sourcing of knowledge by a manufacturing firm from its enterprise knowledge portal to improve convenience of internal users and to share valuable contents among internal users), may cause firm performance to deteriorate. To guide their thinking and behavior, organizational members depend heavily on decontextualized and encoded knowledge in routines, such as formal rules or policies. Such a condition can result from over-reliance on system- and internal-oriented strategies, which could result in the loss of the causal ambiguity of internal knowledge (Haas & Hansen, 2005). As ambiguity renders the duplication or imitation of knowledge difficult, the loss of ambiguity results in outgoing knowledge spillovers and the erosion of the performance advantage of a firm (Gopalakrishnan & Bierly, 2006). For example, Haas and Hansen (2005) demonstrated that increased reliance on internal codified knowledge results in deteriorations in team performance. Furthermore, routines based on system- and internal-oriented strategy are habitual; this may prove detrimental to the innovativeness or creativity of a firm (Patnayakuni, Ruppel, & Rai, 2006). Hence, firms may be led to focus on exploiting existing codified knowledge rather than exploring new ones, thereby creating core rigidities (i.e., inappropriate knowledge sets that preserve the status quo and limit new insights) and resulting in barriers to performance improvement (Leonard-Barton, 1995).

However, the KBV suggests that a combination of system- and external-oriented knowledge sources (e.g., a government KM center established for systematically connecting to and communicating with external parties) can provide firms with opportunities to improve their competitiveness. By accessing specialized and standardized external codified knowledge, such as technical reports, trade journals, and other sources, a firm can develop a broader knowledge base and keep abreast of emerging technologies, which enables it to create and update its knowledge (Schulz, 2001). For example, Caloghirou, Kastelli, and Tsakanikas (2004) found evidence that scientific/business journals positively affect the level of innovativeness of firms. Furthermore, a firm can readily adopt external codified knowledge and assimilate it with other activities and processes to create new knowledge, since standardized codified knowledge is generally regarded as less sensitive to space than embedded knowledge specific to an individual is. Gopalakrishnan and Bierly (2001) empirically demonstrated that the more explicit the knowledge associated with an innovation, the more likely it is to be externally sourced. Therefore, we propose the following hypotheses:

> ***H1a:*** *The simultaneous use of system- and internal-oriented sourcing strategies worsens firm performance compared to the use of a single strategy. Hence, a substitutable relationship exists between them.*
>
> ***H1b:*** *The simultaneous use of system- and external-oriented sourcing strategies leads to better firm performance compared to the use of a single strategy. Hence, a complementary relationship exists between them.*

3.1.2 Person-Oriented Strategy and Origin Dimension

The KBV proposes that a combination of person- and internal-oriented knowledge (e.g., valuable experience, know-how, and networks of internal experts sourced by a firm in the steel industry through communities of practice) can provide a firm with competitive advantage (Zahra & Nielsen, 2002). Knowledge from this sourcing combination cannot be built overnight, as such knowledge has firm-specific and tacit characteristics that make it difficult for competitors to imitate and copy (Nonaka & Takeuchi, 1995). Moreover, individuals can readily access and acquire knowledge from internal personnel (e.g., through asking collocated coworkers) rather than from a codified source (e.g., by searching for best practices) (Teigland & Wasko, 2003). For example, Zahra and Nielsen (2002)

demonstrated that the use of internal person-oriented sourcing is positively related to the numbers of new products, radicalness of new products, patents, and technology commercialization.

However, a combination of person- and external-oriented knowledge (e.g., an insurance firm's asking salespeople to attend various outside education programs related to presentation, communication, and computer skills to efficiently communicate with customers), may exert an adverse effect on its performance. Knowledge from external personnel (e.g., external experts or consultants) is largely tacit in nature because it is tightly embedded in external individuals (Leiponen, 2006). Thus, it is generally difficult to understand and interpret knowledge from these sources, and this leads to its frequent misapplication (Bierly & Chakrabarti, 1996). This problem is exacerbated when the firm lacks expertise in that knowledge (Kessler et al., 2000). Likewise, the combination of external personnel knowledge and the existing knowledge base of a firm may prove time-consuming or may result in solutions incompatible with a specific situation of a firm (Teigland & Wasko, 2003). Zahra and Nielsen (2002) found that external person-oriented sourcing is negatively related to the number of patents and radicalness of new products. This leads to the following hypotheses:

> ***H1c:*** *The simultaneous use of person- and internal-oriented sourcing strategies leads to better firm performance compared to the use of a single strategy. Hence, a complementary relationship exists between them.*
>
> ***H1d:*** *The simultaneous use of person- and external-oriented sourcing strategies worsens firm performance compared to the use of a single strategy. Hence, a substitutable relationship exists between them.*

3.2. High-Depth or Wide-Breadth KSSs

3.2.1. KSSs Focusing on Type Dimension

The presence of a system-oriented KSS can positively affect a person-oriented KSS. A system-oriented KSS spurs greater sourcing from documents or information systems (Kankanhalli et al., 2003; Zander & Kogut, 1995), which, in turn, necessitates a more person-oriented KSS, because the retention of experts or skilled colleagues is critical for the creation of new and more codified knowledge. A person-oriented KSS also facilitates the value of a system-oriented KSS. Greater context-specific characteristics of person-oriented KSSs allow managers to more accurately use their codified knowledge to solve their problems. Thus, prior studies have supported the notion of complementarity between system- and person-oriented KSSs. For example, Kyriakopoulos and Ruyter (2004) empirically demonstrated that the use of both strategies enhances short-term financial performance and new product creativity. Consistent with such studies, this study agrees with the idea of the complementarity between system- and person-oriented KSSs.

Recall that the simultaneous use of system- and internal-oriented KSSs is hypothesized to have a negative impact on firm performance (H1a), whereas the simultaneous use of person- and internal-oriented KSSs is hypothesized to have a positive impact on firm performance (H1c). However, based on the above mentioned complementary relationship between system- and person-oriented KSSs, the relative magnitude of the positive effect of person- and internal-oriented KSS is believed to be greater than that of the negative effect of system- and internal-oriented KSS. The principal negative effects of the system- and internal-oriented KSSs (i.e., loss of causal ambiguity and core rigidities) can be diminished by adopting person- and internal-oriented KSSs. The person- and internal-oriented KSSs can suggest new meanings, interpretations, or linkages among existing internal codified knowledge based on the firm-specific skills and experiences of internal personnel (Moorman and Miner, 1998), thereby attenuating the negative effects of the system- and internal-oriented KSSs. This indicates that the positive impact of the person- and internal-oriented KSSs may be prolonged by adopting the system- and internal-oriented KSS in combination. In addition, knowledge from internal personnel may be susceptible to loss because the holder of that knowledge can leave the firm. To protect knowledge and enjoy the benefits of person- and internal-oriented KSS, knowledge from internal personnel should be captured, shared, and applied using information systems within the firm. Although managing

personal knowledge is difficult, the system- and internal-oriented KSS makes this knowledge more fluid and transferable (Schulz, 2001), thus facilitating the value of person- and internal-oriented KSS.

In a similar fashion, the positive effect of system- and external-oriented KSSs is believed to be greater than the negative effect of the person- and external-oriented KSSs. Note that the adoption of system- and external-oriented KSSs has been hypothesized to exert a positive impact on firm performance (H1b), whereas the adoption of person- and external-oriented KSSs has been hypothesized to exert a negative impact on it (H1d). The positive impact of external system-oriented KSSs is likely to be intensified when combined with the external person-oriented KSSs. In this case, the external person-oriented KSSs help unfreeze mental maps or shared mental models of internal members, allowing a firm to remain open to multiple viewpoints (Kyriakopoulos & Ruyter, 2004). This openness enables a firm to interpret, understand, and apply codified external knowledge more diversely, providing a means of overcoming barriers to developing new knowledge and capabilities (Capron & Mitchell, 2009). In contrast, the negative impact of external person-oriented KSSs is likely to be diminished when combined with external system-oriented KSSs. Internal members seek to protect their status and power, and, thus, may strongly resist attempts to bring in external personnel knowledge that is difficult to understand and codify (Capron & Mitchell, 2009). However, external personnel tend to have a higher level of external system-oriented knowledge, such as industry and occupational best practices, than internal members of a firm do (Matusik & Hill, 1998). Thus, the more firms want access to the higher level of external system-oriented knowledge, the more they need to broaden the connection with external personnel. This reduces the resistance of internal members to the use of knowledge from external personnel. This leads us to the following hypotheses:

> ***H2a**: The simultaneous use of system-, person-, and internal-oriented sourcing strategies leads to better firm performance compared to the use of a single strategy. Hence, a complementary relationship exists among them.*
>
> ***H2b:** The simultaneous use of system-, person- and external-oriented sourcing strategies leads to better firm performance compared to the use of a single strategy. Hence, a complementary relationship exists among them.*

3.2.2. KSSs Focusing on Origin Dimension

It is a truism that internal- and external-oriented KSSs exist separately, but it has been suggested that a combination thereof tends to be more valuable for firms (De Clercq & Dimov, 2008; Zack, 1999). External-oriented knowledge sourcing can enhance the value of internal-oriented knowledge sourcing by providing firms with access to new knowledge, resulting in the expansion of their existing knowledge base (Kyriakopoulos & Ruyter, 2004). In addition, internal-oriented knowledge can substantially improve the outcomes of organizations by combining effective external learning because organizations cannot anticipate the value of and apply insights from external knowledge without a certain level of internal knowledge (Cohen & Levinthal, 1990). Thus, the complementary relationship between internal- and external-oriented KSSs has been both theoretically and empirically investigated. For example, Cassiman and Veugelers (2006) illustrated that the combination of internal R&D and external knowledge sourcing activities increases the innovation performance of a firm. Consistent with the broader arguments from KM literature, this study believes in complementarity between internal- and external-oriented KSSs.

Accordingly, this study supports the notion that the relative magnitude of the positive effects of system- and external-oriented KSS is larger than the negative effect of the system- and internal-oriented one. The KBV suggests that the system- and external-oriented KSSs may enhance firm performance by bringing in new and explicit knowledge generated by outside firms, and by enabling firms to develop and retain diverse perspectives on critical business issues (H1b). This positive impact of the system- and external-oriented strategy could be enhanced by effectively combining it with system- and internal-oriented strategy because the speed with which a firm can value, assimilate, and apply external system-oriented knowledge depends on its internal knowledge level (Cohen & Levinthal, 1990). On the contrary, the negative impact of system- and internal-oriented KSS (H1a) could be mitigated by adopting the system- and external-oriented one. System- and external-

oriented sources not only produce more dynamic and heterogeneous knowledge, but also generate new meanings and interpretations via the combination of internal codified knowledge (Schulz, 2001), consequently avoiding the loss of causal ambiguity and core rigidities induced by system- and internal-oriented strategy. Thus, the achievement of competitive advantage depends on the ability of a firm to absorb and utilize system- and external-oriented knowledge, as well as the firm's ability to integrate it with system- and internal-oriented knowledge (DeCarolis & Deeds, 1999; Hoang & Rothaermel, 2010).

Moreover, this study supports the notion that the positive effect of a person- and internal-oriented KSS is beyond the negative effect of the person- and external-oriented one. The positive impact of a person- and internal-oriented KSS (H1c) is enhanced with a person- and external-oriented strategy. Exposure to a greater variety of external personnel knowledge that is inconsistent with current norms or beliefs enhances the creativity of internal members. This enables internal members to perceive things differently, break out of perceptual or cognitive patterns, and add to the breadth of knowledge considered by internal members in their choice sets (Taylor & Greve, 2006). Therefore, firms are more likely to create new and unique knowledge by combining internal tacit knowledge with new external personnel knowledge. Furthermore, the negative impact of a person- and external-oriented KSS (H1d) is diminished when the person- and internal-oriented KSS is already well established. The internal person-oriented KSS leads to firm-specific knowledge that enables internal members to monitor and evaluate externally generated knowledge, resulting in lower resistance to external personnel knowledge (Bierly, Damanpour, & Santoro, 2009). The internal- and person-oriented KSS of a firm also enables it to fully realize the benefits of external personnel knowledge, as it cultivates the firm's ability to better understand the value of external knowledge (Hoang & Rothaermel, 2010). Therefore, collaboration between internal members and external experts may prove effective in integrating internal tacit knowledge with external person-oriented sources, thus resulting in better firm performance. This leads us to the following hypotheses:

H3a: *The simultaneous use of internal-, external-, and system-oriented sourcing strategies leads to better firm performance compared to the use of a single strategy. Hence, a complementary relationship exists among them.*

H3b: *The simultaneous use of internal-, external-, and person-oriented sourcing strategies leads to better firm performance compared to the use of a single strategy. Hence, a complementary relationship exists among them.*

Table 1. Main Argument of Each Hypothesis

Hypothesis	Main Argument
1a The simultaneous use of system- and internal-oriented sourcing strategies worsens firm performance (i.e., substitutability).	Loss of causal ambiguity due to system- and internal-oriented strategies increases risk of imitation by rivals.
1b The simultaneous use of system- and external-oriented sourcing strategies leads to better firm performance (i.e., complementarity).	Developing a broader knowledge base and keeping abreast of emerging technologies based on system- and external-oriented strategies enable a firm to create and update its knowledge.
1c The simultaneous use of person- and internal-oriented sourcing strategies leads to better firm performance (i.e., complementarity).	Firm-specificity and tacitness of person- and internal-oriented strategies make it difficult for competitors to imitate and copy.
1d The simultaneous use of person- and external-oriented sourcing strategies worsens to lower firm performance (i.e., substitutability).	It is difficult to understand and interpret embedded knowledge in external individuals, leading to misapplication of it frequently.

Table 1. Main Argument of Each Hypothesis (cont.)

Hypothesis	Main Argument
2a The simultaneous use of system-, person-, and internal-oriented sourcing strategies leads to better firm performance (i.e., complementarity).	The person- and internal-oriented sourcing strategy can suggest new meanings, interpretations, or linkages among existing internal codified knowledge based on internal personnel's firm-specific skills and experiences. The system- and internal-oriented strategy makes knowledge from internal personnel more fluid and transferable, thus facilitating the value of person- and internal-oriented strategy.
2b The simultaneous use of system-, person- and external-oriented sourcing strategies leads to better firm performance (i.e., complementarity).	External person-oriented strategy helps unfreeze mental maps or shared mental models of internal members, enabling a firm to interpret, understand, and apply codified external knowledge more accurately and diversely. The more firms want access to the higher level of external system-oriented knowledge, the more they need external personnel knowledge.
3a The simultaneous use of internal-, external-, and system-oriented sourcing strategies leads to better firm performance (i.e., complementarity).	The speed with which a firm can access, absorb, and integrate external system-oriented knowledge depends on the level of prior internal knowledge. System external-oriented sources generally produce knowledge that is more dynamic and varied, allowing generation of new meanings and interpretations via the combination with internal codified knowledge.
3b The simultaneous use of internal-, external-, and person-oriented sourcing strategies leads to better firm performance (i.e., complementarity).	Exposure to a greater variety of knowledge from external personnel enables internal members to perceive things differently, break out of perceptual or cognitive patterns, and add to the breadth of knowledge that internal members consider in their choice sets. An internal person-oriented sourcing strategy leads to firm-specific knowledge that enables internal members to monitor, screen, and evaluate externally generated knowledge, resulting in less resistance to external personnel knowledge.

The main argument of the hypotheses proposed above is summarized in Table 1. Recall that certain combinations are hypothesized as complementarities, whereas others are hypothesized as substitutabilities. This implies that the impact of adopting the four KSSs together on firm performance is unclear because each of these combinations mixes opposing effects. Furthermore, it remains unclear as to whether one type of combination effect overwhelms the other. Thus, we do not theoretically hypothesize the impact of adopting the four KSSs together on firm performance. However, since it is valuable to statistically test their impact, we briefly describe the results of this testing in the analysis section.

