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Lei Chi
Rensselaer Polytechnic Institute, chil2@rpi.edu

Yin-Chi Liao
Rensselaer Polytechnic Institute, liaoy@rpi.edu

Shu Han
Yeshiva University, shan@yu.edu

K. D. Joshi
Washington State University, joshi@wsu.edu

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Completed Research Paper

Lei Chi
Lally School of Management & Technology
Rensselaer Polytechnic Institute
Troy, NY 12180
chil2@rpi.edu

Yin-Chi Liao
Lally School of Management & Technology
Rensselaer Polytechnic Institute
Troy, NY 12180
liaoy@rpi.edu

Shu Han
Sy Syms School of Business
Yeshiva University
New York, NY 10016
shan@yu.edu

K. D. Joshi
College of Business
Washington State University
Pullman, WA 99163
joshi@wsu.edu

Abstract

This study draws on absorptive capacity theory and organizational learning perspective to examine and elaborate the roles of IT in influencing firm innovation in the alliance network context of pharmaceutical industry. We focused on three types of IT-enabled knowledge capabilities and one specific type of alliance network structure - structural holes - and examine whether and how they interact to jointly affect firm innovation. Firm innovation is observed through pharmaceutical firms' patent inventions. We collected 82 firm-year observations from 20 unique pharmaceutical companies over the period of 2000-2006. We found that three types of IT-enabled knowledge capabilities differentially interact with structural holes to affect pharmaceutical firms' patent inventions. Our study makes important contributions to theory and practice on IT, interfirm alliance network, and firm innovation.

Keywords: Alliance network, firm innovation, structural holes, IT-enabled knowledge capabilities

Introduction

Today in a field where knowledge base is complex and continuously expanding, to stay on top of the field, a firm has to constantly seek new knowledge and competence for technology development and innovation (Powell 1998). Innovation is defined as "the design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures, or business models for the purpose of creating new value for customers and financial returns for the firm" (Advisory Report to the Secretary of Commerce of the US 2008). In the market, while incremental innovation redistribute shares within an existing market, radical innovation imply a high potential for market expansion that substantially increase the size of the existing market by using significantly different technology and offering significantly greater benefits that were previously not available (Aboulnasr, Narasimhan, Blair and Chandy 2008). Increasingly, the locus of firm innovation is found at networks of interfirm alliances (Powell et al. 1996). Alliances can help firms learn externally by drawing upon novel knowledge stocks of partners and develop new technological competence (Stuart and Podolny 1996). Alliances can also facilitate firms to draw upon novel knowledge from technologically unfamiliar domains for potential breakthrough innovation (Rosenkopf & Almeida 2003). Alliance network structure has recently been found to have important impacts on firm innovation. For example, Shan et al. (1994) found that network centrality as indicated by the number of collaborative relationships a firm had formed was positively related to the firm's innovation output. Powell et al. (1996) found that network centrality of firms is a major factor that drives the initiation and continuance of R&D alliances and dynamics of high-speed learning in the interfirm networks of biotechnology industry.

Meanwhile, information technology (IT) has recently become critical for supporting knowledge management initiatives and nurturing firm innovation (Alavi & Leidner 2001). IT enables the creation, dissemination, and usage of knowledge (Davenport, Prusak, & Strong 2008). IT helps leverage synergies among disparate knowledge elements distributed in different business units (Tanriverdi 2005). Thus, IT greatly augments and enables a set of knowledge management capabilities, which are referred to as IT-enabled knowledge capabilities (Joshi, Chi, Datta & Han 2010).

With the proliferation of interfirm alliance, firms are increasingly using IT to support business partnerships and manage knowledge flows in interfirm alliance networks. A bulk of IT literature has examined and demonstrated the importance of IT in the alliance context. For instance, Christiaanse and Venkatraman (2002) examined the partnership between American Airlines and its marketing channel partners and found that IT allows American Airlines to develop co-specialized knowledge and expertise with its marketing channel partners. Subramani (2004) examined the context of supply chain partnerships and found that IT not only allowed a firm to exploit existing knowledge and build relationship-specific expertise with suppliers, but also allowed the firm to explore new knowledge and expertise domains in the supply chain. Saraf, Langdon and Gosain (2007) examined the relationship between a firm and its channel partners and customers and found that the firm's information systems integration with partners and information systems flexibility facilitate knowledge sharing and process coupling between the firm and its partners. Malhotra, Gosain, and El Sawy (2005) found that the compatibility between the IT configuration, knowledge exchange and processing capability of a firm and those of its supply chain partners tends to impact knowledge creation in the supply chain. Chi, Ravichandran & Andrevski (2010) have found that IT-enabled firm capabilities can moderate the effects of spanning structural holes in alliance networks on firm competitive behavior, which subsequently affects firm performance outcomes.

Recognizing that alliance network and IT are two important antecedents of firm innovation and that IT plays a significant role in enhancing business partnership, we were motivated to ask the following question: Do alliance network structure and IT interact to jointly affect firm innovation? No study has yet examined this question. Answers to this question are important for advancing our understanding of IT's role in influencing firm innovation in alliance networks. Our research will contribute to the understanding of whether and how IT can help firms exploit their positions in the alliance network to achieve greater level of innovation. They can also guide managers to more fully tap into the potential of IT for enhancing innovation besides achieving operational efficiency.

In this paper, drawing on absorptive capacity theory (Zahra and George 2002) and organizational learning perspective, we focused on one specific type of alliance network structure – structural holes – and three types of IT-enabled knowledge capabilities – IT-enabled potential knowledge capability, IT-enabled realized knowledge capability, and IT-enabled socializing knowledge capability. We examined the interaction effects of IT-enabled

knowledge capabilities and structural holes on firm innovation. We focused on structural holes as they were well examined network structure in the literature and were found to have important impacts on firm innovation. We collected 82 firm-year observations from 20 unique pharmaceutical companies over the period of 2000-2006. Our results have suggested that IT-enabled knowledge capabilities differentially interact with structural holes to impact firm innovation. Our study makes important contributions to theory and practice on IT, interfirm alliance network, and firm innovation.

The remaining of the paper is organized as follows: Section 2 introduces theoretical background and develops research hypotheses; Section 3 introduces research methods and data analysis; Section 4 presents data analysis results; Section 5 discusses results and findings. Section 6 highlights research implications for theory and practice; Section 7 concludes the paper with future research directions.

