Ph. D. Dissertation in Engineering

Firm's Internal and External Factors in Driving Exploratory Innovation

: From a Knowledge-Based Perspective

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이 논문을 공학박사학위 논문으로 제출함

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Abstract

Firm's Internal and External Factors in Driving Exploratory Innovation

: From a Knowledge-Based Perspective

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Exploratory innovation, which refers to the generation of something valuable by using unfamiliar knowledge obtained from exploration, has received considerable attention as an important way to gain a competitive advantage and achieve sustainable growth. The increased importance of exploratory innovation resulted in the growing interest in underlying mechanisms of innovation, such as knowledge exploration (i.e., a nonlocal search beyond the firm's current expertise) and recombinatory search framework (i.e., an analytic tool that explains the link between knowledge elements and innovation). Recently, literature on exploratory innovation has investigated a firm's internal and

external knowledge environments on promoting exploratory innovation with the mechanisms of innovation as an implicit premise. However, the research on exploratory innovation is still in its early stages and has focused on individual topics rather than analyzing the entire process by which a firm creates exploratory innovation. In this regard, there is room to develop the previous discussions by taking a closer look at this field. This dissertation aims to increase the academic understanding of the mechanisms of exploratory innovation by investigating two key questions: First, "what characteristics of a firm's intrinsic and embedded knowledge base promote exploratory innovation?"; because the knowledge base is embedded in the organization and exists in a complex form changing over time, it is necessary to consider it a dynamic collection that includes knowledge elements and their combinations rather than a simple repository of knowledge elements, Second, "what is the effective way to source external knowledge among alliance partner firms to create exploratory innovation?"; when considering the external knowledge environment to promote exploratory innovation, it is necessary to understand not only the compositions of external knowledge resources but also the structural factors of interfirm networks, which affect accessibility and appropriability for external knowledge resources.

From the internal focus, previous research on exploratory innovation has primarily focused on investigating and explaining a firm's internal knowledge base as a simple repository of knowledge elements. Concerning the structure of knowledge, only recently has research begun to investigate characteristics of a knowledge base as a network of

knowledge elements. In this regard, this dissertation examines the firm's internal knowledge network and its effects on the subsequent exploratory innovation. Chapter 3 suggests a theoretical framework to express a firm's knowledge base as a single network composed of knowledge elements (i.e., component knowledge) and their combinations (i.e., architectural knowledge) and investigate the dynamics of such a knowledge network over time. Specifically, Chapter 3 distinguishes accumulated component and architectural knowledge, and investigates their impact on subsequent exploratory innovation, i.e., the creation of new elements and new combinations. The uncovered relationships between the two types of accumulated knowledge and the two types of exploratory innovations, help us comprehend the dynamics of the firm's knowledge network. Using patent data of 111 US semiconductor companies from 2000–2010, Chapter 3 empirically verifies an inverted U-shape relationship between the level of accumulated architectural knowledge and subsequent new knowledge combinations. As a firm accumulates experience of combining knowledge resources, new ways of knowledge application occur more frequently. This accumulated architectural knowledge helps organizational learning and broadens knowledge applicability to foster exploratory innovation. However, because of path-dependent attributes, knowledge application becomes rigid inertia that makes it harder to seek new ways. Furthermore, the relationships between accumulated component knowledge and new knowledge combinations, and between accumulated architectural knowledge and new knowledge elements were found to be positive. It shows that the accumulation of component knowledge can be essential for creating new knowledge

combinations, and the accumulation of architectural knowledge also helps form new knowledge elements. In other words, learning about elements as a basis for new inventions should precede the creation of new inventions by combining elements. Additionally, accumulating knowledge from the experience of combining various elements is important to extend a firm's area of expertise by gaining new knowledge elements. The results highlight the important role of the firm's accumulated knowledge resources in creating exploratory innovation and contribute to the research on the antecedents of exploratory innovation.