4. Research Methodology

4.1. Measure Development

The research constructs employed herein were designed to measure the types and origins of knowledge sourcing and firm performance. Based on related studies, we developed a questionnaire to empirically test the hypotheses proposed. Perceptual measures were employed for all variables. We used dichotomous scales to measure knowledge sourcing types and origins to overcome the standard assumptions of the payoff function, such as concavity and divisibility, and to avoid multicollinearity among KSSs (Massini & Pettigrew, 2003; Mohnen & Roller, 2005); this has been validated and used in other studies regarding R&D strategies (Cassiman & Veugelers, 2006). In addition, the use of dichotomous scales helps to alleviate potential measurement error that might arise from use of a Likert scale (Cohen & Malerba, 2001). Finally, we measured firm performance by multi-item constructs using a five-point Likert scale ranging from "very low" to "very high".

More specifically, we derived measures of knowledge sourcing types and origins from conceptual definitions and theoretical statements in the related literature. For example, we measured the system-oriented type by modifying previous measures (e.g., explicit-oriented (Choi et al., 2008), non-relational

learning (Rulke et al., 2000), and published sourcing (Gray & Meister, 2006)) as a dichotomous scale. Respondents were asked to choose "1" for each sourcing type and origin only if their firm used a particular KSS to a high degree and "0" in the case of no, low, or medium use of the given KSS[2]. Measures were used to categorize KSSs. We measured firm performance as subjective self-reported[3] items using a widely employed measurement for firm performance (Deshpande, Jarley, & Webster, 1993). It comprised output items including overall success, market share, growth rate, profitability, and innovativeness compared with key competitors. Table 2 lists and describes the operational definitions of instruments and their related literature; Appendix B provides the structure of all measures used herein.

Table 2. Operational Definitions and Related Literature

Variables	Operational Definition	Key Studies
System-oriented	1 if a firm ***highly*** depends on computerized and codified form through information technologies and formal documents for knowledge acquisition, access, and reuse, and codified forms for knowledge sharing 0 else (i.e., no, low, or medium)	Hansen et al. (1999), Gray and Meister (2004), Haas and Hansen (2005), Schulz (2001), Zander and Kogut (1995)
Person-oriented	1 if a firm ***highly*** depends on experts and co-workers, face-to-face help by experts, informal dialogues, and one-to-one mentoring for knowledge acquisition, access, and reuse 0 else (i.e., no, low, or medium)	Hansen et al. (1999), Gray and Meister (2004), Nonaka and Takeuchi (1995), Zack (1999), Zahra and Nielsen (2002)
External-oriented	1 if a firm ***highly*** depends on knowledge from customers, knowledge from competitors, knowledge from scientific community (ex., journals and publications), knowledge from consultants, and knowledge from suppliers 0 else (i.e., no, low, or medium)	Kyriakopoulos and Ruyter (2004), Nevo et al. (2007), Prabhu et al. (2005), Zahra and Nielsen (2002)
Internal-oriented	1 if a firm ***highly*** considers internal knowledge from colleagues or managers in its own firm, knowledge from internal information systems or documents (ex., reports and newsletter), knowledge from internal discussion forums/electronic communities, formal training programs arranged by a firm, knowledge from internally developed products/services as an important and trustable source and frequently uses them 0 else (i.e., no, low, or medium)	Bierly and Chakrabarti (1996), Kyriakopoulos and Ruyter (2004), Prabhu et al. (2005), Teigland and Wasko (2003)
Firm performance	Degree of overall success, market share, growth rate, profitability, and innovativeness in comparison with major competitors	Deshpande et al. (1993), Lee and Choi (2003), Ravichandran and Lertwongsatien (2005)
Size	Logarithm of the number of employees	Belderbos et al. (2006), Santoro and Bierly (2006), Zahra and Nielsen (2002)
Age	The number of years a firm has existed	Gopalakrishnan and Bierly (2006), Zahra and Nielsen (2002)
R&D investment	Averaged R&D expenditures during the past three years	Bogner and Bansal (2007), Katila and Ahuja (2002), Lin et al. (2006)
Industry Type	1 if a firm belongs to manufacturing industry 2 if a firm belongs to financial industry 0 if a firm belongs to service industry	Cassiman and Veugelers (2006), Santoro and Bierly (2006), Zahra and Nielsen (2002)

[2] A related issue involves how to categorize KSSs on the basis of this binary measure. Every firm uses system-, person-, internal-, and external-oriented knowledge sources to a certain extent. Thus, this study strictly applies and measures the degree of KSS adoption. For example, if a firm uses system-oriented knowledge sources to a low, or even a medium, degree, it is regarded as one that does not adopt a system-oriented knowledge sourcing strategy. While certain information may be lost, this approach is consistent with our definition of KSS. Additionally, a similar approach has been adopted in previous studies (Laursen & Salter, 2006; Leiponen & Helfat, 2010).

[3] Although the use of self-reported items could introduce bias, this allows for a more comprehensive analysis than would otherwise be possible. Previous studies have shown high levels of convergence between such subjective estimates of performance and more objective measures (Whittington, Pettigrew, Peck, Fenton, & Conyon, 1999).

Controlling for factors that may affect the relationship between KSSs and firm performance is an important task as well. First, the analysis controlled for firm size because of its potential impact on firm performance (Zahra & Nielsen, 2002) and sourcing capabilities (Haas & Hansen, 2005). We used logarithmic transformation of the firm's total number of employees to measure it because there was a broad variation in the number of employees (i.e., ranging from 10 to 86,143) in this sample (Santoro & Bierly, 2006). Second, we controlled for firm age, measured by the number of years a firm has existed, because firms that have been in the market longer typically have better access to external sources and greater internal sourcing capabilities (Gopalakrishnan & Bierly, 2006). Third, the analysis also included a firm's R&D investment as a control variable, which has been suggested to influence firm performance (Lin et al., 2006). Finally, this study controlled for industry type, as different industry environments can have different impacts on firm performance and can influence the extent to which firms employ internal versus external knowledge sources (Teece, 1986).

We carried out the pilot test in two phases. In the first phase, five academics with significant expertise in the area of KM reviewed the four knowledge sourcing types and origins and six items that measured firm performance. Based on their comments, we carefully modified items for knowledge sourcing types and removed one item from firm performance. In the second phase, we collected data from 32 firms that had implemented enterprise-wide KM initiatives, and then checked the reliability and validity of the firm performance items. The two phases of measure development resulted in a significant degree of refinement and restructuring of the survey instrument as well as in the establishment of the initial face validity of the measures. Furthermore, we confirmed that firms simultaneously adopted several KSSs.

4.2. Sampling and Data Collection

Once the instrument was modified in accordance with the pilot test, we collected data using the self-administered questionnaire, as shown in Appendix B. As a sampling frame, we identified1,500 firms from the Annual Corporation Report in Korea. We mailed survey questionnaires to executives responsible for KM and sent follow-up postcards one week later. We again mailed the same questionnaires four and seven weeks later to increase the response rate (Dillman, 2000). A total of 401 companies responded (i.e., 237 chief information officers (CIOs), 148 management strategy executives, and 16 others), corresponding to a 26.7 percent response rate. We eliminated total of 29 responses due to incomplete data, leaving 372 responses for the final analysis.

Table 3 demonstrates that the median organization in the sample has a total of $1,344.5 billion in sales revenue, 323.5 employees, and 29 years of existence (see Appendix C). Respondents represent a diverse set of industries. We divided the samples into three industry types: manufacturing (45.96 percent), services (39.25 percent), and finance (14.79 percent). Seventy-one firms have annual total sales revenues of $1 billion or more; 94 firms have 1,000 employees or more; and 47 firms have existed for more than 50 years.

Based on the guidelines suggested by Babbie (1973), this study checked for non-response bias and found no significant differences between firms responding and firms not responding in terms of total sales revenue ($t=1.477$, $p > 0.10$) and number of employees ($t=0.944$, $p > 0.30$). Moreover, no significant differences were noted between firms responding in the first and the second mailings in terms of total sales revenue ($t=1.028$, $p > 0.30$) and number of employees ($t=0.959$, $p > 0.30$).

Table 3. Respondent Characteristics

Industry Type	Industry Subtype	Number of Firms	Percent (%)
Manufacturing	Chemistry	26	6.99
	Clothing	18	4.84
	Electronics	31	8.33
	Food/beverage	22	5.91
	Iron/steel	9	2.42
	Machinery	40	10.75
	Paper	4	1.08
	Pharmaceutical	19	5.10
	Others	2	0.54
Finance	Bank	8	2.15
	Insurance	11	2.96
	Securities	21	5.65
	Others	15	4.03
Service	Communication	16	4.30
	Construction	30	8.06
	Entertainment	12	3.23
	Hotels	3	0.81
	Information processing	30	8.06
	Publishing	10	2.69
	Retailing	23	6.18
	Transportation/Tourism	19	5.11
	Others	3	0.81
	Median	**Min**	**Max**
Total sales revenue	1344.5	33.5	589727.6
Total number of employees	323.5	10	86143
Age of firms	29	5	110

4.3. Reliability and Validity of Measures

The instruments we adopted for this study had been previously employed and validated by other researchers, and their content validity had been established via a two-phased pilot test. Reliability and validity tests for the four KSSs were inapplicable because they were measured using dichotomous variables. In order to evaluate the reliability of firm performance instruments, we employed Cronbach's alpha. We used a higher cutoff value of 0.7, as it had been previously adopted (Nunnally, 1978). To obtain convergent validity, we dropped items with item-to-total correlation scores below 0.5 from further analysis. To check for discriminant validity, we employed factor analysis (Kerlinger, 1986). We adopted factor analysis with Varimax to verify unidimensionality among firm performance items. Items with factor loading values of less than 0.5 were deleted. Table 4 shows the results of the reliability and validity tests, while Table 5 displays the correlations among variables[4].

[4] Since some variables such as KSS are dichotomous and others such as performance are continuous, polychoric and polyserial correlations were calculated (Jöreskog & Sörbom, 1993).

Table 4. Statistics for Reliability and Validity Tests

Measure	Acronym	Items	Mean	S.D.	Reliability (Cronbach alpha)	Convergent Validity (Correlation of item with total score-item)	Discriminant Validity (Factor loading on single factors)
Knowledge sourcing strategy	KSS	4					
Person-oriented	KPO	1	0.298	0.458	NA	NA	NA
System-oriented	KDO	1	0.551	0.498			
Internal-oriented	KIO	1	0.519	0.500			
External-oriented	KEO	1	0.710	0.454			
Performance							
Firm performance	FP	5	3.923	0.728	0.795	0.602, 0.583, 0.6280.527, 0.539	0.766, 0.758, 0.7830.695, 0.706
Control variables							
Size	SIZ	1	6.073	1.407	NA	NA	NA
Age	AGE	1	29.77	16.72			
R&D Investment	R&D	1	138.506	672.763			
Industry types	INT	1	1.841	1.001			

Table 5. Correlations among Variables

Variables	1	2	3	4	5	6	7	8	9
1. Firm performance	1.000								
2. Person-oriented	0.001	1.000							
3. System-oriented	0.258	-0.365	1.000						
4. Internal-oriented	0.411	0.191	-0.189	1.000					
5. External-oriented	0.585	-0.147	0.328	0.614	1.000				
6. Size	0.098	0.193	0.289	0.113	-0.006	1.000			
7. Age	0.053	0.075	0.133	0.041	-0.077	0.383	1.000		
8. R&D Investment	0.027	0.046	0.129	0.016	-0.072	0.416	0.081	1.000	
9. Industry types	-0.040	0.096	0.076	-0.092	-0.097	0.130	0.288	0.031	1.000

4.4. Descriptive Statistics

Table 6 shows that the person-oriented strategy is not the most frequently adopted strategy (111 cases), whereas the external-oriented strategy (264 cases) is the most frequently adopted scheme. Moreover, 205 firms were engaged in a system-oriented strategy, whereas 193 firms were engaged in an internal-oriented strategy. The comparison shows that the propensity to source knowledge is similar across the three different industry types.

The number of KSS combinations is shown in Table 7. Among 372 firms, 351 (94.3 percent) have at least one KSS. Evidently, KSSs based on organizational boundaries are the most prominent: external only (30), internal only (5), combined (42), both combined with system-oriented (91), or both combined with person-oriented (12). Only 25 firms adopted all four KSSs. Certain KSSs are not frequently combined and have relatively few observations: internal with system-oriented (5) and internal with person-oriented (8). Table 7, likewise, shows the number of KSS combinations along with the industry types. In the case of the finance industry, no firm solely adopted a person-oriented strategy.

Table 6. Distribution of Firms Across Industries and Knowledge Sourcing Strategies

Industry (number of firms, %)	Person-oriented	System-oriented	External-oriented	Internal-oriented	Total
Manufacturing (171, 45.97%)	59	86	118	85	348
Financial (55, 14.78%)	15	36	38	28	117
Service (146, 39.25%)	37	83	108	80	308
Total (372, 100%)	111	205	264	193	

Table 7. Distribution of Knowledge Sourcing Strategies by Industry

Knowledge Sourcing Strategies	Number of cases (All)	Number of cases (Manufacturing)	Number of cases (Finance)	Number of cases (Service)
None	21 (5.65%)	14 (8.19%)	1 (1.82%)	6 (4.11%)
Person-oriented	5 (1.34%)	1 (0.58%)	0 (0%)	4 (2.74%)
System-oriented	53 (14.25%)	20 (11.70%)	11 (20.00%)	22 (15.07%)
External-oriented	30 (8.06%)	16 (9.36%)	2 (3.64%)	12 (8.22%)
Internal-oriented	5 (1.34%)	3 (1.75%)	1 (1.82%)	1 (0.68%)
Person- and system-oriented	6 (1.61%)	3 (1.75%)	2 (3.64%)	1 (0.58%)
Person- and external-oriented	44 (11.83%)	25 (14.62%)	6 (10.91%)	13 (8.90%)
Person- and internal-oriented	8 (2.15%)	5 (2.92%)	1 (1.82%)	2 (1.37%)
System- and external-oriented	14 (3.76%)	4 (2.34%)	4 (7.27%)	6 (4.11%)
System - and internal-oriented	5 (1.34%)	3 (1.75%)	1 (1.82%)	1 (0.68%)
External- and internal-oriented	42 (11.29%)	15 (8.77%)	7 (12.73%)	20 (13.70%)
Person-, system-, and external-oriented	6 (1.61%)	1 (0.58%)	2 (3.64%)	3 (2.05%)
Person-, system-, and internal-oriented	5 (1.34%)	2 (1.17%)	1 (1.82%)	2 (1.37%)
Person-, external-, and internal-oriented	12 (3.23%)	6 (3.51%)	1 (1.82%)	5 (3.42%)
System-, external-, and internal-oriented	91 (24.46%)	39 (22.81%)	12 (21.82%)	40 (27.40%)
Person-, system-, external- and internal-oriented	25 (6.72%)	14 (8.19%)	3 (5.45%)	8 (5.48%)
Total	372 (100%)	171 (100%)	55 (100%)	146 (100%)

4.5. Testing Approach: Complementarity and Substitutability

This study directly estimates the contribution of combinations of two, three, and four KSSs to the relevant outcome measure using supermodularity and submodularity based on the productivity approach (Arora, 1996). In order to formalize the hypotheses, a general production function was specified for the firm: the firm maximizes a performance measure $f(x)$ with regard to the vector of sourcing strategies. For example, to test complementarity among four KSSs, the firm maximizes a performance measure $f(x)$ with regard to the vector of four sourcing strategies, X = (person-oriented, system-oriented, internal-oriented, and external-oriented).

When the practices are measured by discrete values[5], the following definition of complementarity holds:

> Practices x_1 and x_2 are considered complementary in function f if, and only if,
> $f(x_1+1, x_2+1, x_3, \ldots, x_n) + f(x_1, x_2, x_3, \ldots, x_n) \geq f(x_1+1, x_2, x_3, \ldots, x_n) + f(x_1, x_2+1, x_3, \ldots, x_n)$
> with the inequality holding strictly for at least one value of $(x_1, \ldots, x_n)$.