Theory and Hypotheses

Firm Innovation

Innovation is especially important in a rapidly-changing environment for firms' survival and success (Danneels 2002). Firm innovation is widely viewed as new knowledge resulted from knowledge transformation and exploitation (Nerkar & Shane 2007, Porter & Stern 2000; Furman, Porter & Stern, 2002; Penner-Hahn & Shaver 2005; Goldenberg et al. 2001) and often embodied in the form of patent inventions (Penner-Hahn and Shaver 2005). Patent inventions represent significant discoveries, developed ideas or solutions to technical problems that can be commercialized into new products or services with potential financial returns (Luecke and Katz 2003). Newly developed ideas in the form of patent inventions often imply a high potential for market destabilization, not only cannibalizing business from existing competitors, but also repositioning existing products relative to each other (van Heerde, Mela, and Manchanda 2004; Aboulnasr, Narasimhan, Blair and Chandy 2008). These innovations can destroy existing markets and yet often yield vast new market opportunities (Aboulnasr, Narasimhan, Blair and Chandy 2008), substantially changing the competitive landscape in the market.

Alliance Network Structure

Interfirm alliances involve long-term collaborative relationships between firms and suppliers, customers, competitors, and other organizational entities such as government agencies, research institutions in which firms retain control over their own resources but jointly decide on their use (Ebers 1997). In these relationships, firms may engage in a broad range of collaborative arrangements, such as procurement, R&D, manufacturing, marketing, management, information technology development, and licensing. Relational capabilities of firms are not static, but rather evolve over time as firms both develop existing relationships and explore new ones (Powell 1998). Interfirm alliances provide a viable mechanism for organizational learning. Through learning, firms discover and obtain new knowledge and capabilities through interacting with one another in the alliance network (Brass, Galaskiewicz, Greve, and Tsai 2004). For instance, Stuart and Podolny (1996) found that firms can acquire needed technological capabilities through forming alliances with technological partners. Powell et al. (1996) found that firms in technologically intensive and fast developing fields such as biotechnology rely on collaborative relationships to "access, survey, and exploit emerging technological opportunities" (Powell 1998, pp. 230). Interfirm alliance networks provide vehicles for producing, synthesizing, and distributing ideas. In these networks, firms are linked to each other in diverse fields. Interaction with others in diverse fields not only increases firms' awareness and comprehension of new knowledge and resources, but also speeds up the rate of learning (Powell et al. 1996).

In the alliance network literature, structural holes are widely viewed as an important network structure that is potentially beneficial to firms. A structural hole exists between two firms that are connected through another firm, and thus do not have direct links with each other. A structural hole separates non-redundant sources of information, "sources that are more additive than overlapping" (Burt 2005). Burt (2004) argued that good ideas which people value are often unevenly distributed in different parts of the network. People who span structural holes have an early access to diverse, often contradictory, information and interpretations from diverse sources which increase their potential to see good ideas and synthesize them to create value than people who do not span structural holes. Thus, structural holes are critical in enhancing learning and creativity. Likewise, we argue the same for firms in alliance networks. When a firm spans structural holes, it enjoys preferential access to unique information from disconnected parts of the network (Burt, 1992), which increases its potential to learn and comprehend diverse knowledge to better discover new opportunities for market growth and innovation. Prior research has found that firms that span more

structural holes enjoy higher revenue growth (Baum, Calabrese & Silverman, 2000) and greater market share (Zaheer & Bell, 2005).

IT-Enabled Knowledge Capabilities

IT-enabled knowledge capabilities involve three fine-tuned dimensions, namely, IT-enabled potential knowledge capability, IT-enabled realized knowledge capability, and IT-enabled socializing knowledge capability (Joshi et al. 2010). These capabilities capture a firm's dynamic capabilities of processing knowledge with the help of IT.

IT-Enabled Potential Knowledge Capability (IT-Potential)

Potential knowledge capability makes the firm receptive to acquiring and assimilating internal and external knowledge (Lane & Lubatkin 1998; Zahra and George, 2002). It provides firms an ability to value and acquire knowledge. Information technologies that help enable and support knowledge acquisition and assimilation are characterized as IT-enabled potential knowledge capability (IT-potential). IT can enhance firm's assimilation capability by creating organizational memory in the form of electronic repositories (Alavi and Leidner 2001). Through organizational learning, firms accumulate valuable knowledge that needs to be stored and preserved for future use (Tippins & Sohi 2003). Various enterprise applications support knowledge acquisition process. For instance, ERP helps gather data from diverse key business processes and functions and integrate them into a central repository for shared use within and across the firm. CRM gathers and integrates customer-related data from different functions of marketing, sales and customer services and diverse sources (e.g., Web, email, call center, store outlet, mail) into a single, consistent view about customers for better insights. SCM gathers and integrates diverse information from manufacturing plants, suppliers, distributing centers, and logistics partners along the supply chain.

IT-Enabled Realized Knowledge Capability (IT-Realized)

This ability involves transformation and exploitation capabilities (Zahra and George 2002). Transformation capability synthesizes, develops and refines the existing and newly acquired and assimilated knowledge. Transformation can occur by adding, deleting or re-interpreting the absorbed knowledge in a different manner or for knowledge reuse. Transformation also allows organizations to view and develop knowledge through bisociation. This is achieved when knowledge from "two self-consistent but incompatible frames of reference" (Koestler 1966: 35) is visualized and integrated to create new insights, to facilitate the recognition of opportunities, and to alter the way the firm sees itself and its competitive landscape. Information technologies that help enable and support knowledge transformation and exploitation are characterized as IT-enabled realized knowledge capability (IT-realized). Business intelligence tools such as data mining and analytical tools allow firms to transform existing data and knowledge to gain new insights and understanding. Visualization techniques can support bisociation by integrating and mapping disparate knowledge sets to uncover new knowledge. Examples of information technologies that can help enhance knowledge exploitation capability include case-based reasoning, expert systems, inventory management systems, CAD/CAM systems, map creation software, and spreadsheets.

IT-Enabled Socializing Knowledge Capability (IT-Socializing)

IT-enabled socializing knowledge capability (IT-socializing) cultivates knowledge synergies through supporting firms' various formal and informal social integration mechanisms (Tippins and Sohi 2003; Zahra and George 2002). For instance, e-mail, message boards, e-community of practice, and groupware systems are all instrumental in cultivating social interaction and knowledge sharing among individuals and groups. Furthermore, the emergent multimedia tools and Web2.0 technologies such as wikis and blogs have opened up new opportunities to share knowledge and ideas, accelerating knowledge discovery and innovation (Shneiderman 2007).

In the next section, we examine the differential roles of three IT-enabled knowledge capabilities in the interfirm alliance network. We argue that firms can use IT to more fully tap into the potential benefits of structural holes to enhance firm innovation.

IT-Enabled Knowledge Capabilities, Structural Holes and Firm Innovation

When firms span structural holes – the sparse regions between disconnected firms in the network, they are likely to enjoy greater information benefits than firms that do not span structural holes (Burt 1992). Information and

knowledge circulate more easily within the network clusters than across the clusters. When knowledge is complex, it becomes increasingly difficult to transfer knowledge across network clusters. Thus, firms that span disconnected parts of networks are likely to access to unique and novel information and knowledge of partners (Burt, 1992). Being exposed to diverse perspectives, new ideas, and information that is highly scattered in the network also increases firms' ability to better comprehend new knowledge when it comes from a technologically unfamiliar domain and to learn about whether it may produce viable solution and when and how to apply the new knowledge, thus enhancing firms' potential to draw upon that knowledge for subsequent innovation.

Although structural holes increase firms' potential for innovation, we argue that IT-enabled knowledge capabilities allow firms to exploit this potential by harnessing the external resources of partners to more fully reap the potential benefits of spanning structural holes.

IT-Enabled Potential Knowledge Capability, Structural Holes and Firm Innovation

In the alliance network, knowledge may unevenly reside in different technological domains, functions, departments, divisions, or dispersed geographical locations of alliance partners. Firms spanning structural holes by connecting to diverse partners with heterogeneous knowledge resources and capabilities are likely to face increased knowledge flow and complexity in managing the interdependencies among diverse partners. Increased knowledge flow increases firms' awareness and comprehension of novel knowledge and new opportunities for innovation, if harnessed effectively. Unless firms have the capacity to deal with this increased knowledge flow and complexity, they are unlikely to attain the full benefits of spanning structural holes. IT-potential capability enhances firms' capacity to deal with the volume and complexity of knowledge across networks.

Specifically, IT-potential capability offers a broad range of tools for knowledge acquisition and assimilation and enhances firms' ability to scan across a wide range of knowledge sources of their alliance partners for a greater amount of knowledge and ideas that otherwise would be costly or difficult to obtain. Sophisticated retrieval technology such as query software, search engines, and knowledge maps can help identify, collect, and extract useful knowledge from a wider variety of knowledge resources with greater speed and accuracy. Integrated supply chain systems that support business process coupling among the alliance partners allow access to and understanding of diverse knowledge stocks. These integrated supply chain systems promote communications and shared meaning by imposing similar process representations among alliance partners which facilitate awareness and comprehension of novel knowledge that may be drawn upon for developing new technical solutions or inventions. IT-potential capability also enhances firms' awareness of the meta-knowledge of the acquired knowledge by increasing firms' ability to process a large amount of information from diverse sources and awareness of the relevant knowledge that may reside in alliance partners who specialize in different technological domains. A firm's access to and acquisition of its partners' knowledge stocks depend on the extent to which the firm knows which partner possesses what knowledge, and which partner can solve certain problems (Cohen and Levinthal 1990). Use of IT tools, such as directory services and expert finder, can strengthen a firm's awareness of its partners' knowledge and expertise. For instance, Proctor & Gamble (P&G) develops sophisticated IT systems to allow its suppliers, retailers, trade partners, and diverse technology partners worldwide to submit new ideas into P&G's databases (Huston and Sakkab 2006).

Besides knowledge acquisition, IT-enabled knowledge assimilation can also enhance firms' ability to handle increased knowledge flows and complexity presented by structural holes. Organizational memories/repositories serve as an effective tool to codify, reserve, and store the external knowledge acquired from alliance partners within the firm. These systems thus increase firms' ability to create new knowledge and inventions by sharing novel knowledge elements gathered from distant contexts of alliance partners while codified and stored in the system with other parts (e.g., business units, functions, geographical locations) of the firm and increasing the chance of recombining or reusing these knowledge elements. Through organizational learning, firms accumulate valuable knowledge that needs to be stored and preserved for future use (Tippins & Sohi 2003). IT can provide the necessary mechanisms and tools to preserve and store this knowledge. IT can help store information in the formats such that it can be accessible to firm employees and enable them to interpret it in a consistent manner, thereby becoming a part of the whole organization's memory. There are several information technologies that can help enhance organizational memory. For instance, content management systems, document management systems, databases, and data warehouses can help store various forms of data, audio, video, image, information, and knowledge.

Taken together, we argue that IT-potential capability increases firms' ability to more fully tap into the potential information benefits afforded by structural holes to enhance firm innovation. Therefore,

H1: IT-enabled potential knowledge capability of a firm positively interacts with the firm's access to structural holes to affect firm innovation.

IT-Enabled Realized Knowledge Capability, Structural Holes and Firm Innovation

IT-realized capability offers a wide range of tools for knowledge transformation and exploitation and enhances firms' in-depth analysis of acquired knowledge to gain a better understanding and new insights. This enhanced ability becomes necessary when sources of the acquired knowledge are from diverse alliance partners with heterogeneous knowledge domains and capabilities. IT-realized capability facilitates the reuse of existing knowledge in more creative ways. It can help relate and interpret technologically disparate knowledge by merging, categorizing, reclassifying, and synthesizing distinct knowledge elements into meaningful forms. Moreover, IT-realized capability can help integrate and associate novel knowledge elements from diverse alliance partners to create new insights and knowledge for the firm. IT tools such as business intelligence can help mine, interpret and discover patters and insights from large amounts of data. Graphic tools such as CAD and CAM enhance development of new technical solution or generation of new inventions by visualizing and simulating potential new combinations or new components. When firms span structural holes, a strong IT-realized capability is likely to increase firms' ability to better integrate and make sense of the diverse knowledge elements of alliance partners and thus firms' ability to draw upon those knowledge elements to create new knowledge for the firm. Therefore,

H2: IT-enabled realized knowledge capability of a firm positively interacts with the firm's access to structural holes to affect firm innovation.