[5] When practices are measured by continuous variables, complementarity implies that cross-partial derivatives of the function f with respect to the practices are positive.

The number of nontrivial inequality constraints implied by the definition of supermodularity is equal to $2^{(K-2)}\sum_{i=1}^{K-1} i$, where K is the number of KSSs (see Appendix D for details).

To illustrate this, consider a situation in which there are four KSS choice variables: K_1, K_2, K_3, and K_4. Since K = 4, 24 nontrivial inequality constraints are required. Conditions for complementarity between the first two KSSs (e.g., person-oriented and system-oriented) correspond to the following four inequalities, where at least one of the inequalities must hold strictly:

$$f(1,1,0,0) + f(0,0,0,0) \geq f(1,0,0,0) + f(0,1,0,0)$$
$$f(1,1,1,0) + f(0,0,1,0) \geq f(1,0,1,0) + f(0,1,1,0)$$
$$f(1,1,0,1) + f(0,0,0,1) \geq f(1,0,0,1) + f(0,1,0,1)$$
$$f(1,1,1,1) + f(0,0,1,1) \geq f(1,0,1,1) + f(0,1,1,1).$$

The definition for substitutability is identical to the definition above, except that "larger" is replaced by "smaller". It is sufficient to check the pair-wise inequalities in cases in which there are more than two dimensions in the lattice (Topkis, 1978). Specifically, the objective function is supermodular (or submodular) if, and only if, all pair-wise relations satisfy the condition of complementarity (or substitutability). Thus, whenever all 24 inequality constraints are satisfied, complementarity over four KSSs is given.

4.6. Empirical Model

This study considers a firm performance function C; the value is determined by the knowledge sourcing variables selected by the firms, denoted as K_i. Firm performance is characterized by the firm performance function $C(K_i, \theta_j)$, where θ_j represents the control variables, such as firm size and age.

To test for complementarities between the choice variables of KSSs (e.g., person-, system-, internal-, and external-oriented), we adopt the framework proposed by Mohnen and Roller (2005). We directly analyzed the estimated form of firm performance function to test for supermodularity or submodularity regarding the choice variables K_i of the KSSs. Therefore, the estimated firm performance function can be written as follows:

$$C_i = \sum_{l=o}^{2^K-1} \gamma_l S_l + \beta\theta_j + \varepsilon_i$$

where C_i pertains to firm performance for firm *i*. This study includes a set of state dummy variables denoted by S_l, in accordance with the previous explanation. Sixteen state dummy variables are defined by following the conventions of binary algebra in this study. The coefficients of the corresponding state dummy variables r_l allow us to test complementarity in KSSs. As mentioned above, θ_j are firm-level control variables (see Appendix D for details).

5. Analysis and Results

Our measures of firm performance are regressed on the exclusive combinations of KSSs along with four control variables (see Appendix E). As previously mentioned, assessing complementarity (or substitutability) between KSSs requires the joint testing of required inequality constraints for each pair-wise comparison. Table 8 reports the test results of H1a to H1d, using the Wald test.

Complementarity is noted between system- and external-oriented strategies, whereas weak complementarity is observed between person- and internal-oriented strategies. Substitutability between person- and external-oriented strategies is also supported. However, the substitutability test result for system- and internal-oriented is not supported.

Table 8. Complementarity or Substitutability Test Between Two KSSs

Combinations	Effect	All firms	Results
System- (x) and internal-oriented (y)	Substitutability test	F (1, 368) =0.12	No substitutability
System- (x) and external-oriented (y)	Complementarity test	F (1, 368) =4.78**	Complementarity
Person- (x) and internal-oriented (y)	Complementarity test	F (1, 368) =3.37*	(Weak) Complementarity
Person- (x) and external-oriented (y)	Substitutability test	F (1, 368) =16.80***	Substitutability

Note: *** p<0.01, ** p<0.05, * p<0.1.

Conditions for complementarity: $\pi(x_{high}, y_{high}) + \pi(x_{low}, y_{low}) \geq \pi(x_{high}, y_{low}) + \pi(x_{low}, y_{high})$.

Conditions for substitutability: $\pi(x_{high}, y_{high}) + \pi(x_{low}, y_{low}) \leq \pi(x_{high}, y_{low}) + \pi(x_{low}, y_{high})$.

The test for complementarity (or substitutability) among three KSSs requires the joint testing of two inequality constraints for each pair-wise comparison. Table 9 shows the results from the Wald tests for firm performance in accordance with the method developed by Mohnen and Roller (2005)[6]. Each complementarity and substitutability test presented in Table 9 is capable only of testing for complementarity (or substitutability), not strict complementarity (or substitutability). In order to assess whether strict complementarity (or substitutability) is observed, complementarity and substitutability should be simultaneously tested (see Appendix D for details). There is significant evidence to support the complementarity hypotheses if the complementarity hypothesis cannot be rejected and substitutability is rejected simultaneously. Evidence for strict complementarity is weaker if complementarity cannot be rejected, but substitutability is inconclusive. Finally, when the test results accept both complementarity and substitutability simultaneously, strict complementarity is seen to be rejected (Percival, 2009).

For the critical values of 1.642 and 7.094, corresponding to an alpha 0.1[7], the null hypothesis of supermodularity (or submodularity) will be definitely accepted if the test value is below 1.642. However, for values between 1.642 and 7.094, the test will be inconclusive; for values above 7.094, the null hypothesis will definitely be rejected (see Kodde & Palm, 1986, for details). For example, the test for complementarity between system- and person-oriented strategies (0.032) cannot be rejected, but its substitutability is definitely rejected (13.372) in the first combination.

Test results are also summarized in symbolic form in Table 9. Complementarity is observed among system-, person-, and internal-oriented KSS combinations. However, neither complementarity nor substitutability is found in the other combinations. For system-, person-, and external-oriented KSS combinations, complementarity between system- and person-oriented strategies and between system- and external-oriented strategies is observed. Substitutability, however, can be observed between person- and external-oriented strategies. Complementarity for internal-, external-, and system-oriented KSS combinations is found between internal- and external-oriented, and external- and system-oriented strategies. However, substitutability between internal- and system-oriented strategies is supported. For internal-, external-, and person-oriented KSS combinations, complementarity between internal- and person-oriented strategies, and between internal- and external-oriented strategies is observed. Substitutability between person- and external-oriented strategies is strictly supported.

[6] We appreciate Professor Pierre Mohnen's assistance. He kindly shared his algorithm for testing complementarity and substitutability.

[7] Critical values for α =0.01 are 5.412 for the lower bound and 12.483 for the upper bound; those for α =0.05 are 2.706 for the lower bound and 8.761 for the upper bound. This study adopted α =0.1 in accordance with Mohnen and Roller's (2005) work, which, along with the 10 percent significance level, is used widely in many studies that have adopted the productivity approach with dichotomous variables (Love & Roper, 2009).

Table 9. Complementarity and Substitutability Tests Among Three KSSs

Combinations	Effect	Sourcing Strategies Pairs		
		x & y	x & z	y & z
System- (x), person- (y), and internal-oriented (z)	Complementarity test	0.032	1.536	1.416
	Substitutability test	13.372	2.358	3.076
	Test results	C*	C	C
System- (x), person- (y), and external-oriented (z)	Complementarity test	0.198	0.524	19.664
	Substitutability test	21.714	7.654	0.028
	Test results	C*	C*	S*
Internal- (x), external- (y), and system-oriented (z)	Complementarity test	0.362	3.608	0.574
	Substitutability test	3.556	0.490	2.408
	Test results	C	S	C
Internal- (x), external- (y), and person-oriented (z)	Complementarity test	0.004	0.024	12.454
	Substitutability test	12.482	16.670	0.008
	Test results	C*	C*	S*

Note: x, y, and z represent different knowledge sourcing strategies for each combination. For example, x means system-oriented sourcing strategy in the first combination, whereas x means internal-oriented sourcing strategy in the third combination.

Based on Kodde and Palm (1986), the critical values for α =0.10 are 1.642 for the lower bound and 7.094 for the upper bound. If the test statistic is below the lower bound, the null hypothesis of complementarity or substitutability cannot be rejected. If the statistic is above the upper bound, the null hypothesis is rejected. The test is inconclusive for intermediate values.

C: Complementarity, S: Substitutability, I: Inconclusive at the 10% level.

The asterisk (*) denotes that failure to reject the null is also accompanied by a rejection of the alternative.

As mentioned previously, the assessment of complementarity (or substitutability) among four KSSs requires the joint testing of four inequality constraints for each pair-wise comparison. As anticipated, the results provide no clear evidence of either complementarity or substitutability among the four KSSs (see Appendix F for details). Table 10 summarizes the results of hypothesis testing along with data supporting both complementarity and substitutability among KSSs. The following section details the findings and their implications.

Table 10. Summary of Hypothesis Testing

Hypothesis	Results	Implications
1a The simultaneous use of system- and internal-oriented sourcing strategies worsens to lower firm performance.	Not Supported	This sourcing combination may play the role of both enabler (ease of access and comprehension; economies of reuse and search costs decrease) and inhibitor (loss of ambiguity and decontextualized knowledge) to improve firm performance simultaneously.
1b The simultaneous use of system- and external-oriented sourcing strategies leads to better firm performance.	Supported	Complementary relationship between system- and internal-oriented sourcing strategies.
1c The simultaneous use of person- and internal-oriented sourcing strategies leads to better firm performance.	Supported	Complementary relationship between person- and internal-oriented sourcing strategies.
1d The simultaneous use of person- and external-oriented sourcing strategies worsens to lower firm performance.	Supported	Substitutable relationship between person- and external-oriented sourcing strategies, which confirms the theories of in-group favoritism and out-group derogation.

Table 10. Summary of Hypothesis Testing (cont.)

Hypothesis	Results	Implications
2a The simultaneous use of system-, person-, and internal-oriented sourcing strategies leads to better firm performance.	Supported	Complementary relationship among system-, person-, and internal-oriented sourcing strategies. Negative effects of system- and internal-oriented sourcing can be diminished by adopting a person- and internal-oriented sourcing strategy, while the positive impacts of a person- and internal-oriented sourcing strategy could be prolonged by adopting a system- and internal-oriented strategy together.
2b The simultaneous use of system-, person- and external-oriented sourcing strategies leads to better firm performance.	Not Supported	No complementary relationship among three KSSs due to the substitutable relationship between person- and external-oriented strategies. Person- and external-oriented sourcing strategies might not be affected even in the presence of system- and external-oriented sourcing strategies because of the importance of a shared mental model when applying external system-oriented knowledge into a firm
3a The simultaneous use of internal-, external-, and system-oriented sourcing strategies leads to better firm performance.	Not Supported	No complementary relationship among three KSSs due to the substitutable relationship between system- and internal-oriented sourcing strategies. Internal- and system-oriented sourcing strategies might not be affected even in the presence of external- and system-oriented sourcing strategies because of the "leaky" characteristic of the combination.
3b The simultaneous use of internal-, external-, and person-oriented sourcing strategies leads to better firm performance.	Not Supported	No complementary relationship among three KSSs due to the substitutable relationship between internal- and person-oriented sourcing strategies, and external- and person-oriented strategies. External- and person-oriented sourcing strategies might not be affected even with the higher performance of internal- and person-oriented sourcing strategies because of i) different influence paths of internally and externally sourced knowledge or ii) a lack of socialization capabilities, which provides organizational members with an attractive identity as well as a collective interpretation of reality.

6. Discussion and Implications

6.1. Pursuing Two: Low Depth and Narrow Breadth

The results of our study do not support substitutability between system- and internal-oriented KSSs, thus disagreeing with H1a. This study initially anticipated substitutability between these two KSSs because the pursuit of both strategies could reduce the ambiguity of internal knowledge of firms. However, the results show that the ability of a firm to source knowledge residing in internal information systems or documents (i.e., system- and internal-oriented knowledge) can contribute, to a certain extent, to its competitiveness. As internal computerized knowledge provides ease of access and comprehension (Kyriakopoulos & Ruyter, 2004), this sourcing strategy combination facilitates knowledge sharing (Zahra & Nielsen, 2002). In addition, it enables a firm to achieve economies of reuse and decreases search costs by reconfiguring internal computerized knowledge to fit new situations (Teigland & Wasko, 2003), thereby improving its performance. Thus, this sourcing combination may play the role of both an enabler and an inhibitor as far as improving firm performance is concerned.

Our results show a complementary relationship between system- and external-oriented sourcing strategies, thus supporting H1b. As the amount of external codified knowledge increases, the knowledge base of a firm expands because the combination of the two sources renders knowledge more concrete and transferable. Thus, external codified knowledge can be readily integrated with

other activities and processes. The combination of the two knowledge sources, therefore, facilitates knowledge dissemination, transformation, and application, ultimately improving firm performance (Kyriakopoulos & Ruyter, 2004).

Our results also support a complementary relationship between person- and internal-oriented KSSs, thus supporting H1c. In particular, increasing the level of a person-oriented (or internal-oriented) KSS results in higher marginal returns from an internal-oriented (or person-oriented) KSS. Firms can improve performance by focusing on internal- and person-oriented KSSs because the adoption of these two strategies allows them to develop their own core competencies and gain more benefits. Likewise, such integration allows for more control and greater understanding of tacit knowledge in the knowledge sourcing process (Kessler et al., 2000).

The results of our study reveal a substitutable relationship between person- and external-oriented KSSs (thus supporting H1d), in accordance with theories of in-group favoritism and out-group derogation (Borgatti & Cross, 2003), and with several previous empirical results (Kessler et al., 2000). Specifically, if knowledge is largely embedded in the person, it will be difficult to integrate externally created knowledge into the existing knowledge of the firm because of differences in languages, forms, and codes (Cohen & Levinthal, 1990). Thus, knowledge from external experts is regarded by internal members as a threat to their world view (Menon & Pfeffer, 2003).

6.2. Pursuing Three KSSs: High Depth

A complementary relationship between system-, person-, and internal-oriented strategies is observed, thus supporting H2a. Firms can increase efficiency by codifying their knowledge and effectiveness by sharing embedded or embodied knowledge among employees using internal system- and person-oriented strategies (Kyriakopoulos & Ruyter, 2004). These three strategies can also function as complements that cancel out the drawbacks of one another. In particular, the adoption of the three strategies improves firm performance by reducing “leaky” knowledge and “sticky” knowledge. The former involves the undesirable flow of knowledge to external sources (Brown & Duguid, 2001) induced by the system- and internal-oriented sourcing combination (Zander & Kogut, 1995). The latter involves the difficulty in knowledge transfer (Szulanski, 1996) induced by the person- and internal-oriented combination. This result is consistent with the findings of previous studies, suggesting that neither an internal system- nor an internal person-oriented KSS alone is sufficient to effectively manage organizational knowledge (Leiponen, 2006).

Contrary to our expectations, our results reveal no clear evidence of either a complementary or substitutable relationship among system-, person-, and external-oriented strategies, and therefore, H2b is not supported. One possible explanation for the unexpected result is the importance of a shared mental model when applying external system-oriented knowledge to a firm. To develop adequate and accurate manuals or tools based on external system-oriented knowledge for the execution of complex tasks, individuals involved in the development process need to form a shared mental model detailing which actions must be selected under which conditions; this cannot be performed appropriately by external personnel (Kessler et al., 2000). In addition, the simultaneous use of external system- and external person-oriented KSSs may lead to a dependency on external system- or external person-oriented sources. This dependency results in a lack of appropriate internal system- or internal person-oriented knowledge sources, thus preventing the successful absorption of external system- or external person-oriented sources (Cohen & Levinthal, 1990). Thus, the substitutable relationship between person- and external-oriented KSSs may be unaffected even in the presence of system- and external-oriented KSSs.