IT-Enabled Socializing Knowledge Capability, Structural Holes and Firm Innovation

IT-socializing capability offers a wide range of audio, video and multimedia and communication tools for knowledge sharing and greatly enhances the firms' ability to share experiences and understanding across diverse contexts and jointly develop innovative technological solutions with their alliance partners. IT-socializing capability is especially critical to firms' search for novel knowledge from diverse alliance partners because it provides the foundation – a common language – for people and firms from different technological domains or geographical locations to communicate with each other. Knowledge is sticky and bounded within contexts. It is thus difficult to interpret or understand diverse external knowledge from different contexts, especially knowledge that is significantly different from a firm's existing knowledge base (Szulanaki 1996). A common language or interface needs to be established for knowledge transfer to happen (Grant 1996). A common language can be formed through various forms of social integration mechanisms, formal or informal ones (Zahra and George 2002; Jensen et al 2005). IT-socializing capability can greatly support various formal and informal social integration mechanisms. For instance, use of video conferencing and groupware facilitates formal integration, while tools such as e-community of practice, wikis, and blogs create opportunities for informal integration.

Media richness literature (e.g., Dennis et al. 2008; Daft and Lengel 1986; Daft, Lengel and Trevino 1987) suggests that richness provided by IT socializing tools allows "wide ranging and deep interactions between individuals and, thus, permit the establishment of trust and development of common understanding – both are critical for inter-firm knowledge flow" (Rosenkopf & Almeida 2003 pp. 755). When firms span structural holes, they are likely to have exposure to diverse alliance partners with widely different technological domains. Interacting with these diverse partners may often involve complex knowledge exchanges. A high IT-enabled socializing knowledge capability by providing rich media and communication capacity can greatly facilitate the varied, intricate, and multifaceted knowledge exchanges for complex ideas, abstract artifacts and richer meaning and vocabulary between firms and their alliance partners (Chin, Jr., Myers, and Hoyt 2002). For instance, e-mail, groupware systems, and video conferencing are all instrumental in cultivating social interaction and enriching knowledge sharing among individuals and groups. Wikis and blogs have opened up new opportunities to share knowledge and ideas, accelerating knowledge discovery (Shneiderman 2007). Therefore, we posit that IT-socializing capability is likely to increase the potential benefits of spanning structural holes to enhance firm innovation.

H3: IT-enabled socializing knowledge capability of a firm positively interacts with the firm's access to structural holes to affect firm innovation.

Methods

Sample Selection

To empirically test our research model, we collected data from the pharmaceutical industry. Pharmaceutical industry has been widely studied in a number of alliance and innovation related research (Schilling, 2007; Rothaermel, 2004; Powell et al., 1996). Pharmaceutical industry provides us with an excellent testing bed for examining the role of IT in strengthening the association between inter-firm alliance and innovation, because of its widespread patenting practice, proliferated inter-firm alliance, and aggressive IT usage. Pharmaceutical industry is noticeable for its scientific and commercial advances, a high rate of patenting, and proliferated inter-firm collaborations between pharmaceutical companies and a wide range of organizations ranging from universities, public research institutions, venture capital firms, financial institutions, to small biotech firms. In this industry, the sources of scientific leadership are widely dispersed and rapidly developing, and the relevant skills and resources needed to produce new medicines are broadly distributed; no single organization has been able to internally master and control all the competencies required to develop a new medicine; the fast pace of technical advances has made it difficult for any company to stay abreast on many fronts (Powell et al. 1996). Thus, pharmaceutical firms need constant knowledge-seeking and exploration of new knowledge to keep up the paces of high-speed learning in order to stay competitive (Rothaermel, 2001). As interfirm alliance networks are instrumental in fostering learning and increasing rate of learning, strategic alliances have become a common strategic initiative in the pharmaceutical industry (Powell et al. 1996). Additionally, pharmaceutical firms actively patent their inventions as one of their innovation strategies (Levin, 1987).

In the past twenty years, the pharmaceutical companies have aggressively tapped into IT trying to speed up the development of new drugs, as for a pharmaceutical company it typical takes about 15 years and as much as $800 million to bring a drug to market, from the time the need for the drug is identified to the time it achieves FDA approval, "the faster a drug company can get a product to market, the longer the company can keep the patent" (InformationWeek500, September 12, 2002). Based on the InformationWeek 500 survey, a pharmaceutical company on average has spent about 4% of its total revenue on IT each year since 2000. These companies are large companies with multi-billion-dollar revenues. Four percent of the revenue means millions of dollars, which is a significant amount of IT spending each year.

Data

We tested our hypotheses on a sample of U.S. public firms in the pharmaceutical industry (SIC 2834) from 2000 to 2006. We obtained data from three major sources: (1) alliance data from Thomson Corp.'s SDC Platinum database, (2) patent data from NBER patent database (Hall et al., 2001), and (3) control variable data from COMPUSTAT, (4) IT data from Harte-Hanks database. As a result, we obtained a final sample of an unbalanced panel data of 82 firm-year observations involving 20 unique pharmaceutical firms for a seven-year sample period from 2000 to 2006.

Patent Data

Patent data have been widely used to study firm innovation. Patents are embodiments of new knowledge and provide a trace of firm innovation. They are a measure of novel invention that is externally validated through the patent examination process (Griliches 1990). We collected granted patent data, because granted patents provide a good proxy for significant firm inventions that have a high potential to be commercialized for revenues (Chandy, Hopstaken, Narasimhan, and Prabhu 2005). Patent counts have been used to measure innovative output in a number of previous studies (e.g., Bound et al. 1984; Henderson and Cockburn 1996; Penner-Hahn & Shaver 2005; Nerkar 2003; Nerkar & Shane 2007), and have been shown to be valid and robust indicators of firm innovation (e.g., Basberg 1987; Trajtenberg 1987).

We collected patent data from NBER patent database (Hall et al. 2001). We drew all the patents that were granted to our sample firms during 2001-2006. We tracked the corporate history of name change, and merger and acquisition, and aggregated the patent data to parent company. Altogether, we obtained 9,435 granted patents made by the 20 pharmaceutical firms during 2001-2006.