6.3. Pursuing Three KSSs: Wide Breadth

The results of this study do not support H3a. The adoption of a system- and internal-oriented (or system- and external-oriented) KSS does not yield a higher return when a system- and external-oriented (or system- and internal-oriented) strategy is already present. This intriguing result may be explained in part by the “leaky” characteristic of internal- and system-oriented KSSs. The results of empirical studies suggest that the fear of knowledge leakage can result in greater use of internal

sourcing (Capron & Mitchell, 2009). However, system- and internal-oriented KSS are insufficient to prevent the knowledge of a firm from leaking across organizational boundaries because the system- and internal-oriented KSS also renders knowledge more concrete and transferable. The negative impact of system and internal-oriented KSS may be exacerbated if the KSS is adopted in the presence of a system- and external-oriented KSS. This is because both internal system-oriented and external system-oriented KSSs render knowledge more fluid and leaky.

Results point to neither a substitutable nor complementary relationship among internal-, external-, and person-oriented strategies, and, thus, H3b is not supported. This unexpected result can be explained using different influence paths of internally and externally sourced knowledge (Carlo Lyytinen, & Rose, forthcoming). When a firm depends heavily on externally sourced knowledge, its performance may be a function of its potential absorptive capacity (i.e., capacity of the acquisition and assimilation of external knowledge) as well as realized absorptive capacity (i.e., capacity of the transformation and exploitation of the knowledge). However, when a firm focuses on internally embedded knowledge to invent new services or products, its realized absorptive capacity is the only important capability, because it is not necessary to acquire and assimilate external knowledge. Therefore, internal- and person-oriented KSSs focusing on enhancing realized absorptive capacity do not guarantee increases in potential absorptive capacity and may not influence external- and person-oriented KSSs. Another possible explanation for this is the importance of firms' socialization capabilities, which provide their members with an attractive identity as well as a collective interpretation of reality (Roberts, Galluch, Dinger, & Grover, forthcoming). The integration of external- and person-oriented knowledge with the internal personnel knowledge of a firm frequently causes problems due to a lack of socialization capabilities including general frames of reference, common standards, shared language, and codes (Kessler et al., 2000). Under such conditions, the negative impact of person- and external-oriented KSSs would not be diminished even in the presence of person- and internal-oriented KSSs.

6.4. Post-Hoc Tests in Different Knowledge Intensity Environments

The value of simultaneous adoption of KSSs varies depending on environmental conditions such as knowledge intensity (Coff, 1999). Knowledge intensity can be defined as the extent to which a firm depends on the knowledge inherent in its activities and outputs as a source of competitive advantage (Autio, Sapienza, & Almeida, 2000). Knowledge intensive (KI) environments are characterized by rapid and unpredictable changes in knowledge embedded in products and services (Miller & Shamsie, 1996), which makes it difficult to build sustainable competitive advantage. Because changes in knowledge are frequent, unpredictable, and discontinuous, consuming outdated knowledge in KI environments, like consuming expired meat, can damage firm performance (Dennis & Vessey, 2005). Firms in KI environments can achieve a sustainable competitive advantage by fulfilling the challenge of the ever-changing environmental demands of new knowledge (Chen, Hwang, & Raghu, 2010). By contrast, non-KI environments are characterized by stable and predictable changes. Since knowledge changes slowly and predictably, consuming outdated knowledge in non-KI environments, like consuming expired cereal, is not optimal, but it will not damage firm performance (Dennis & Vessey, 2005). To survive in a non-KI environment, firms gradually build and improve their knowledge base and core competences (Nadkarni & Narayanan, 2007). Since KSSs of firms in KI environments must be distinct from those of firms in non-KI environments, post-hoc analyses of different complementarities and substitutabilities of KSSs between KI and non-KI were carried out (see Appendix G for details).

The post-hoc testing results include several interesting findings (refer to Table 11). First, unlike the results from all firms, complementarity between person- and internal-oriented strategies is not found in the KI environment. One possible explanation for this result is that the principal concern of firms in the KI environment is to create greater strategic flexibility. The unpredictable nature of the KI environment increases the risks for firms. It is becoming increasingly difficult to maintain competitive advantage through internal knowledge sourcing. Firms attempt to source knowledge from outside to enhance their flexibility and agility (Parmigiani & Mitchell, 2009). Furthermore, quickly created new knowledge based on the application of widely shared and understood scientific principles and

methods is essential because it enables a firm to readily provide a deliberate, planned, and coordinated response (Dennis & Vessey, 2005; Eisenhardt & Martin, 2000). Therefore, person- and internal-oriented KSSs appear to be inappropriate in the KI environment.

Second, the results of the post-hoc comparison do not present complementarity between system- and external-oriented strategies in the non-KI environment, an observation that is inconsistent with results involving data on all firms. This intriguing result may be explained, in part, by the lower munificence of the non-KI environment with regard to available knowledge spillovers (Chen & Lin, 2004; Grimpe & Sofka, 2009). That is, the competitive advantage of firms in the non-KI environment is frequently predicated on the transformation of existing knowledge into economically useful knowledge rather than on the latest external scientific and technological knowledge (Santamaría, Nieto, & Barge-Gil, 2009). In addition, the transformation and adaptation of knowledge to different circumstances involves a complex knowledge base, including practical knowledge that can be typically sourced through "learning by doing" and personal interaction (Coff, 1999). Therefore, system- and external-oriented KSSs are not complementary in the non-KI environment.

Table 11. Complementarity or Substitutability Test Between Two KSSs by Environment

Combinations	Effect	Firms by environment		Results
System- (x) and internal-oriented (y)	Substitutability test	Knowledge intensive	F (1, 210) =0.42	No substitutability
		Non-knowledge intensive	F (1, 154) =1.92	No substitutability
System- (x) and external-oriented (y)	Complementarity test	Knowledge intensive	F (1, 210) =3.72**	Complementarity
		Non-knowledge intensive	F (1, 154) =1.06	No complementarity†
Person- (x) and internal-oriented (y)	Complementarity test	Knowledge intensive	F (1, 210) =0.49	No complementarity†
		Non-knowledge intensive	F (1, 154) =4.46**	Complementarity
Person- (x) and external-oriented (y)	Substitutability test	Knowledge intensive	F (1, 210) =22.22***	Substitutability
		Non-knowledge intensive	F (1, 154) =0.19	No substitutability†

Note: *** p<0.01, ** p<0.05, * p<0.1.

Conditions for complementarity: $\pi(x_{high}, y_{high}) + \pi(x_{low}, y_{low}) \geq \pi(x_{high}, y_{low}) + \pi(x_{low}, y_{high})$

Conditions for substitutability: $\pi(x_{high}, y_{high}) + \pi(x_{low}, y_{low}) \leq \pi(x_{high}, y_{low}) + \pi(x_{low}, y_{high})$

The cross symbol (†) denotes that the results are different from those with full cases.

Third, no substitutability was detected between person- and external-oriented KSSs in the non-KI environment, an observation that is contrary to the results of the test using all firms. One possible reason for this is that firms in the non-KI environment depend heavily on well-defined and slowly changing industry-specific shared codes and languages (Coff, 1999). Under such environment, the new knowledge created by outside sources fits better into the context of established power structures and existing legitimization processes, because it is likely to be understood, interpreted, and realized in relation to the prior knowledge developed on the basis of shared codes and languages among participants (Oliver, 1997). Thus, resistance to externally created new knowledge, one of the main reasons for the substitutability of person- and external-oriented KSSs, may be generally low. Furthermore, the principal concern of firms in the non-KI environment is increasing operational efficiency (Chen et al., 2010). As the main concern is not related to strategic decisions, firms can source knowledge from external personnel only when necessary and without fear of losing their world view.

Table 12. Complementarity and Substitutability Test Among Three KSSs by Environment

Combinations	Effect		Sourcing Strategies Pairs		
			x & y	x & z	y & z
System- (x), person- (y), and internal-oriented (z)	Knowledge intensive	Complementarity test	0.100	4.670	3.250
		Substitutability test	11.972	0.690	1.630
		Test results	C*	S†	S†
	Non-knowledge intensive	Complementarity test	0.220	0.174	0.244
		Substitutability test	4.472	5.250	4.244
		Test results	C	C	C
System- (x), person- (y), and external-oriented (z)	Knowledge intensive	Complementarity test	0.306	0.482	16.832
		Substitutability test	14.482	6.744	0.084
		Test results	C*	C	S*
	Non-knowledge intensive	Complementarity test	0.954	0.902	4.282
		Substitutability test	9.368	3.810	1.212
		Test results	C*	C	S
Internal- (x), external- (y), and system-oriented (z)	Knowledge intensive	Complementarity test	1.542	6.960	0.622
		Substitutability test	1.442	0.062	2.892
		Test results	I†	S	C
	Non-knowledge intensive	Complementarity test	0.330	0.634	3.306
		Substitutability test	8.184	4.686	1.364
		Test results	C*	C†	S†
Internal- (x), external- (y), and person-oriented (z)	Knowledge intensive	Complementarity test	0.030	0.054	12.760
		Substitutability test	8.946	8.124	0.004
		Test results	C*	C*	S*
	Non-knowledge intensive	Complementarity test	0.046	0.422	2.952
		Substitutability test	9.050	11.296	1.172
		Test results	C*	C*	S

Note: x, y, and z represent different knowledge sourcing strategy for each combination. For example, x means system-oriented sourcing strategy in the first combination, whereas x means internal-oriented sourcing strategy in the third combination.

Based on Kodde and Palm (1986), the critical values for α =0.10 are 1.642 for lower bound and 7.094 for upper bound. If the test statistic is below the lower bound, the null hypothesis of complementarity or substitutability cannot be rejected. If the statistic is above the upper bound, the null hypothesis is rejected. The test is inconclusive for intermediate values.

C: Complementarity, S: Substitutability, I: Inconclusive at 10% level.

The asterisk (*) denotes that failure to reject the null is also accompanied by rejection of alternative.

The cross symbol (†) denotes that the results are different from those with full cases.

Finally, no complementary relationship is observed among system-, person-, and internal-oriented KSSs in the KI environment (refer to Table 12). This may be explained by the fact that firms in more dynamic, more complex, or fast-growing environments have to respond to a more diverse set of suppliers, customers, and competitors in a timely manner (Xue, Ray, & Gu, 2011). It appears desirable for firms in the KI environment to acquire and retain sufficient breadth in the coverage of different knowledge, which is nearly impossible solely on the basis of internal knowledge. Firms should capitalize on external knowledge sources to expand and update their knowledge base. Otherwise, their knowledge quickly becomes obsolete (Murray, Kotabe, & Westjohn, 2009). Consequently, internal system- and person-oriented KSSs seem to be undesirable in the KI environment.

Organizational studies of scholars emphasize the importance of both system- and person-oriented KSSs based on the knowledge sourcing type dimension (Haas & Hansen, 2005; Santoro & Bierly, 2006) as well as internal- and external-oriented KSSs based on the knowledge sourcing origin dimension (De Clercq & Dimov, 2008; Zack, 1999) in terms of firm performance. However, the results

of this study find an attrition of fit among KSSs, revealing no universal pattern of complementarity or substitutability among them. Rather, this study sees a more complex picture with complementarity or substitutability in different combinations of the KSSs, as discussed above. This suggests the need for a more focused strategic approach that considers the specific patterns of complementarity or substitutability in implementing KSSs. The knowledge intensity of a specific firm could prove a useful pointer to more focused and successful KSSs.

6.5. Implications for Research

The results of this study bear several implications for researchers. First, this study contributes to the existing literature regarding KSSs by identifying the danger inherent in a lack of focus and a fairly general combination of knowledge sourcing type and origin. The majority of theories consider sourcing type based on knowledge stock and sourcing origin based on knowledge flow as having a complementary relationship. Existing knowledge stock influences the extent of knowledge flow across the boundary of a firm, and knowledge flow, in turn, affects the accumulation of new knowledge asset stocks (Dierickx & Cool, 1989). However, the complementary relationship between knowledge stock and knowledge flow should be interpreted with caution in its application to the field of knowledge sourcing research. The integration of knowledge sourcing type and sourcing origin requires a variety of different specialized KSSs. Each firm must determine the proper combination of KSSs based on the type and origin dimensions to maximize its overall performance, because achieving a high level of competence in many sourcing strategies (i.e., excessive depth and breadth) can be both expensive and frequently unrealistic. Through the initial empirical evidence gathered, the results of this study demonstrate that the adoption of knowledge sourcing type and sourcing origin dimensions without relevant depth and breadth generates no expected value.

Second, this study extends the extant knowledge in this field by examining the complementarity of three and four KSSs. Without taking their combined impact into consideration, most previous studies have tended to investigate the independent effects of such strategies on performance. While several studies, such as that of Zahra and Nielsen (2002), have considered different KSSs in a collective manner, they only have investigated the impact of pair-wise combinations of KSSs on performance. To the best of our current knowledge, this study is the first attempt to simultaneously analyze three and four different KSSs, and to provide empirical evidence regarding the complementary and substitutable relationships across them. Furthermore, this study tests complementarity and substitutability on the basis of the productivity approach, which has been regarded as a definitive method for the testing of complementarity and substitutability.

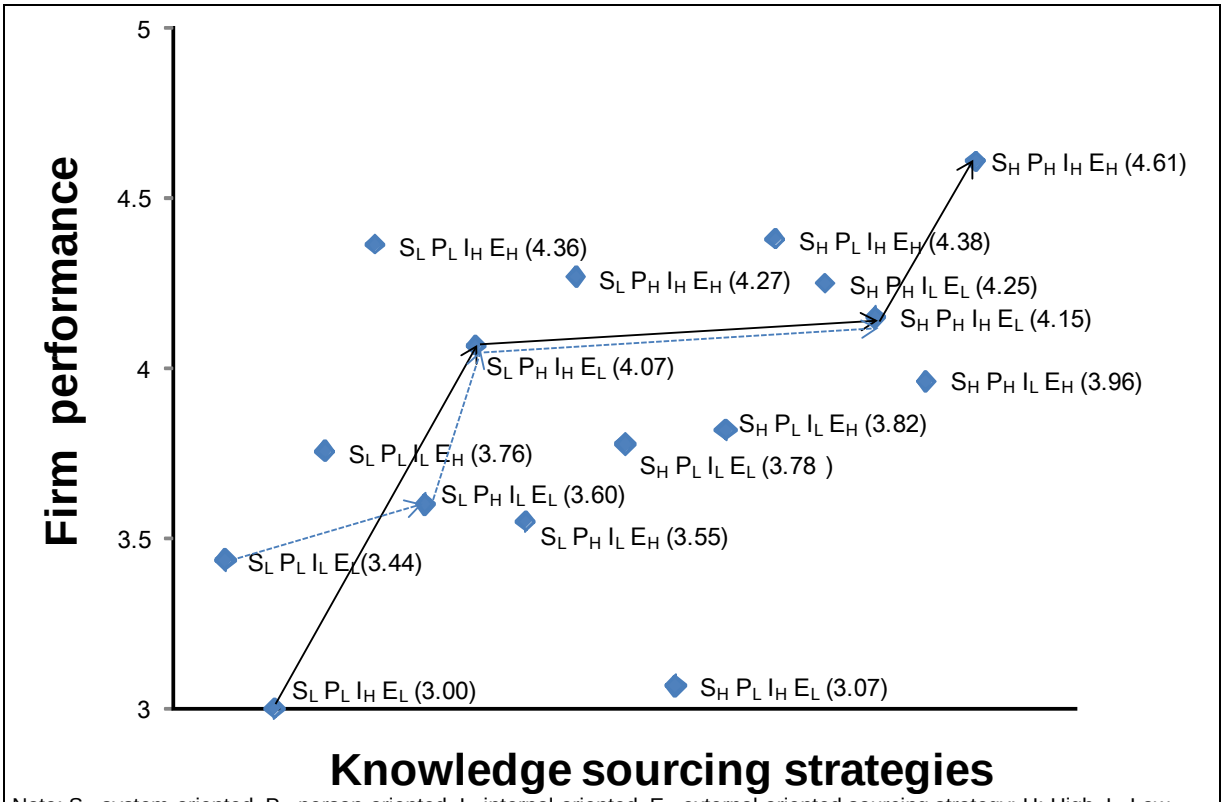
Finally, this study contributes to KSS research by investigating complementary and substitutable relationships among more than two discrete variables. Since previous studies have employed continuous variables, complementary and substitutable relationships among KSSs were investigated by adding interaction terms. Multicollinearity and substantial loss of degree of freedom may be an issue, although continuous measures may improve the precision of the estimates. This study avoided this problem by using dichotomous measures. According to Mohnen and Roller (2005, p. 1432), “the formalization of complementarities to discrete structures permits the analysis of such complex and discrete entities as organizational structures, institutions, and government policies. It provides a way to capture the intuitive ideas of synergies and systems effects”. This study reflects the reality of KSS adoption and elucidates the manner in which different KSSs work together beyond the consideration of two discrete strategies.

6.6. Implications for Practice

This study has valuable practical implications for managers who make decisions regarding the selection of KSSs between sourcing types and origins. One such implication involves the complementarity between system- and external-oriented KSSs, between person- and internal-oriented strategies, and among system-, person-, and internal-oriented KSSs. As revealed in this study, individual KSSs do not evidence a positive impact on firm performance, with the exception of the external-oriented strategy (see Appendix E). Thus, separately promoting each strategy may prove to be a waste of time and resources. These findings imply that managers should adopt either system-

and external-oriented sourcing strategies or person- and internal-oriented strategies in combination. Additionally, system-, person-, and internal-oriented KSSs evidence complementary relationships. These two results imply that the positive impacts of person- and internal-oriented KSSs can be further improved by adopting a system-oriented strategy. Thus, managers should adopt system-, person-, and internal-oriented KSSs simultaneously rather than person- and internal-oriented strategies alone, if resources permit.

Another implication for practitioners is that the combination of three or all four strategies results in no complementarity or substitutability, with the exception of system-, person-, and internal-oriented KSSs. This differs substantially from the traditional belief that innovative organizations that integrate tacit and explicit knowledge without regard to organizational boundaries tend to outperform competitors who pursue only one of these (Bierly & Chakrabarti, 1996; Zack, 1999). Managers who intend to achieve higher performance by implementing effective and efficient KSSs must shape the depth and breadth of their knowledge sourcing. Pursuing three or all four KSSs could lead to the same results as would be seen if no KSS were pursued.



Note: S= system-oriented, P= person-oriented, I= internal-oriented, E =external-oriented sourcing strategy; H: High, L=Low

Figure 2. Example Plot of Lattice for Four KSSs

The final implication for practitioners is that managers could gain insight into ways to obtain efficiencies from existing KSSs by using the results of lattices and complementarities to maximize firm performance in further KSS investments. These lattices allow for a visual representation of the factors affecting the path dependences that exist for successful KSS adoption patterns (Percival, 2009). Figure 2 shows an example plot of the lattice in the case of adopting four KSSs. The vertical axis represents firm performance in adopting the KSSs, and the horizontal axis represents the KSSs. The lattices include a sample path that a firm may follow to move from the worst state (i.e., internal-oriented; $S_LP_LI_HE_L$) to the optimal state (system-, person-, internal-, and external-oriented: $S_HP_HI_HE_H$) in single-step movements. By using the created lattice diagram based on complementarity effects, managers may decide on the priorities of their further KSS investments. For example, if a firm

currently adopts no KSS (i.e., $S_L P_L I_L E_L$), a recommended path may be to focus initially on a person-oriented strategy to source complex and tacit knowledge, followed by the adoption of an internal-oriented strategy to develop unique and firm specific knowledge, and finally a system-oriented strategy to render the knowledge more concrete and transferable.

6.7. Limitations and Future Research

This study has a few limitations, several of which offer opportunities for future research. The primary limitation of this work is the small sample size (see Appendix H), which could lead to KSSs with seriously minimal representation. A larger set of firms must be analyzed in the future to enhance the robustness of the results. Furthermore, many interesting analyses that may enhance the results of this study can be conducted on a large set of firms. For example, complementarity and substitutability analyses by industry or sub-industry using a large set of firms would clearly be worthwhile. Second, although the self-reported performance measure in this study allows for a more comprehensive analysis than would be possible otherwise, the results may depend on the type of performance measure employed. A study that investigates different firm performance using different KSSs, such as innovation (Cassiman & Veugelers, 2006) and time savings (Haas & Hansen, 2005), should provide more robust results. Furthermore, the potential differences in short- and long-term effects of different KSSs could be investigated using different measures of firm performance. For example, an external-oriented KSS would be beneficial to the long-term view of success (e.g., radical innovation) but harmful to the short-term view of success (e.g., incremental innovation). Since long-term success requires a more fundamental departure from existing norms and routines, external-oriented KSS should be helpful for achieving long-term success. However, external-oriented KSS could make existing knowledge obsolete, and thus, hurt firms' short-term outcomes (Bierly et al., 2009).

Third, this study could provide better operationalization of KSS constructs, enhanced content validity of the measures, and reduced measurement errors[8] if continuous measures were used. In addition, a study adopting continuous measures would clearly be of great interest. For example, the curvilinear (i.e., inverted U-shape) relationship between breadth (or depth) and performance could be tested to determine an appropriate level of sourcing breadth (or depth) using continuous measurements (Katila & Ahuja, 2002). Fourth, the KSSs and performance data employed in this study were gathered from a single key informant. Although information from a single executive responsible for KM should provide a high level of confidence in the quality of information collected, selection bias may still be an issue. A better picture may emerge if multiple respondents are used.

Fifth, although the respondent companies are restricted to Korean companies, the unique culture of Korea is not taken into consideration. Korea is one of the most collectivist countries in the world. Thus, Korean firms have tended to emphasize group harmony and commitment, and also evidence a strong tendency toward conformity with prevailing norms, traditions, and values (Bock, Zmud, Kim, & Lee, 2005). This cultural characteristic might increase favorable attitudes toward internal- and person-oriented knowledge, and negative attitudes toward knowledge generated by external individuals. The KSSs adoption patterns of firms in less collective cultures need to be analyzed in the future in order to improve the generalizability of the results. Sixth, behavioral perspectives of knowledge sourcing need to be addressed. Knowledge sourcing decisions improve firm performance, providing firms with superior ability to better understand essential KSSs or their combinations. However, such decisions do not explain what a firm does to effectively realize the benefits of KSSs. Thus, future research that includes knowledge sourcing behaviors would enhance our understanding. Finally, the value of the same mix of knowledge sources varies depending on conditions, such as knowledge gaps, social constraints, firm size, and so on (Capron & Mitchell, 2009; Gopalakrishnan & Bierly, 2006). Therefore, questions regarding the conditions under which certain KSSs work well together need to be addressed. Moreover, investigating which factors enable certain firms to make better use than others of the same mix of knowledge sources is another direction for future research (Gray & Meister, 2004; Hoang & Rothaermel, 2010).

[8] Since respondents may have difficulty making fine-grained distinctions between a high and low (or even medium) degree of KSS use, this could result in measurement error.

7. Conclusion

To provide a firm with competitive advantage in the knowledge economy, it is important to understand how to utilize KSSs, consisting of system-, person-, external-, and internal-oriented perspectives, based on knowledge sourcing type and sourcing origin dimensions. Using the KBV and the complementarity theory, this study investigates the performance implications of different adoption patterns of KSSs to provide a holistic view of the impact of KSSs on firm performance. The results of this study reveal several key findings: successful KSSs require a judicious combination of system- and external-oriented, and person- and internal-oriented strategies; the combination of person- and external-oriented KSS is substitutable; there is no complementarity among the three and four different KSSs, with exception of the combination of system-, person-, and internal-oriented sourcing. All this implies that KSSs need to be implemented with an appropriate level of depth and breadth. Using the productivity approach to consider the complementarity among the strategies renders the results of this study more robust. This study provides practical results for managers by simultaneously considering three and four KSSs, reflecting the reality of KM in the business environment.

Acknowledgments

The authors would like to sincerely thank the Senior Editor and three anonymous reviewers for their insightful comments and suggestions during the review process. This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2010-332-B00084). This work was also supported by the 2012 research fund of Kookmin University in Korea.

References

Arora, A. (1996). Testing for complementarities in reduced-form regressions: A note. *Economics Letters, 50*(1), 51-55.

Athey, S., & Stern, S. (1998*). An empirical framework for testing theories about complementarity in organizational design* (NBER Working Papers 6600).

Autio, E., Sapienza, H. J., & Almeida, J. G. (2000). Effects of age at entry, knowledge intensity, and imitability on international growth. *Academy of Management Journal*, *43*(5), 909-924.

Babbie, E. R. (1973). *Survey research methods*. Belmont, CA: Wadsworth.

Barua, A., Lee, C. H. S., & Whinston, A. B. (1996). The calculus of reengineering. *Information Systems Research*, *7*(4), 409-428.

Belderbos, R., Carree, M., & Lokshin, B. (2006). Complementarity in R&D cooperation strategies. *Review of Industrial Organization,* 28(4), 401-426.

Bierly, P. E., Chakrabarti, A. (1996). Generic knowledge strategies in the U.S. pharmaceutical industry. *Strategic Management Journal*, *17*, 123-135.

Bierly, P. E., Damanpour, F., & Santoro, M. D. (2009). The application of external knowledge: Organizational conditions for exploration and exploitation. *Journal of Management Studies*, *46*(3), 481-509.

Bock, G.-W., Zmud, R. W., Kim, Y.-G., & Lee, J.-N. (2005). Behavioral intention formation in knowledge sharing: Examining the roles of extrinsic motivators, social-psychological forces, and organizational climate. *MIS Quarterly*, *29*(1), 87-111.

Bogner, W. C., & Bansal, P. (2007). Knowledge management as the basis of sustained high performance. *Journal of Management Studies*, *44*(1), 165-188.

Borgatti, S. P., & Cross, R. (2003). A relational view of information seeking and learning in social networks. *Management Science*, *49*(4), 432-445.

Brown, J. S., & Duguid, P. (2001). Knowledge and organization: A social-practice perspective. *Organization Science, 12*(2),198-213.

Caloghirou, Y., Kastelli, I., & Tsakanikas, A. (2004). Internal capabilities and external knowledge sources: Complements or substitutes for innovative performance? *Technovation, 24*(1), 29-39.

Capron, L., & Mitchell, W. (2009) Selection capability: How capability gaps and internal social frictions affect internal and external strategic renewal. *Organization Science*, *20*(2), 294-312.

Carlo, J. L., Lyytinen, K., & Rose, G. M. (forthcoming). A knowledge-based model of radical innovation in small software firms. *MIS Quarterly*.

Cassiman, B., & Veugelers, R. (2006). In search of complementarity in the innovation strategy: Internal R&D and external knowledge acquisition. *Management Science*, *52*(1), 68-82.

Chen, A. N. K., Hwang, Y., & Raghu, T. S. (2010). knowledge life cycle, knowledge inventory, and knowledge acquisition strategies. *Decision Science*, *41*(1), 21-57.

Chen, C.-J., & Lin, B.-W. (2004). The effects of environment, knowledge attribute, organizational climate, and firm characteristics on knowledge sourcing decisions. *R&D Management, 34*(2), 137-146.

Choi, B., Poon, S. K., & Davis, J. (2008). effects of knowledge management strategy on organizational performance: A complementarity theory-based approach. *Omega*, *36*(2), 235-251.

Coff, R. W. (1999). How Buyers cope with uncertainty when acquiring firms in knowledge-intensive industries: Caveat emptor. *Organization Science, 10*(2), 144-161.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, *35*(1), 128-152.

Cohen, W. M., & Malerba, F. (2001). Is the tendency to variation a chief cause of progress? *Industrial and Corporate Change*, *10*(3), 587-608.

De Clercq, D., & Dimov, D. (2008). Internal knowledge development and external knowledge access in venture capital investment performance. *Journal of Management Studies*, *45*(3), 585-612.

DeCarolis, D. M., & Deeds, D. L. (1999). The impact of stocks and flows of organizational knowledge on firm performance: An empirical investigation of the biotechnology industry. *Strategic Management Journal*, *20*(10), 953-968.

Dennis, A. R., & Vessey, I. (2005). Three knowledge management strategies: Knowledge hierarchies, knowledge markets, and knowledge communities. *MIS Quarterly Executive*, *4*(4), 339-412.

Deshpande, R., Jarley, U., & Webster, F. (1993). Corporate culture, customer orientation, and innovativeness in Japanese firms: A quadrad analysis. *Journal of Marketing, 57*(1), 23-37.

Dierickx, I., & Cool, K. (1989). asset stock accumulation and sustainability of competitive advantage. *Management Science, 35*(12), 1504-1511.

Dillman, D. A. (2000). *Mail and Internet surveys: Total design method (2nd Ed.).* New York: John Wiley.

Eisenhardt, K. M., & Martin, J. (2000). Dynamic capabilities: What are they? *Strategic Management Journal*, *21*(10-11), 1105-1121.

Gopalakrishnan, S., & Bierly, P. E. (2001). Analyzing innovation adoption using a knowledge-based approach. *Journal of Engineering and Technology Management*, *18*(2), 107-130.

Gopalakrishnan, S., & Bierly, P. E. (2006). The impact of firm size and age on knowledge strategies during product development: A study of the drug delivery industry. *IEEE Transactions on Engineering Management*, *53*(1), 3-16.

Gouriéroux, C., Holly, A., & Monfort, A. (1982). Likelihood ratio test, Wald test, and Kuhn-Tucker test in linear models with inequality constraints on the regression parameters. *Econometrica*, *50*(1), 63-80.

Grant, R. M. (1996). Toward a knowledge-based theory of the firm. *Strategic Management Journal*, *17*(7), 109-122.

Gray, P. H. and D. B. Meister (2004) "Knowledge Sourcing Effectiveness," Management Science (50) 6, pp. 821-834.

Gray, P. H., & Meister, D. B. (2006). Knowledge sourcing methods. *Information & Management, 43*(2), 142-156.

Grimpe, C., & Sofka, W. (2009). Search Patterns and absorptive capacity: Low- and high-technology sectors in European countries. *Research Policy*, *38*(3), 495-506.

Haas, M. R., & Hansen, M. T. (2005). When using knowledge can hurt performance: The value of organizational capabilities in a management consulting company. *Strategic Management Journal*, *26*(1), 1-24.

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1998). *Multivariate data analysis with readings* (5th Ed.). Englewood Cliffs, NJ: Prentice Hall.

Hansen, M., Nohria, N., & Tierney, T. (1999). What's your strategy for managing knowledge? *Harvard Business Review, 77*(2), 106-116.

Hoang, H., & Rothaermel, F. T. (2010). Leveraging internal and external experience: Exploration, exploitation, and R&D project performance. *Strategic Management Journal*, *31*(7), 734-758.

Jöreskog, K. G., & Sörbom, D. (1993). *LISREL8: Structural equation modeling with SIMPLIS command language* (2nd Ed.). Chicago, IL: Scientific Software International.

Kankanhalli, A., Tanudidjaja, F., Sutanto, J., & Tan, B. C. Y. (2003). The role of IT in successful knowledge management initiatives. *Communication of ACM*, *46*(9), 69-73.

Katila, R., & Ahuja, G. (2002). Something old, something new: A longitudinal study of search behavior and new product introduction. *Academy of Management Journal*, *45*(6), 1183-1194.

Kennedy, P. (2001). *A guide to econometrics* (4th Ed.). Cambridge, MA: MIT Press.

Kerlinger, F. N. (1986). *Foundations of behavioral research*. Fort Worth, TX: Rinehart and Winston.

Kessler, E. H., Bierly, P. E., & Gopalakrishnan, S. (2000). Internal vs. external learning in new product development: Effects of speed, costs and competitive advantage. *R&D Management*, *30*(3), 213-223.

Kodde, D. A., & Palm, F. C. (1986). Wald Criteria for jointly testing equality and inequality restrictions. *Econometrica*, *54*(5), 1243-1248.