Alliance Network Data

We collected alliance data to build interfirm networks for our sample. Alliances have been shown as a major mechanism for firms to access partner's knowledge and resources (Powell et al. 1996). We used Thomson Corp.'s SDC Platinum database as a main source for obtaining alliance data. Compared to other similar data sources (e.g., MERIT-CATI, CORE, RECAP, or Bioscan), SDC database is the most comprehensive database regarding its coverage of agreement types (Schilling, 2009), and is commonly used in extant research (Anand, 2000; Dovev, 2007). We drew alliance data from "Joint Ventures/Strategic Alliances" section of SDC database. We included collaborations of all agreement types (e.g. joint venture, strategic alliance, and licensing agreement), and across various kinds of collaborative arrangements (e.g., R&D, manufacturing, marketing and service provision, supply). The reason to incorporate alliances with a wide range of activities is that each type of collaboration provides a potential pathway of knowledge spillover between firms (Rosenkopf & Almeida, 2003; Schilling, 2007). Furthermore, prior studies (e.g., Powell et al. 1996) have found that firms enter in the interfirm networks through one kind of collaborative activity or another and then tend to deepen their collaboration with partners by engaging in more diversified activities. The on-going collaboration through engaging in diversified activities drives the dynamics of learning in the network and increases awareness and comprehension of new knowledge that may be drawn upon for subsequent innovation.

To fully capture the characteristics and structures of the alliance network, we constructed a complete network that involves pharmaceutical firms, their direct partners, and their direct partners' partners. While ego networks of pharmaceutical firms present the links between pharmaceutical firms and their direct contacts, a complete network comprises ego networks and also the ties among the direct contacts of pharmaceutical firms. Thus, a complete network provides more comprehensive information than ego networks regarding the extent of connectivity among pharmaceutical firms' partners. Such approach is especially critical when we construct our network measure of structural holes. To construct a complete network, we first identified alliances formed by firms with four-digit SIC code of 2834 from 1998 to 2005. This initial search generated a set of participants which contain pharmaceutical firms and their partners. We then searched for all alliances formed by this set of participants for the same period. This additional search generated 5,254 alliances involving 11,854 participants formed by all pharmaceutical firms and their partners during 1998-2005.

One problem regarding the construction of interfirm networks was that actual date of alliance termination was often underreported. Prior research has used three- or five-year moving windows approach by making the assumption that the average alliance duration was about three or five years (Schilling 2007; Dovev 2007; Stuart 2000). In this research, we chose a more conservative approach to create network matrices using a three-year moving window. For example, the network matrix for 2000 included all alliances formed between 01/01/1998 and 12/31/2000. Altogether, we created six network snapshots for the aggregation period of 2000 - 2005 (i.e., 1998-2000, 1999-2001, 2000-2002, 2001-2003, 2002-2004, 2003-2005). We built undirected binary adjacency matrices for alliance networks (Wasserman and Faust 1994); that is, we coded 1 in the corresponding adjacency matrix when two firms were in the same strategic alliance and 0 otherwise.

IT Data

We collected IT data through the Harte-Hanks database. Harte-Hanks is a market intelligence company, which conducts surveys or on-site interviews about the IT usage of various hardware and software at selected corporate sites of major US companies each year. From Harte-Hanks, we obtained information on 50 different IT applications used during 2000-2005 time period within the pharmaceutical companies included our sample. The IT applications for our sample ranged from business intelligence, database, document management, content management, groupware, portal, multimedia to various enterprise applications such as CRM, SCM, ERP and enterprise application integration such as Web services, middleware.

Variables

Dependent Variables

We used the total number of patents that were granted to each firm each year as a proxy for firm innovation. The number of granted patent counts of our sampled firms ranges from 0 to 405. The greater the number of granted patents, the greater amount of firm innovation outputs.

Independent Variables

Structural Holes. Extent of access to structural holes was obtained by subtracting one by network constraint. Network constraint measures a firm's lack of access to structural holes and was calculated as follows (Burt, 1992: 54):

$$\text{Constraint}_i = \sum_j \left[p_{ij} + \sum_k \left(p_{ik} p_{kj} \right) \right]^2$$

where Pij is the proportion of firm i's direct relations invested in contact j, and ΣPikPkj indicates the extent to which another partner k in which i has invested substantial time and resources is also connected to contact j. Thus, for firm i, the contact j is redundant to the extent that another i's contact k is also connected to j. The values of structural holes range from 0 to 1, and the higher values of structural holes indicate that a firm has a greater extent of access to structural holes by spanning more structural holes in the network.

IT-Enabled Knowledge Capabilities. Our IT constructs were calculated from Harte-Hanks data. Harte-Hanks data provide site-level details about the revenue and various IT applications at each selected site of a pharmaceutical company. For example, for each year, Harte-Hanks tracked and surveyed 36 sites of Johnson & Johnson, 9 sites of Eli Lilly, 32 sites of Merck & Co., 21 sites of Novartis Corp. In order to obtain firm-level measure, we first adjusted each site s's IT applications by the total applications of all companies used in each year to account for the variation in IT applications from one year to another. Second, we weighted each site's revenue by the total of all selected sites of a company to account for different IT-enabled knowledge capabilities of different sites and then aggregated the weighted IT applications of all selected sites to represent a pharmaceutical company i's IT-enabled knowledge capabilities in year t, $IT_{i,t}$.

$IT_{s,i,t}$ = number of IT applications at site s of company i in year t;

IT_t = total number of IT applications in year t;

$r_{s,i,t}$ = revenue at site s of company i in year t;

n_i = number of selected sites of company i;

$$IT_{i,t} = \sum_{s=1}^{n_i} \left(\frac{IT_{s,i,t}}{IT_t} \times \frac{r_{s,i,t}}{\sum_{s=1}^{n_i} r_{s,i,t}} \right)$$

We adopt Joshi et al.'s (2010) categorization of IT-enabled knowledge capabilities into three subconstructs: *IT-potential, IT-realized, IT-socializing*. IT-potential capability is reflected in IT applications including data reading or digital capture technology, search tools & directory services, databases (data warehouses), document management systems, content management systems, enterprise applications (e.g., SCM, CRM, ERP). IT-realized capability is reflected in IT applications including business intelligence, data analytics, data mining, visualization, simulation, decision support system, CAD/CAM. IT-socializing capability is reflected in IT applications including e-community of practice (e.g., blogs, wikis, BBS), messaging (e.g., email, instant messaging, mobile messaging), conferencing (e.g., videoconferencing, multimedia), portal, groupware, enterprise application integration (e.g., Web services, middleware, SOA). IT applications at each site were first counted and mapped to each of the three IT constructs. Then the three types of IT-enabled knowledge capabilities were calculated using the above formula. We used the total counts of IT applications at each site rather than the number of IT applications at each site for producing a particular patent, because counting all IT applications at each site would allow us to take into consideration the possible spillover effects of various IT applications. Some IT applications such as visualization and data analytical tools may be directly involved in synthesizing diverse knowledge from partners for generating patent inventions. While other IT applications such as CRM may indirectly help firms generate inventions through acquiring and analyzing perspectives and ideas from customers. Thus, considering all IT applications instead of those directly involved in generating patents will enable us to more fully capture how IT influences the effects of structural holes on firm innovation.