Kyriakopoulos, K., & Ruyter, K. D. (2004). Knowledge stocks and information flows in new product development. *Journal of Management Studies*, *41*(8), 1469-1498.

Laursen, K., & Salter, A. (2006). Open for innovation: The Role of openness in explaining innovation performance among U.K. manufacturing firms. *Strategic Management Journal, 27*(2), 131-150.

Lee, H., & Choi, B. (2003). Knowledge management enablers, processes, and organizational performance: An integrative view and empirical examination. *Journal of Management Information Systems, 20*(1), 179-228.
Leiponen, A. (2006). managing knowledge for innovation: The case of business-to-business services. *The Journal of Product Innovation Management*, *23*(3), 238-258.
Leiponen, A., & Helfat, C. E. (2010). Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic Management Journal, 31*(2), 224-236.
Leonard-Barton, D. (1995). *Wellsprings of knowledge.* Boston, MA: Harvard Business School Press.
Lin, B.-W., Chen, C.-J., & Wu, H.-L. (2006). Patent portfolio diversity, technology strategy, and firm value. *IEEE Transactions on Engineering Management*, *53*(1), 17-26.
Lokshin, B., Carree, M., & Belderbos, R. (2004). *Testing for complementarity and substitutability in case of multiple practices*. METEOR Research Memorandum.
Love, J. H., & Roper, S. (2009). Organizing innovation: Complementarities between cross-functional teams. *Technovation*, *29*(3), 192-203.
Massini, S., & Pettigrew, A. M. (2003). Complementarities in organizational innovation and performance. In A. M. Pettigrew, R. Whittington, L. Melin, C. Sanchez-Runde, F. Van den Bosch, W. Ruigrok, & T. Numagami (Eds.), *Innovative forms of organizing* (pp. 133-172). London: Sage Publications.
Matusik, S. F., & Hill, C. W. L. (1998). The utilization of contingent work, knowledge creation, and competitive advantage. *Academy of Management Review, 23*(4), 680-697.
Menon, T., & Pfeffer, J. (2003). Valuing internal vs. external knowledge: explaining the preference for outsiders. *Management Science*, *49*(4), 497-513.
Milgrom, P., & Roberts, J. (1995). Complementarities of fit: Strategy, structure, and organizational change. *Journal of Accounting and Economics*, *19*(2), 179-208.
Miller, D., & Shamsie, J. (1996). The resource-based view of the firm in two environments: The Hollywood film studios from 1936 to 1965. *Academy of Management Journal*, *39*(3), 519-543.
Mitchell, V. L. (2006). Knowledge integration and information technology project performance. *MIS Quarterly*, *30*(4), 919-939.
Mohnen, P., & Roller, L.-H. (2005). Complementarities in innovation policy. *European Economic Review*, *49*(6), 1431-1450.
Moorman, C., & Miner, A. S. (1998). Organizational improvisation and organizational memory. *Academy of Management Review, 23*(4), 698-723.
Murray, J. Y., Kotabe, M., & Westjohn, S. A. (2009). Global sourcing strategy and performance of knowledge-intensive business services: A two-stage strategic fit model. *Journal of International Marketing*, *17*(4), 90-105.
Nadkarni, S., & Narayanan, V. K. (2007). Strategic schemas, strategic flexibility, and firm performance: The moderating role of industry clockspeed. *Strategic Management Journal*, 28(3), 243-270.
Nevo, S., Wade, M. R., & Cook, W. D. (2007). An examination of the trade-off between internal and external it capabilities. *Journal of Strategic Information Systems, 16*(1), 5-23.
Nonaka, I., & Takeuchi, H. (1995). *The knowledge creating company*. New York: Oxford University Press.
Norusis, M. (1993). *SPSS for Windows: Base system user's guide*. Chicago, IL: SPSS.
Nunnally, J. C. (1978). *Psychometric theory* (2nd Ed.). New York: McGraw-Hill.
Oliver, C. (1997). Sustainable competitive advantage: Combining Institutional and resource-based views. *Strategic Management Journal*, *18*(9), 697-713.
Parmigiani, A. (2007). Why do firms both make and buy? An investigation of concurrent sourcing. *Strategic Management Journal, 28*(3), 285-311.
Parmigiani, A., & Mitchell, W. (2009). Complementarity, capabilities, and the boundaries of the firm: The impact of within-firm and inter-firm expertise on concurrent sourcing of complementary components. *Strategic Management Journal*, *30*(10), 1065-1091.
Patnayakuni, R., Ruppel, C. P., & Rai, A. (2006). Managing the complementarity of knowledge integration and process formalization for systems development performance. *Journal of Association for Information Systems*, *7*(8), 545-567.
Percival, J. C. (2009). Complementarities between advanced manufacturing technologies. *IEEE Transactions on Engineering Management*, *56*(1), 115-128.

Powell, T. C., & Dent-Micallef, A. (1997). Information technology as competitive advantage: The role of human, business, and technology resources. *Strategic Management Journal*, *18*(5), 375-405.

Prabhu, J., Chandy, R., & Ellis, M. (2005). The impact of acquisitions on innovation: Poison pill, placebo, or tonic? *Journal of Marketing*, *69*(1), 114-130.

Ravichandran, T., & Lertwongsatien, C. (2005). Effect of information systems resources and capabilities on firm performance: A resource-based perspective. *Journal of Management Information Systems*, *21*(4), 237 - 276.

Roberts, N., Galluch, P., Dinger, M., & Grover, V. (forthcoming). Absorptive capacity and information systems research: Review, synthesis, and directions for future research. *MIS Quarterly*.

Rulke, D. L., Zaheer, S., & Anderson, M. H. (2000). Sources of managers' knowledge of organizational capabilities. *Organizational Behavior and Human Decision Processes*, *82*(1), 134-149.

Ryu, C., Kim, Y. J., Chaudhury, A., & Rao, H. R. (2005). Knowledge acquisition via three learning processes in enterprise information systems: Learning-by-investment, learning-by-doing, and learning-from-others. *MIS Quarterly*, *29*(2), 245-278.

Santamaría, L., Nieto, M. J., & Barge-Gil, A. (2009). Beyond formal R&D: Taking advantage of other sources of innovation in low- and medium-technology industries. *Research Policy*, *38*(3), 507-517.

Santoro, M. D., & Bierly, P. E. (2006). Facilitators of knowledge transfer in university-industry collaborations: A knowledge-based perspective. *IEEE Transactions on Engineering Management*, *53*(4), 495-507.

Schulz, M. (2001). The uncertain relevance of newness: Organizational learning and knowledge flow. *Academy of Management Journal, 44*(4), 661-681.

Schulz, M., & Jobe, L. A. (2001). Codification and tacitness as knowledge management strategies: An empirical exploration. *Journal of High Technology Management Research, 12*(1), 139-165.

Szulanski, G. (1996). Impediments to the transfer of best practice within the firm. *Strategic Management Journal, 17*(2), 27-44.

Taylor, A., & Greve, H. (2006). Superman or the Fantastic Four? Knowledge combination and experience in innovative teams. *Academy of Management Journal*, *49*(4), 723-740.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing, and public policy. *Research Policy*, *15*(6), 285-306.

Teigland, R., & Wasko, M. M. (2003). Integrating knowledge through information trading: Examining the relationship between boundary spanning communication and individual performance. *Decision Sciences, 34*(2), 161-286.

Topkis, D. M. (1978). Minimizing a submodular function on a lattice. *Operations Research*, *26*(2), 305-321.

Whittington, R., Pettigrew, A., Peck, S., Fenton, E., & Conyon, M. (1999). Change and complementarities in the new competitive landscape: A European panel study, 1992-1996. *Organization Science*, *10*(5), 583-600.

Xue, L., Ray, G., & Gu, B. (2011). Environmental uncertainty and IT infrastructure governance: A curvilinear relationship. *Information Systems Research*, *22*(2), 389-399.

Zack, M. H. (1999). Developing a knowledge strategy. *California Management Review, 41*(3), 125-145.

Zaheer, A., Hernandez, E., & Banerjee, S. (2010). Prior alliances with targets and acquisition performance in knowledge-intensive industries. *Organization Science*, *21*(5), 1072-1091.

Zahra, S. A., & Nielsen, A. P. (2002). Sources of capabilities, integration and technology commercialization. *Strategic Management Journal*, *23*(5), 377-398.

Zander, U., & Kogut, B. (1995). Knowledge and the speed of the transfer and imitation of organizational capabilities: An empirical test. *Organization Science*, *6*(1), 76-92.

Appendices

Appendix A: Review of Key Extant Studies on KSS Combinations

Table A-1. Review of Key Extant Studies on KSS Combinations

KSS Combinations	Main Arguments	Empirical Test Focus	Analysis Method Used	Key Selected Studies
Depth-focused studies				
System- and person-oriented	Pursuing the two KSSs simultaneously improves a firm's efficiency by codifying knowledge, thus enhancing its effectiveness by providing customized knowledge to customers.	Testing complementarity between two KSSs using productivity approach[9]	Supermodularity[10] function with two variables	Choi et al. (2008)
			Interaction terms with two variables based on regression	Kyriakopoulos and Ruyter (2004)
		Conceptual study	N/A	Kankanhalli et al. (2003) Moorman and Miner (1998)
	Pursuing both KSSs simultaneously would have to mix organizational elements appropriate to each strategy and thus can lose the benefits of each strategy.	Conceptual study	N/A	Hansen et al. (1999)
Breadth-focused studies				
Internal- and external-oriented	Pursuing both KSSs together allows a firm to draw on a wide range of knowledge sources and adaptive response. Thus it can exploit existing knowledge and explore a broad set of external knowledge.	Testing complementarity between two KSSs using productivity approach	Supermodularity function with two variables	Cassiman and Veugelers (2006); Choi et al. (2008)
			Interaction terms with two variables based on logit regression, and GMM (generalized method for moments)	De Clercq and Dimov (2008); Hoang and Rothaermel (2010); Parmigiani (2007); Prabhu et al. (2005)
		Testing individual KSS impacts on performance	Clustering analysis	Bierly and Chakrbarti (1996)
		Conceptual study	N/A	Zack (1999)
	Pursuing the two KSSs dynamically increases costs of integrating existing firm knowledge with new knowledge from the outside.	Testing individual KSS impacts on performance	SEM; Correlation analysis	Capron and Mitchell (2009); Kessler (2000)

[9] Testing for complementarity and substitutability can be achieved via two different econometric approaches (Athey & Stern, 1998). The first, called the correlation approach, tests conditional correlations based on the residuals of reduced form regressions of the organizational practices on observable exogenous variables (Mohnen & Roller, 2005). The second, the so-called productivity approach, regresses a measure of productivity on a set of regressors, including the interaction effect between different practices. Coefficients of the interactions can be regarded as estimates of complementarity and substitutability parameters (Belderbos et al., 2006). This approach tests complementarity and substitutability by investigating whether the production function is supermodular. Unlike the first approach, this one can provide a statistical resolution for complementarity and substitutability, and thus, has been employed broadly in recent empirical work (Cassiman & Veugelers, 2006; Mohnen & Roller, 2005; Percival, 2009). We believe that it represents the appropriate approach for this study to analyze the fits and misfits of knowledge sourcing strategies.

[10] Given a function f on a lattice X, f is supermodular and its arguments are complements, if and only if, for any x and y in X, $f(x)-f(x\wedge y)\leq f(x\vee y)-f(y)$. A lattice $(X,\geq)$ is a set X with a partial order $\geq$ with the property that for any x and y in X. X likewise contains the smallest element under the order that is larger than both x and y, and the largest element that is smaller than x and y. $x\vee y$ (read "x join y") denotes the smallest element larger than x and y, while $x\wedge y$ (read "x meet y") denotes the largest element smaller than x and y.

Table A-1. Review of Key Extant Studies on KSS Combinations (cont.)

KSS Combinations	Main Arguments	Empirical Test Focus	Analysis Method Used	Key Selected Studies
Depth- and breadth-focused studies				
Internal-person	Internal-person strategy makes it difficult for others to copy specific tacit knowledge of the firm.	Testing individual KSS impacts on performance	PLS; Regression	Patnayakuni et al. (2006); Zahra and Nielsen (2002)
	Internal-person strategy provides little additional knowledge over what a firm may already know.	Testing complementarity between two KSSs using productivity approach	Interaction terms with two variables based on regression	Kyriakopoulos and Ruyter (2004)
		Testing individual KSS impacts on performance	PLS	Teigland and Wasko (2003)
External-person	External-person strategy fills serious voids in a firm by expanding its knowledge base.	Testing complementarity between two KSSs using productivity approach	Interaction terms with two variables based on regression	Kyriakopoulos and Ruyter (2004)
		Testing individual KSS impacts on performance	Regression; PLS	Rulke et al. (2000); Teigland and Wasko (2003);
	External-person strategy lacks legitimacy and will not be used by a firm.	Testing substitutability between two KSSs using productivity approach	Interaction terms with two variables based on logistic regression	Nevo et al. (2007)
		Case study	N/A	Menon and Pfeffer (2003)
		Testing individual KSS impacts on performance	Regression	Zahra and Nielsen (2002)
Internal-system	Internal-system lends flexibility to generate different knowledge and upgrade existing ones.	Testing complementarity between two KSSs using productivity approach	Interaction terms with two variables based on regression	Kyriakopoulos and Ruyter (2004)
		Testing individual KSS impacts on performance	PLS; Regression	Patnayakuni et al. (2006); Zahra and Nielsen (2002)
	Internal-system strategy prompts organizational members to rely excessively on tailored or outmoded prior knowledge.	Testing individual KSS impacts on performance	Regression	Haas and Hansen (2005); Gopalakrishnan and Bierly (2006)
External-system	External-system strategy reduces investing in the development of internal knowledge base.	Testing complementarity between two KSSs using productivity approach	Interaction terms with two variables based on regression	Kyriakopoulos and Ruyter (2004)
		Testing individual KSS impacts on performance	Regression	Gopalakrishnan and Bierly (2001); Zahra and Nielsen (2002)
	External-system strategy results in knowledge not tailored to a firm's specific situation.	Testing individual KSS impacts on performance	Regression; PLS	Rulke et al. (2000); Teigland and Wasko (2003)

Table A-1. Review of Key Extant Studies on KSS Combinations (cont.)