Control Variables

Firm size. Firm size was controlled as it influences firm's patent inventions. Firm size was measured as the number of full-time employees at time t. It was log transformed to reduce the skewness of distribution.

Prior firm performance. Prior performance was also controlled as it may influence firm's R&D resources and subsequent patent inventions (Chen, 2008). Prior firm performance was measured by firms' return on assets (ROA) at time t. We didn't use return on equity in order to avoid potential distortions caused by differences in financial leverage across firms (Greve, 2003).

R&D intensity. We controlled for R&D intensity, which was defined as R&D expenditure divided by sales. R&D intensity has been argued to impact firms' ability to identify, assimilate, and utilize knowledge (Tsai, 2001; George, 2001). Thus, R&D intensity was controlled to exclude its potential impacts on firm innovation. We log transformed this measure to reduce the skewness of the distribution.

Technological diversity. We also controlled for the technological diversity of a firm. A firm's technological diversity reflects the diversity of the firm's knowledge base and may influence both the absorptive capacity of the firm and the impact of patents within the firm (Stuart and Podolny, 1996). We calculated the technological diversity using an entropy measure to obtain the distribution of a firm's patents over the technological sub-categories over a three-year period (time t-2 – t) (Silverman, 1999). It is calculated as follows:

$$\text{Technological Diversity}_i = \sum Pj \times \ln\left(\frac{1}{Pj}\right)$$

where Pj is the percentage of a firm i's patents filed in the jth technological sub-category developed by Hall et al. (2001), and 1/Pj is the weight for the jth technological sub-category. The score is the sum of weighted ratio over 36 technological sub-categories. The value ranges from 0 to 2.39. Higher value represents greater technological diversity.

Statistical Method

The dependent variable was lagged by one year to the independent variables and control variables to mitigate the concern of potential endogeneity problem. To accommodate the nature of dependent variable – granted patent counts – as a count variable which assumes non-negative, integer values. Linear regression is not the most appropriate approach because the assumptions of constant variance and normal distribution of the error terms are violated when dependent variables of the regression are count variables. A Poisson regression approach is preferred to model count data (Hausman, 1984). Poisson distribution relies on a strong assumption on the equality of the mean and variance. Negative binomial model provides an alternative approach to model count data and it relaxes the equality assumption, allowing for overdispersion by incorporating an individual, unobserved effect into the conditional mean (Hausman, 1984). Granted patent counts of our sample show a mean value of 94.35 and a variance of 9643.2. Our data, with variance exceeding the mean (overdispersion), failed to meet equality assumption. We performed likelihood ratio test on overdispersion. Alpha value of the likelihood ratio test was significantly different from zero, suggesting that negative binomial model was more appropriate than Poisson regression. Thus, we used negative binomial regression to analyze our data.

Several approaches were used to control for unobserved heterogeneity stemming from firm effects or time periods (Heckman, 1979). We included year fixed effects to control for systematic temporal effects such as differences in macroeconomic conditions that may affect all sampled firms' patenting activities. We also controlled for unobserved firm-specific differences by including firm fixed effects. Fixed-effect models assume that unobserved firm heterogeneity is time-invariant and are considered to be stringent models. Furthermore, as we have multiple annual observations of each firm, the observations are not independent and the standard errors are not properly estimated. Hence, we used robust standard error estimation in which all observations belonging to the same firm have a common standard error (White, 1980).

To examine the interaction effects of IT and structural holes on firm innovation, interaction terms between three IT-enabled knowledge capabilities and structural holes were introduced in the model. To avoid the problem of multicollinearity, we centered the values of these variables before creating interaction terms (Aiken & West, 1991). We also tested multicollinearity by computing variance inflation factors for all models. All VIFs were lower than 4 (much lower than the critical value of 10) and thus ruled out the concerns of potential multicollinearity problem.

Results

Table 1 provides descriptive statistics and correlations of all variables. Table 2 presents the statistical results of negative binomial regression. In Table 2, Model 1 presents a baseline model which includes only control variables. Models 2-7 tested the moderating effects of each IT-enabled knowledge capability individually. Model 8 tested a complete model with all three IT-enabled knowledge capabilities. H1 hypothesized that IT-potential positively interacts with structural holes to affect firm innovation. Our result (Model 3 and Model 8) failed to support H1 as coefficient estimates for the interaction term between IT-potential and structural holes are not statistically significant. This result suggests that IT-potential does not significantly strengthen the positive effect of structural holes on firm innovation. H2 which hypothesized that IT-realized positively interacts with structural holes to affect firm innovation was not supported. The coefficient estimates of the interaction term between IT-realized and structural holes are not statistically significant in Model 5 and Model 8 of Table 2. Similar to IT-potential, this result suggests that IT-realized does not significantly strengthen the positive effect of structural holes on firm innovation. H3 which hypothesized a positive interaction effect between IT-socializing and structural holes on firm innovation was supported. The coefficient estimates for the interaction term between IT-socializing and structural holes are positive, significant in Model 7 ($\beta=6.192$, $p<0.05$) and Model 8 ($\beta=6.533$, $p<0.1$). This result suggests that IT-socializing plays a significant role in strengthening the positive effect of structural holes on firm innovation.

Table 1. Summary Statistics and Correlations[a]

Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7
1. Patent count	94.35	98.20	0	405							
2. Structural holes	0.72	0.28	0	0.97	0.44						
3. IT-potential	0.16	0.08	0	0.48	0.00	0.02					
4. IT-realized	0.05	0.08	0	0.46	0.08	0.06	0.59				
5. IT-socializing	0.42	0.19	0.10	0.95	0.10	0.08	0.08	-0.02			
6. Firm size (No. of employees [b])	2.87	1.77	-2.85	4.80	0.62	0.64	0.17	0.13	-0.03		
7. Technological diversity	1.03	0.61	0	2.23	0.56	0.61	0.13	0.06	0.07	0.70	
8. R&D intensity[b]	-1.78	0.79	-3.30	1.63	-0.19	-0.09	-0.07	-0.07	0.23	-0.50	-0.15

[a] Absolute value of correlation coefficient greater than 0.17 is significant at 0.05 level.
[b] Values are natural-logarithm transformed.