KSS Combinations	Main Arguments	Empirical Test Focus	Analysis Method Used	Key Selected Studies
Present study				
All possible combinations	Complementarity and substitutability of all possible combinations will be examined, including system-internal, system-external, person-internal, person-external, system-person-internal, system-person-external, internal-external-system, internal-external-person, and system-person-internal-external KSSs.	Testing complementarity and substitutability of all possible combinations using productivity approach	Supermodularity function with four variables	–

Appendix B: Questionnaire Items

Table B-1. Questionnaire Items

Questions	Remarks
If the following descriptions closely fit your knowledge sourcing strategies, please choose "yes," otherwise choose "no" (Dichotomous scale). *Please choose "yes" only if your firm uses or depends on each of the following knowledge sourcing strategy to a high degree. If your firm uses or depends on each of the following knowledge sourcing strategy to a low or even a medium degree, please choose "no".*	
System-oriented sourcing strategy In my firm, knowledge acquisition, access, and reuse highly depend on computerized and codified form through information technologies such as database or electronic repository and formal documents; and knowledge is shared through codified forms. 1. Yes 2. No	Adopted from Choi et al. (2008); Gray and Meister (2004); Schulz (2001)
Person-oriented sourcing strategy In my firm, knowledge acquisition, access, and reuse highly depend on experts and co-workers, face-to-face help by experts, informal dialogues, and one-on-one mentoring. 1. Yes 2. No	Adopted from Choi et al. (2008); Gray and Meister (2004); Leiponen (2006)
External-oriented sourcing strategy My firm highly depends on knowledge from customers, competitors, scientific community (e.g., journals and publications), external consultants, and suppliers. 1.Yes 2. No	Adopted from Choi et al. (2008); Nevo et al. (2007)
Internal-oriented sourcing strategy My firm considers internal knowledge from colleagues or managers in its own firm, knowledge from internal information systems or documents (ex., reports and newsletter), knowledge from internal discussion forums/electronic communities, formal training programs arranged by a firm, knowledge from internally developed products/services as a highly important and trustable source and frequently uses them 1.Yes 2. No	Adopted from Choi et al. (2008); Rulke et al. (2000); Teigland and Wasko (2003)
Please indicate the extent to which you agree or disagree with the following statements about the status of knowledge management in your organization (1=strongly disagree to 5=strongly agree).	
Firm performance (5 items) Compared with key competitors, my firm 1: … is more successful 2: … has greater market share 3: … is growing faster 4: … is more profitable 5: … is more innovative	Adopted from Choi et al. (2008); Deshpande et al. (1993); Ravichandran and Lertwongsatien (2005)
Please answer the following questions that are related to your organizational context.	
How many full time employees does your firm have? ( )	Adopted from Belderbos et al. (2006); Zahra and Nielsen (2002)
When was your firm established? ( )	Adopted from Gopalakrishnan and Bierly (2006); Zahra and Nielsen (2002)
On average, how much money did your firm spend on R&D during the past three years? ( )	Adopted from Bogner and Bansal (2007); Katila and Ahuja (2002); Lin et al. (2006)
Which industry does your firm belong to? (Please specify) ( )	Adopted from Santoro and Bierly (2006); Zahra and Nielsen (2002)

Appendix C: Respondent Details

Table C-1. Total Sales Revenue

Range	Number of firms	Percent (%)	Cumulative Percent (%)
Less than $10 million	8	2.15	2.15
$ 10 million to below $50 million	87	23.39	25.54
$ 50 million to below $100 million	60	16.13	41.67
$ 100 million to below $500 million	111	29.84	71.51
$ 500 million to below $1 billion	35	9.41	80.91
$ 1 billion to below $ 5 billion	48	12.90	93.82
$ 5 billion to below $ 10 billion	14	3.76	97.58
$ 10 billion and above	9	2.42	100
Total	372	100	
	Median: 1344.5	Min: 33.5	Max: 589727.6

Table C-2. Total Number of Employees

Range	Number of firms	Percent (%)	Cumulative Percent (%)
Less than 50	12	11.02	11.02
50 to below 250	137	18.28	29.30
250 to below 500	84	33.33	62.63
500 to below 1000	45	12.10	74.73
1000 to below 3000	76	20.43	95.16
3000 to below 10000	7	1.88	97.04
10000 to below 30000	8	2.15	99.19
30000 and above	3	0.81	100
Total	372	100	
	Median: 323.5	Min: 10	Max: 86143

Table C-3. The Number of Years Since the Founding of the Organization

Range	Number of firms	Percent (%)	Cumulative Percent (%)
Less than 10	49	13.17	13.17
10 to below 30	152	40.86	54.03
30 to below 50	124	33.33	87.37
50 to below 70	43	11.56	98.92
70 to below 90	3	0.81	99.73
90 and above	1	0.27	100
Total	372	100	
	Median: 29	Min: 5	Max: 110

Appendix D: Complementarity and Substitutability Testing Approach

D-1. Definitions and Conditions for Complementarity and Substitutability

The test for complementarity or substitutability used in this study is based on the production function approach. In this approach, a measure of organization performance (i.e., production) is related to exclusive combinations of organizational practices (e.g., KSSs). Consider a firm that maximizes a performance measure $f(x)$, with respect to the vector of practices $X = (x_1,...,x_n)$. When the practices are measured by continuous variables, the following definition of complementarity holds (Athey and Stern, 1998):

> Practices x_i and x_j are considered complementary in the function f if, and only if, $\partial^2 f / \partial x_i \partial x_j$ is always larger or equal to zero, and larger than zero for at least one value of $(x_1,...,x_n)$.

The definition for substitutability is identical to the definition above, except that "larger" is replaced by "smaller". Complementary and substitutable relationships among organizational practices can be tested via the introduction of interaction terms.

If the practices have discrete values, derivatives are replaced by the unit difference. For example, if we consider the first two practices, the following definition holds:

> Practices x_1 and x_2 are considered complementary in the function f if, and only if, $f(x_1+1, x_2+1, x_3,..., x_n) + f(x_1, x_2, x_3,..., x_n) \geq f(x_1+1, x_2, x_3,..., x_n) + f(x_1, x_2+1, x_3,..., x_n)$ with the inequality holding strictly for at least one value of $(x_1,...,x_n)$.

If $n = 2$ (i.e., only two practices), the collection of possible combinations of practices is P = {(0,0), (0,1), (1,0), (1,1)}. For example, a firm may adopt a high level of system- and internal-oriented KSS (i.e., P = (1,1)) or a low level of system- and internal-oriented KSS (i.e., P=(0,0)). Using the above definition of supermodularity implies that there is only one nontrivial inequality constraint $f(1,1) + f(0,0) > f(0,1) + f(1,0)$. The intuition from the inequality is that adopting both practices together produces more positive effects on performance than the sum of the results produced by each individual practice.

We now derive the inequality constraints that must be satisfied for the performance function to be supermodular. If the K practices are binary (i.e., high (=1) or low (=0)), there are 2^K possible combinations of practices in P. For example, with four practices, the possible combination P contains 2^4=16 elements: (0,0,0,0), (0,0,0,1)…(1,1,1,1). The set P is a lattice, since the elements are ordered as the component-wise order under the "max" operation (Mohnen & Roller, 2005).

In addition, one useful result can be seen in the report of Topkis (1978) that pair-wise complementarity over any subset implies supermodularity within that subset. Explicitly, it is sufficient to check the pair-wise inequalities in cases in which there are more than two dimensions in the lattice. Using the above definition of supermodularity, considering that we only need to check pair-wise complementarities, the number of nontrivial inequality constraints is equal to $2^{(K-2)} \sum_{i=1}^{K-1} i$, where K is the number of practices.

Examples

A simple example may be useful for illustrative purposes. As we only need to check pair-wise complementarities, and we consider *K=3*, we have three possible pairs of practices: x_1 and x_2, x_1

and x_3, and x_2 and x_3. Then, we can write the constraints corresponding to complementarity between each pair of practices. Thus, six nontrivial inequality constraints are required. More specifically, two nontrivial inequality constraints are obtained regarding complementarity between x_1 and x_2 in performance function f :

$$f(1,1,0) + f(0,0,0) \geq f(1,0,0) + f(0,1,0)$$
$$f(1,1,1) + f(0,0,1) \geq f(1,0,1) + f(0,1,1) .$$

Similarly, the two nontrivial inequalities necessary to hold for x_1 and x_3 practices to be complementary are as follows:

$$f(1,x_2,1) + f(0,x_2,0) \geq f(1,x_2,0) + f(0,x_2,1) .$$

where $x_2 = \{0,1\}$ again. Additionally, the two nontrivial inequalities necessary to hold for x_2 and x_3 practices to be complementary are as follows:

$$f(x_1,1,1) + f(x_1,0,0) \geq f(x_1,1,0) + f(x_1,0,1) .$$

where $x_1 = \{0,1\}$ once again. The definition for substitutability is identical to the definition above, except that "larger" is replaced by "smaller".

With four practices, the situation is more complex with each pairing of practices evidencing either complementarity or substitutability. Since *K=4*, 24 nontrivial inequality constraints are required. Complementarity between the first two practices requires the following:

$$f(1,1,x_3,x_4) + f(0,0,x_3,x_4) \geq f(1,0,x_3,x_4) + f(0,1,x_3,x_4) \quad \text{(D1)}$$

where $x_3x_4 = \{00,10,01,11\}$.

The remaining 20 constraints corresponding to complementarity between practices x_1 and x_3, x_1 and x_4, x_2 and x_3, x_2 and x_4, and finally x_3 and x_4 are analogous. Thus, whenever all 24 inequality constraints are satisfied, complementarity over all practices is given.

D-2.Testing Procedure

To test the inequality constraints implied by complementarity, we need consistent estimates of the effects of practices on firm performance (Mohnen and Roller, 2005). With two practices, the test for complementarity is a one-sided t-test of the null hypothesis of the following: $f(1,1) + f(0,0) = f(0,1) + f(1,0)$. Specifically, $\beta_{11} + \beta_{00} = \beta_{10} + \beta_{01}$. However, in the case of more than two practices, the number of inequality constraints that should be simultaneously tested is 2^{n-2}. Statistical tests of $H_0 : R\beta = r$ versus $H_1 : R\beta \geq r$ with R having rank k in the standard linear model are $y = X\beta + \varepsilon$ with one of the inequalities holding strictly (see Gouriéroux, Holly, & Montfort, 1982). This can be regarded as a distance or Wald test that permits the simultaneous testing of the set of inequality constraints. According to Kodde and Palm (1986), who provided the lower and upper bound critical values for this test, the null hypothesis is accepted if the values of the Wald test are below the lower bound. By way of contrast, values above the upper bound result in a rejection of the null hypothesis. The test is inconclusive when values fall between the two bounds.

Examples

To test H4, we consider the firm performance function C, whose value is determined by the four knowledge sourcing variables chosen by firms, denoted as $K = (K_1, K_2, K_3, K_4)$. Firm performance is characterized by the firm performance function $C(K_i, \theta_j)$, where θ_j represents control variables, such as firm age and industry type. Thus, the firm performance function can be expressed as follows:

$$C(K_i, \theta_j) = f(K_1, K_2, K_3, K_4, \theta_j) \quad \text{(D2)}$$

To test for complementarities between the choice variables of KSSs (i.e., person-, system-, internal-, and external-oriented), we adopt the framework proposed by Mohnen and Roller (2005). The estimated form of the firm performance function is directly analyzed to test supermodularity or submodularity with regard to the choice variables K_i of the four KSSs. Therefore, the firm performance function estimated can be expressed as follows:

$$C_i = \sum_{I=0}^{2^k-1} \gamma_I S_I + \beta\theta_j + \varepsilon_i \quad \text{(D3)}$$

where C_i pertains to firm performance for firm i. This study includes a set of state dummy variables denoted by S_I. Sixteen state dummy variables are defined by following the convention of binary algebra[11] in this study. Coefficients of the corresponding state dummy variables r_I allow us to test complementarity in KSSs. In accordance with Equation (D2), θ_j are firm-level control variables.

Using (D1) and (D3), the four constraints that need to be satisfied for KSS 1 (i.e., person-oriented) and 2 (i.e., system-oriented) to be complementary can be written as follows:

(Complementarity 1-2) $r_{0+s} + r_{12+s} \geq r_{4+s} + r_{8+s}$ where *s*=0,1,2,3.

Similarly, the other complementarity conditions can be written as:

(Complementarity 1-3) $r_{0+s} + r_{10+s} \geq r_{2+s} + r_{8+s}$ where *s*=0,1,4,5.

(Complementarity 1-4) $r_{0+s} + r_{9+s} \geq r_{1+s} + r_{8+s}$ where *s*=0,2,4,6.

(Complementarity 2-3) $r_{0+s} + r_{6+s} \geq r_{2+s} + r_{4+s}$ where *s*=0,1,8,9.

(Complementarity 2-4) $r_{0+s} + r_{5+s} \geq r_{1+s} + r_{4+s}$ where *s*=0,2,8,10.

(Complementarity 3-4) $r_{0+s} + r_{3+s} \geq r_{1+s} + r_{2+s}$ where *s*=0,4,8,12.

As mentioned previously, assessing complementarity (or substitutability) between KSSs requires the joint testing of four inequality constraints for each pair-wise comparison. In particular, whenever all 24 inequality constraints are satisfied, complementarity over four KSSs is given. A performance function could be submodular (i.e., KSSs could be substitute) if the above inequalities constraints have opposite signs.

However, note that each of these tests alone considers supermodularity (or submodularity), not *strict* supermodularity (or submodularity). If supermodularity (or submodularity) is not defined "strictly", then it does not exclude the possibility that sourcing strategy X_i (e.g., person-oriented) has no impact on the returns to sourcing strategy X_j (e.g., internal-oriented). Therefore, complementarity and substitutability should be simultaneously tested to evaluate whether strict complementarity is observed.

[11] Specifically, S_0 corresponds to state 0000, S_1 to state 0001,…, S_{15} to state 1111.

Appendix E: Results of Equation (D3)

Since this study employs a self-reported measurement of performance, the normality of the performance variable must be assessed. The Kolmogorov-Smirnov test, which assesses violations of the normality assumption, demonstrates a spurious significance (Norusis, 1993). In such a situation, it is recommended that normal probability plots be visually inspected to assess distribution normality. Such inspections indicated no violation of the normality assumption for the variable. Additionally, the test for homogeneity of variance on the error term was insignificant for performance (Levene statistic = 1.039, p=0.411).

The first column of Table E-1 reports the results of Equation D3. Only the external-oriented strategy exerts a significant positive impact on firm performance. Four combinations of two strategies (except for person- and external-oriented and system- and internal-oriented), all combinations of three strategies, and a combination of all four strategies exert a significant impact on firm performance. None of the control variables has any impact on performance. Overall, adding a second, third, or fourth strategy gradually increases the coefficients of joint strategies. The bundling of KSSs positively influences firm performance, as was clearly confirmed in these results.

Table E-1. Estimates of Equation (D3) for All Knowledge Sourcing Strategies

Effect	(1) OLS	(2) 2SLS
Size	-0.013 (0.029)	0.039 (0.059)
Age	0.001 (0.002)	0.001 (0.002)
R&D investment	0.000014(0.000057)	0.0000065(0.000052)
Manufacturing industry	-0.045 (0.073)	-0.038 (0.073)
Financial industry	0.019 (0.102)	0.011 (0.101)
Person-oriented	0.032 (0.311)	-0.0025 (0.313)
System-oriented	0.144 (0.162)	0.145 (0.161)
External-oriented	0.429** (0.177)	0.438** (0.176)
Internal-oriented	-0.047 (0.309)	-0.059 (0.309)
Person- and system-oriented	0.663** (0.306)	0.677** (0.304)
Person- and external-oriented	0.055 (0.165)	0.055 (0.165)
Person- and internal-oriented	0.712*** (0.259)	0.716*** (0.259)
System - and external-oriented	0.475** (0.219)	0.467** (0.217)
System - and internal-oriented	0.116 (0.312)	0.102 (0.312)
External- and internal-oriented	0.844*** (0.167)	0.842*** (0.167)
Person-, system-, and external-oriented	0.654** (0.291)	0.655** (0.290)
Person-, system-, and internal-oriented	0.925*** (0.311)	0.915*** (0.310)
Person-, external-, and internal-oriented	0.869*** (0.226)	0.848*** (0.225)
System-, external-, and internal-oriented	0.916*** (0.152)	0.913*** (0.151)
Person-, system-, external- and internal-oriented	1.276*** (0.188)	1.158*** (0.238)
Observations	372	372
R-squared	0.314	0.314
F (20, 351)	8.048***	8.063***

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Endogeneity issues may arise because firms' strategic decisions such as KSS adoption may be determined by unobserved firm characteristics, past choices, or firm variables including size and R&D investment. Failure to correct factors that simultaneously affect KSS choice and performance leads to biased and inconsistent estimates (Kennedy, 2001). To check for potential effects of endogeneity, we test a two-stage least squares (2SLS) specification that treats KSSs as endogenous. The pattern of results is similar to those from the OLS model we reported in Table E-1. For example, when we introduce firm size as an instrumental variable for person-, system-, external-, and internal-oriented KSS, the Wu-Hausman F test value is 0.45 (p =0.50); thus, the test fails to reject the null hypothesis that the difference in coefficients is not systematic. However, many of the instruments used in the 2SLS are likely to be endogenous. It is difficult to obtain better instruments in this current context; this is a limitation of this study. Column 2 of Table E-1 presents the 2SLS coefficients results.

Appendix F: Complementarity and Substitutability Test among Four KSSs

Table F-1 reports the results from the Wald tests for firm performance in accordance with the method developed by Mohnen and Roller (2005). Certain pair-wise relations do not satisfy the definition of complementarity (or substitutability). For example, Table F-1 indicates three complementarities (i.e., system- and person-oriented; internal- and person-oriented; and internal- and external-oriented), one substitutability (i.e., person-and external-oriented), and two inconclusive relationships (i.e., system- and internal-oriented; and system- and external-oriented). Hence, the results reject complementarity (or substitutability) among four KSSs. This result is consistent with those of previous studies, suggesting that KSSs with substantial depth and wide breadth do not enhance firm performance (Katila & Ahuja, 2002; Schulz & Jobe, 2001).

Table F-1. Complementarity and Substitutability Test Among Four KSSs

Combinations	Effect	Sourcing Strategies Pairs					
		w & *x*	*w* & *y*	*w* & *z*	*x* & *y*	*x* & *z*	*y* & *z*
System- ( ), person- ( ), internal- ( ), and external-oriented ( )	Complementarity test	0.668	3.054	4.713	12.947	0.570	0.637
	Substitutability test	12.633	2.816	1.680	0.249	13.096	10.030
	Test results	C*	I	I	C*	S*	C*

Note: Based on Kodde and Palm (1986), the critical values for =0.10 are 1.642 for lower bound and 7.094 for upper bound. If the test statistics is below the lower bound, the null hypothesis of complementarity or substitutability cannot be rejected. If the statistics is above the upper bound, the null hypothesis is rejected. The test is inconclusive for intermediate values.
C: Complementarity, S: Substitutability, I: Inconclusive at 10% level.
The asterisk (*) denotes that failure to reject the null is also accompanied by rejection of alternative.

Appendix G: Post-Hoc Tests in Different Knowledge Intensity Environments

Despite the importance of the knowledge intensity of an environment, the literature regarding this issue has been limited in two ways. First, previous studies have focused on KI environment (Zaheer, Hernandez, & Banerjee, 2010), but few research efforts have been made thus far to explore systematic differences in KSSs adopted by firms in KI and non-KI environments. Second, previous literature regarding the nature of knowledge required in the KI environment has provided mixed findings. Some studies have insisted that firms require complex and varied knowledge to cope with rapid and unpredictable change (Chen et al., 2010), whereas some studies have suggested that limited well-defined and very specific knowledge is likely to prove successful in the KI environment (Dennis & Vessey, 2005). Thus, this study addresses the gap by comparing effective KSSs adoption patterns in KI and non-KI environments.

The post-hoc comparison of KSS adoption patterns between KI and non-KI environments are performed at the industry level. Of course, knowledge intensity varies among firms within industries, which is a fundamental assumption underlying the KBV. However, systematic industry-level variation in knowledge intensity may prove to be more substantial because of fundamental differences in markets, technologies, and the expertise deployed (Coff, 1999).

The industry classification of the firms in the sample employed in this study is key to the post-hoc comparison, because this classification is used to gauge whether or not firms in KI environments perform better when they adopt specific KSSs together. As there is no generally accepted approach for the categorization of industries into either KI or non-KI environments (Autio et al., 2000), this study adopted the methods for industrial classification of knowledge intensity by the Organization for Economic Cooperation and Development (OECD). Although the OECD classifications are somewhat coarse, they have provided a useful reference for studying industry differences (Grimpe & Sofka, 2009). According to the classifications used by the OECD, i) firms in high-, and medium-high-tech manufacturing industries such as chemistry (except refined petroleum product; rubber and plastic; other non-metallic mineral), electronics, machinery, and pharmaceutical industries and ii) firms in financial service except real estate, iii) firms in KI service industries such as communications, entertainment, information processing, and advertising were categorized into high knowledge intensity.

Table G-1. Industry Classification of Environmental Knowledge Intensity

Industry Type	Knowledge Intensity of Environment	
	Knowledge Intensive (N=214)	Non-Knowledge Intensive (N=158)
Manufacturing (N=171)	Chemistry (N=12) Electronics (N=31) Machinery (N=40) Pharmaceutical (N=19)	Chemistry* (N=14) Clothing (N=18) Food/beverage (N=22) Iron/steel (N=9) Paper (N=4) Others (N=2)
Finance (N=55)	Bank (N=8) Insurance (N=11) Securities (N=21) Others (N=13)	Others** (N=2)
Service (N=146)	Communication (N=16) Entertainment (N=12) Information processing (N=30) Others*** (N=1)	Construction (N=30) Hotels (N=3) Publishing (N=10) Retailing (N=23) Transportation/Tourism (N=19) Others (N=2)

* Chemistry industry relating to refined petroleum, rubber and plastic, and other non-metallic mineral products belong to non-knowledge intensive environment
** Real estate service industry belong to non-knowledge intensive environment
*** Advertising industry belong to knowledge intensive environment

The firms in medium-low- and low-tech industries such as clothing, foods/beverage, iron/steel, paper product industries and in non-KI service such as construction, hotels, publishing, retailing, and transportation/tourism industries were categorized as low knowledge intensity. Details of the industry classifications applied can be found in Table G-1, and the distribution of KSSs by environmental knowledge intensity is provided in Table G-2.

Table G-2. Distribution of Knowledge Sourcing Strategies by Environmental Knowledge Intensity

Knowledge Sourcing Strategies	Number of Cases (All)	Number of Cases (Knowledge Intensive)	Number of Cases (Non-Knowledge Intensive)
None	21	10	11
Person-oriented	5	2	3
System-oriented	53	34	19
External-oriented	30	15	15
Internal-oriented	5	3	2
Person- and system-oriented	6	5	1
Person- and external-oriented	44	28	16
Person- and internal-oriented	8	6	2
System- and external-oriented	14	9	5
System - and internal-oriented	5	2	3
External- and internal-oriented	42	27	15
Person-, system-, and external-oriented	6	2	4
Person-, system-, and internal-oriented	5	4	1
Person-, external-, and internal-oriented	12	7	5
System-, external-, and internal-oriented	91	52	39
Person-, system-, external- and internal-oriented	25	8	17
Total	372	214	158

Table 11 in the main text reports the test results of complementarity or substitutability using the Wald test. Complementarity is noted between system- and external-oriented strategies in the KI environment, whereas no complementarity is found between system- and external-oriented strategies in the non-KI environment. Complementarity is not observed between person- and internal-oriented strategies in the KI environment, while complementarity is found between person- and internal-oriented strategies in the non-KI environment. Substitutability between person- and external-oriented strategies is supported only in the KI environment. However, the substitutability test result for system- and internal-oriented is not observed, regardless of environmental knowledge intensity.

Table 12 in the main text shows the results of complementarity (or substitutability) among three KSSs from the Wald tests for firm performance. For the system-, person-, and internal-oriented KSS combination in the KI environment, complementarity is noted between system- and person-oriented strategies, whereas substitutability is noted between system- and internal-oriented strategies, and between person- and internal-oriented strategies. Complementarity is found among system-, person-, and internal-oriented KSS combinations in the non-KI environment. For system-, person-, and external-oriented KSS combinations, complementarity is found between system- and person-oriented strategies and between system- and external-oriented strategies in both KI and non- KI environment. Substitutability, however, is detected between person- and external-oriented strategies regardless of environmental knowledge intensity.

For the internal-, external-, and system-oriented KSS combination in the KI environment, internal- and external-oriented strategies could have both a complementary and substitutable relationship. Thus, the combination is inconclusive. A substitutable relationship is observed between internal- and system-oriented strategies, while a complementary relationship between external- and system-oriented strategies exists. For firms in the non-KI environment, two complementarities (i.e., internal- and external-oriented; internal- and system-oriented) and one substitutability (i.e., external- and system-oriented) are found. For the internal-, external-, and person-oriented KSS combination, there are two complementarities (i.e., internal- and external-oriented; internal- and person-oriented) and one substitutability (i.e., external- and person-oriented) in the KI and non-KI environments.

The test results are also summarized in symbolic form in Table 12. In summary, complementarity is only observed among system-, person-, and internal-oriented KSS combinations in the non-KI environment. However, neither complementarity nor substitutability is found in the other combinations in the KI and non-KI environments.

Table G-3 shows the results of complementarity (or substitutability) among four KSSs from the Wald tests for firm performance. Neither complementarity nor substitutability is found in the KI and non-KI environments. For firms in KI environments, there is one complementarity (i.e., system- and personal-oriented), two substitutabilities (i.e., system- and internal-oriented; person- and external-oriented), and three inconclusive relationships (system- and external-oriented; person- and external-oriented; internal- and external-oriented). Firms in the non-KI environments show quite different pair-wise relations. Three complementarities (i.e., system- and internal-oriented; person- and internal-oriented; internal- and external-oriented) and three inconclusive relations (i.e., system- and person-oriented; system- and external-oriented; person- and external-oriented) are found.

Table G-3. Complementarity and Substitutability Test Among Four KSSs by Environment

Combinations	Effect		Sourcing Strategies Pairs					
			w & x	w & y	w & z	x & y	x & z	y & z
System- (w), person- (x), internal- (y), and external-oriented (z)	Knowledge intensive	Complementarity test	0.126	13.856	2.148	1.842	11.132	2.710
		Substitutability test	17.340	0.522	6.638	9.642	1.132	9.204
		Test results	C*	S*†	I	I†	S*	I†
	Non-knowledge intensive	Complementarity test	3.362	1.166	6.404	0.734	6.710	1.174
		Substitutability test	4.314	8.580	3.176	10.382	2.220	11.534
		Test results	I†	C*†	I	C*	I†	C*

Note: Based on Kodde and Palm (1986), the critical values for α =0.10 are 1.642 for lower bound and 7.094 for upper bound. If the test statistics is below the lower bound, the null hypothesis of complementarity or substitutability cannot be rejected. If the statistics is above the upper bound, the null hypothesis is rejected. The test is inconclusive for intermediate values.
C: Complementarity, S: Substitutability, I: Inconclusive at 10% level.
The asterisk (*) denotes that failure to reject the null is also accompanied by rejection of alternative.
The cross symbol (†) denotes that the results are different from those with full cases.

Test results are also summarized in symbolic form in Table G-3. However, as mentioned in the section pertaining to limitations and future research, a number of problems deriving from lack of power can be seen, thereby impeding the correct interpretation of results. Thus, results for the KI environment should be interpreted with caution, and in particular cases, by taking into account combination of the KSSs.

Appendix H: Statistical Power Analysis

Statistical power is a function of three parameters: effect size, significance criterion (alpha), and sample size (Hair, Anderson, Tatham, & Black, 1998). While sample size and alpha are given in this study, effect size should be estimated to calculate the level of statistical power. Typically, the effect size can be estimated from the proportion of explained variance accounted for in previous, well-conceived research (Cohen, 1988). However, when an area of inquiry is new, or insufficient experimental work has been performed (e.g., complementarity of knowledge sourcing strategies), it is possible to use one of Cohen's (1988) three conventional levels representing small, medium, and large sizes of a phenomenon in a population.

H-1. Statistical Power Analysis Using Full Sample

According to Cohen's criteria, effect sizes of 0.02, 0.15, and 0.35 are considered small, medium, and large, respectively (Cohen, 1988). Sample size in this study is 372. For the complementarity or substitutability test between two KSSs, alpha value is set at 0.05. As mentioned before, this study adopts α =0.1 for complementarity or substitutability in testing more than two KSSs. However, since two nontrivial inequality constraints are required for each pair of three KSSs, the alpha value is set at 0.05, not at 0.1 by adopting the Bonferroni correction (Hair et al., 1998). By the same token, the alpha value is set at 0.025 for the complementarity or substitutability test among four KSSs, because four nontrivial inequality constraints are required for each pair of KSSs. Table H-1 presents the results of statistical power analysis for the full sample.

An adequate power level is usually quoted at 0.8 (Cohen, 1988). When the effect size is small, the power values for all tests are less than 0.8, thus resulting in an insufficient power level. However, when the effect size is medium or large, the results of all tests achieve the conventional level of statistical power of 0.8.

Table H-1. Power Level for the Full Sample

Complementarity or Substitutability Test	Sample Size	Alpha Value = 0.05			Alpha Value = 0.025		
		Effect Size			Effect Size		
		Small	Medium	Large	Small	Medium	Large
Two KSSs	372	0.563	0.999	1.000	0.450	0.999	1.000
Three KSSs		0.434	0.999	1.000	0.325	0.999	1.000
Four KSSs		0.312	0.999	1.000	0.216	0.999	1.000

H-2. Statistical Power Analysis by Environmental Knowledge Intensity

As mentioned above, the sample size for the KI environment is 214 and 158 for the non-KI environment. In a similar way, statistical power is calculated for complementarity or substitutability test between two, three, and four KSSs, respectively. Table H-2 reports the results of power analysis for KI and non-KI environments.

Table H-2. Power Level by Environmental Knowledge Intensity

Complementarity or Substitutability Test	KI Environment						
	Sample size	Alpha Value = 0.05			Alpha Value = 0.025		
		Effect Size			Effect Size		
		Small	Medium	Large	Small	Medium	Large
Two KSSs	214	0.334	0.998	1.000	0.237	0.995	1.000
Three KSSs	214	0.245	0.991	0.999	0.162	0.982	0.999
Four KSSs	214	0.174	0.962	0.999	0.108	0.931	0.999

Table H-3. Power Level by Environmental Knowledge Intensity

Complementarity or Substitutability Test	Non-KI Environment						
	Sample Size	Alpha Value = 0.05			Alpha Value = 0.025		
		Effect Size			Effect Size		
		Small	Medium	Large	Small	Medium	Large
Two KSSs	158	0.249	0.982	0.999	0.166	0.967	0.999
Three KSSs	158	0.182	0.948	0.999	0.114	0.909	0.999
Four KSSs	158	0.133	0.857	0.999	0.078	0.778	0.998

When the effect size is small, the results of complementarities or substitutabilities do not achieve the conventional 0.8 level of statistical power regardless of environmental knowledge intensity. However, in the case of medium or large effect size, the power values of all tests except one (i.e., the complementarity or substitutability test among four KSSs in a non-KI environment with medium effect size) exceed the conventional level of 0.8.

Although this study shows a reasonable power level with medium or large effect size, a basic issue still arises concerning the sample size needed in this test. At a minimum, every cell must have more cases than there are dependent variables (Hair et al., 1998). However, some cells (e.g., internal-oriented, and person- and system-oriented in non-knowledge intensive) have just one case, which Table G-2 shows. In addition, some cells have two or three cases. Thus, there is a concern on the lack of power of the complementarity or substitutability test among the four KSSs by environmental knowledge intensity.

About the Authors

Byounggu CHOI is an Associate Professor at the College of Business Administration of the Kookmin University in Seoul, Korea. He was formerly on the faculty of the School of Information Technologies at the University of Sydney. He received his MS and Ph.D. degrees in Management Information Systems from the Korea Advanced Institute of Science and Technology (KAIST). His research interests are knowledge management, e-commerce, and business value of IT. His papers have been published in the *Journal of MIS*, *Journal of the AIS*, *IEEE Transactions on Engineering Management*, *Information & Management*, and others. He has presented several papers at the *ICIS*, *HICSS*, and *PACIS* Conferences, and serves as an editorial board member of *Journal of the AIS* and *Information & Management*.

Jae-Nam LEE is a Professor in the Business School of the Korea University in Seoul, Korea. He was formerly on the faculty of the Department of Information Systems at the City University of Hong Kong. He holds MS and Ph.D. degrees in MIS from the Graduate School of Management of the Korea Advanced Institute of Science and Technology (KAIST). His research interests are IT outsourcing, knowledge management, information security management, e-commerce, and IT deployment and impacts on organizational performance. His published research articles appear in *MIS Quarterly*, *Information Systems Research*, *Journal of MIS*, *Journal of the AIS*, *Communications of the AIS*, *IEEE Transactions on Engineering Management*, *European Journal of Information Systems*, *Communications of the ACM*, *Information & Management*, and others. He is currently serving on the editorial board of *Journal of the AIS*, *Pacific Asia Journal of the AIS*, and *Electronic Commerce Research and Applications*.