Discussion

Overall, our results provide some support for our contention that IT-enabled knowledge capabilities increase the potential benefits of structural holes to enhance firm innovation. Furthermore, we found that different types of IT-enabled knowledge capabilities differentially interact with structural holes to affect firm innovation output.

Our result failed to support our contention of a positive interaction between IT-potential and structural holes. A possible explanation could be that IT-potential did not provide a sufficient means for more fully tapping into the potential information benefits afforded by spanning structural holes in the pharmaceutical alliance networks. IT-potential might be helpful for facilitating explicit, codifiable information search and acquisition about drug data, such as clinical trial data, regulatory, manufacturing, and sales information. However, IT-potential might be less helpful for pharmaceutical companies when information search and acquisition involve complex, tacit knowledge. When pharmaceutical companies spanned structural holes in the alliance network, they were likely to face increased complexity of diverse knowledge, ideas, and interpretations by exposing to a variety of partners. In the pharmaceutical industry, much sophisticated technical knowledge was often tacit in nature (Powell 1998). This knowledge often needed direct personal interactions with the source of knowledge stocks or those who were familiar with the knowledge source. In such situations, the role of IT-potential might be limited in identifying novel, usable knowledge that is relevant, credible, and adaptable to the technical problem at hand, although IT-potential could provide search and retrieval capabilities and enable fast access to diverse codified regulatory and scientific data from digital databases and knowledge repositories. In addition, the role of IT-potential might be limited in handling and assimilating the knowledge that hole-spanning firms face, this knowledge often involved an indissoluble mix of design, process, and expertise and such knowledge is not easily identifiable, codifiable, and transferrable. Thus, to

more fully benefit from spanning structural holes in the alliance network, direct communication channels might need to be first established between the pharmaceutical firms and alliance partners to share understanding and perspectives and promote firms' awareness and comprehension of diverse perspectives and knowledge from partners. But IT-potential capability could be valuable when used in conjunction with IT-socializing tools.

Table 2. Negative Binomial Regression Model with Robust Standard Errors

D.V.: Patent Count	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Structural holes		0.836	0.826	0.877	1.049+	0.878	1.168+	1.398*
		(0.579)	(0.605)	(0.551)	(0.568)	(0.584)	(0.615)	(0.606)
IT-potential		0.356	-0.982					-0.626
		(0.821)	(1.290)					(1.871)
Structural holes* IT-potential			7.732					-4.109
			(5.744)					(9.749)
IT-realized				1.940**	0.842			1.02
				(0.595)	(0.999)			(1.387)
Structural holes* IT-realized					11.217			13.814
					(7.827)			(10.699)
IT-socializing						-0.212	-0.998	-0.944
						(0.501)	(0.632)	(0.707)
Structural holes* IT-socializing							6.192*	6.533+
							(2.964)	(3.853)
log(Employee)	0.079	0.043	0.025	0.082	0.173	0.031	0.000	0.086
	(0.199)	(0.258)	(0.251)	(0.244)	(0.240)	(0.256)	(0.229)	(0.248)
Technological diversity	0.938***	1.004***	0.975***	1.107***	1.121***	0.995***	1.009***	1.157***
	(0.264)	(0.265)	(0.266)	(0.253)	(0.240)	(0.267)	(0.262)	(0.247)
log(R&D intensity)	-0.189	-0.258	-0.219	-0.269	-0.308+	-0.264	-0.213	-0.27
	(0.182)	(0.193)	(0.196)	(0.182)	(0.174)	(0.193)	(0.191)	(0.180)
Constant	0.013	-0.046	0.13	-0.119	-0.498	-0.022	0.206	-0.12
	(0.759)	(1.001)	(1.009)	(0.967)	(0.917)	(1.000)	(0.891)	(1.033)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log-Likelihood	-260.453	-250.144	-249.122	-246.386	-244.711	-250.145	-247.661	-241.832
Wald chi2	17.262	20.357	20.154	32.47	37.449	20.048	23.512	41.427
N	82	79	79	79	79	79	79	79

Robust Standard error in parentheses.
†<0.10
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Our result failed to support our contention of a positive interaction between IT-realized and structural holes. We reason that similar to the case of IT-potential, when pharmaceutical firms spanned structural holes and faced diverse knowledge, perspectives, and interpretations from partners, IT-realized did not provide a sufficient means to fully benefit from information advantage afforded by spanning structural holes in the alliance network. It would be difficult to integrate diverse knowledge sources without sufficient communication and sharing of experiences and understanding with partners. IT-realized capability focused on providing analytical capability to make sense of data.

However, without building a common understanding or language, for instance, certain scientific terms could have different meanings in different fields, the data could not be integrated or re-interpreted for generating new knowledge and inventions. Thus, it is possible that the role of IT-realized capability was limited in directly benefiting hole-spanning firms but it could be valuable when used in conjunction with the IT-socializing tools.

Our result provided support for a positive interaction between IT-socializing and structural holes. As postulated, our result suggests that IT-socializing capability played a significant role in complementing structural holes to more fully tap into the potential information benefits of spanning structural holes and further enhancing creation of patent inventions. Our result suggests that when pharmaceutical firms possessed a high hole access, a strong IT-socializing capability by providing a variety of rich media with varying utilities and providing rich communication channels to direct pharmaceutical firms' attention to the most relevant and useful knowledge had increased pharmaceutical firms' ability to identify and comprehend diverse knowledge at a higher rate than does a low IT-socializing capability. Thus, hole-spanning firms were better able to benefit from their network position by having an early access to diverse knowledge and perspectives of diverse partners and were also better able to integrate different perspectives and contexts from partners for greater drug discovery. For instance, video conferencing and multimedia enable synchronous knowledge exchanges that allow to provide immediate feedback and to convey subtle social cues to enhance understanding of complex knowledge (Dennis et al. 2008). Groupware and portal support both synchronous and asynchronous knowledge exchanges that allow both fast feedback and time for thinking and processing the information (Dennis et al. 2008). Email supports asynchronous knowledge exchanges that allow longer time for processing the information (Dennis et al. 2008). We found that pharmaceutical companies tended to use a combination of a variety of IT-socializing tools (such as video conferencing, multimedia, groupware, portal, email) to support communications and knowledge sharing across diverse contexts of partners.

Contribution

This study contributes to IS theory and practice in multiple important ways. First, our study represents an early effort to systematically investigate the interplay between inter-firm network, IT, and firm innovation. As the locus of innovation is increasingly found in interfirm alliance networks, both network structure and IT are important themes that deserve greater research attention in studying firm innovation. Issues, such as designing a firm's technology infrastructure to better exploit its external resources, as well as understanding how IT systems can be designed to support a firm's network structure and enable the firm to more fully tap into the benefits afforded by the network (Schultze and Orlikowski 2004) are important aspects that deserve research attention yet remain under-explored. The theorizing and empirical work done here is perhaps among the first attempts to explore this rich research domain.

Second, drawing on absorptive capacity theory and organizational learning perspective, we build on Joshi et al.'s (2010) theorization of the three IT-enabled knowledge capabilities to provide a theoretically well grounded characterization of three distinct categories of information technologies that provide and enable a set of dynamic firm capabilities. This theorization allows us to provide a more nuanced understanding of IT's roles in alliance network context by theorizing and empirically investigating the differential impacts of three types of IT-enabled knowledge capabilities on the relationship between structural holes and patent inventions. By doing so, our findings enrich our understanding of how different IT-enabled knowledge capabilities interact with firms' alliance network structure to jointly affect firm innovation. Our findings that IT-socializing capability plays a significant role in complementing structural holes to enhance creation of new patent inventions shed light on an enriched understanding of how firms that span structural holes are better able to fully realize the potential network benefits for enhancing firm innovation. Our results are encouraging because they demonstrate the value of IT in alliance network context.

Third, IT has been widely used in the pharmaceutical industry to gain process efficiency and to cut cost, however, the use of IT for innovation has been limited. Results from this study may provide useful guidelines for companies to better innovate. Results from our work can provide insights and guidance to the managers in the pharmaceutical industry regarding how IT can be used to support and enhance firm innovation. Our results suggest that IT-socializing capability can be particularly important in facilitating greater firm innovation when firms span sparse regions in the alliance networks. Although structural holes present potential opportunities for obtaining information benefits by exposing hole-spanning firms' to diverse partners that may enhance firm innovation, firms are not likely to fully realize these network benefits, unless firms are harnessed to effectively handle the complexity and volume of knowledge they face. Our findings suggest that IT-enabled knowledge capabilities, in particular IT-socializing

capability provides an effective mechanism that helps enhance firms' ability to tap into the potential benefits of structural holes for greater innovation. IT-socializing capability offers a wide range of utilities from rich media and communication tools such as multi-media, videoconferencing which enable synchronous communication, social cues, immediate feedback, and language symbols, and groupware and portal which enable both synchronous and asynchronous communications, as well as email which provides asynchronous communication for longer processing and thinking time. Our results also suggest that IT-potential and IT-realized capabilities by themselves may not provide sufficient mechanisms to fully realize the potential benefits of structural holes for enhancing firm innovation. IT-potential capability provides search and data storage capabilities. IT-realized capability provides analytical tools such as CAD/CAM, visualization, simulation, as well as decision support tools to help synthesize and integrate knowledge across diverse contexts to gain new insights. However, without sufficient communications and shared understanding of various knowledge elements, IT-potential and IT-realized capabilities may play limited roles in complementing hole-spanning and realizing the potential benefits of spanning structural holes in the alliance network. Both these capabilities could be valuable with the presence of a strong IT-socializing capability in complementing structural holes to enhance innovation.

Limitations

As an initial effort to empirically investigate how IT interacts with alliance network structure to jointly affect firm innovation, we only examined the pharmaceutical industry in this study. As a knowledge-intensive industry, pharmaceutical industry involves much technical knowledge that is tacit and complex in nature (Powell 1998). These characteristics of the pharmaceutical industry may not be shared by less-knowledge-intensive industries such as retailing and restaurant industries. Thus, results and findings from our study may not be readily generalized to those less-knowledge-intensive industries. Furthermore, our sample only involves 82 firm-year observations from 20 unique pharmaceutical firms. The small sample size may also limit the explaining power and generalizability of our results and findings.

Conclusion and Future Research

This study draws on absorptive capacity theory and organizational learning perspective to examine and elaborate the roles of IT in influencing firm innovation in the alliance network context of pharmaceutical industry. We focused on three types of IT-enabled knowledge capabilities and one specific type of alliance network structure - structural holes - and examine whether and how they interact to jointly affect firm innovation. Firm innovation is observed through pharmaceutical firms' patent inventions. We found that three types of IT-enabled knowledge capabilities differentially interact with structural holes to affect pharmaceutical firms' patent inventions.

Future research can be extended along many exciting directions. First, in this study, we only examined one specific network structure – structural holes. Prior research has found several other network properties, such as centrality and small world structure, also have important impacts on firm innovation. Future work may examine whether and how three types of IT-enabled knowledge capabilities interact with these network properties to jointly affect innovation output.

Second, firm innovation was observed as patent inventions in this study. Along the innovation pathway, there could be a number of path-dependent value-added outcomes that manifest firm innovation. These innovation outcomes may begin with generated and developed ideas that are innovative (Hansen and Birkinshaw 2007; Nerkar & Shane 2007; Schumpeter 1934, 1950), followed by the conversion of innovation into products and services and releasing them into market (Hansen and Birkinshaw 2007; Schumpeter 1934, 1950), then diffusion of these released products and services (Hansen and Birkinshaw 2007; Rogers 1995), and end with revenues from product and services sales (Nerkar & Shane 2007; Jensen and Webster 2004). Future research can focus on other innovation outcomes such as new product introduction or first sales generated from new product launches, and examine how IT and alliance network structure interact to affect such innovation outcomes. Results from such work can add insights into an enriched understanding of the roles of IT and alliance network structure in firm innovation.

Third, in this study, we only examined the interactions between each IT-enabled knowledge capability and structural holes. While the three IT-enabled knowledge capabilities are distinctly different from each other, two or more of these capabilities may possibly interact with structural holes to jointly influence firm innovation. The small sample size has limited the explaining power of our study to empirically test the three-way and four-way interactions among IT constructs and structural holes. Future research could collect more data to empirically test this.

Fourth, IT-enabled knowledge capabilities have been expanded significantly in function and sophistication in recent years. With these expanded capabilities, we would expect stronger interaction effects between IT-enabled knowledge capabilities and structural holes. Future research could examine these effects by collecting more data about IT and alliance networks in pharmaceutical industry and other industries. Such results could further validate and increase the generalizability of our research model.

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