From the external focus, this dissertation investigates how the focal firm is able to effectively discover and secure the necessary knowledge in the alliance portfolio to create exploratory innovation. Previous literature has primarily focused on examining the external knowledge environment for exploratory innovation, focusing on either the compositions of knowledge resources or the structural factors affecting firms' access to them. For a holistic approach, Chapter 4 proposes a new framework of knowledge flow and search flexibility, both are essential for exploratory innovation, to simultaneously examine the effects of a firm's network position and knowledge composition of the alliance portfolio. Using this framework, Chapter 4 empirically confirms that central and brokering positions have an inverted U-shape relationship with the creation of exploratory innovation through panel data of 142 pharmaceutical companies from 1996-2010. Specifically, a central position promotes smooth knowledge flow due to the focal firm's high social status, allowing it to access valuable knowledge from its partners.

However, exceeding a certain level, the central position decreases search flexibility due to the constraint on decision-making caused by strong relationships. A brokering position fosters search flexibility as it allows the focal firm to control information flows. However, exceeding a certain level, the lack of absorptive capacity negatively influences knowledge flow. Chapter 4 also verifies two combinations of network position and knowledge composition advantageous for increasing exploratory innovation: a central position with partners' wide scope of new knowledge, and a brokering position with partners' wide scope of shared knowledge. These results support the argument that the effects of network position and knowledge composition can complementarily interact with each other, thus potentially compensating the negative effects on either knowledge flow or search flexibility. Specifically, new knowledge breadth can increase the low search flexibility resulting from a central position. The central position allows firms to overcome the information overflow associated with increases in new knowledge breadth. The shared knowledge breadth with partners increases absorptive capacity, which helps firms to understand each other and increases the knowledge flow that is often insufficient for firms at a brokering position. At the same time, the brokering position can prevent firms from becoming too similar to its partners, which would harm the exploration of new ideas. From these results, Chapter 4 contributes to the literature by identifying interaction effects between social network theory and the knowledge-based view and suggests implications for designing a firm's alliance strategy.

Overall, this dissertation increases the understanding of the mechanism of exploratory

innovation by investigating a firm's internal and external factors that influence the creation of exploratory innovation. It provides the following contributions and implications. First, based on the findings of Chapter 3, this dissertation extends the literature on a firm's knowledge resources as a source of innovation by revealing the relationship between knowledge elements and combinations. Applying Henderson and Clark(1990)'s framework, the firm's knowledge network and its subsequent exploratory innovation can be depicted to accumulated component and architectural knowledge and creation of new knowledge elements and combinations. Furthermore, by linking the firm's previously formed knowledge network and its subsequent innovation, these relationships allowed us to explore the dynamics of a knowledge network in which existing elements and combinations are influencing each other to form new knowledge elements and combinations over time. Second, based on the findings of Chapter 4, this dissertation extends the literature on alliance portfolios by simultaneously employing social network theory and the knowledge-based view. Most prior studies examined the characteristics of the alliance portfolio either by focusing on structural properties such as actors' network position or by focusing on nodal properties such as actors' knowledge resources. However, this separation limits the understanding of inter-relational effects between the network position and the knowledge composition in alliance portfolios. This study highlights this inter-relationship and suggests that the potential disadvantageous effects originating from a firm's network position can, under specific conditions, be overcome through a suitable knowledge composition. Third, this dissertation contributes

to innovation literature by addressing a new approach satisfying two key factors for the creation of exploratory innovation, i.e., knowledge flow and search flexibility. Prior studies state that a knowledge flow corresponds with strong relationships, while search flexibility is associated with weak relationships. As both knowledge flow and search flexibility are required for exploration, prior studies focused on finding the optimum level of organizational integration or the relevant strategic choice. However, this dissertation claims that a particular combination between a firm's network position and the knowledge composition of its alliance portfolio can complement both factors' shortcomings, ultimately satisfying both key factors simultaneously.

Keywords: exploratory innovation, knowledge network, component and architectural knowledge, alliance portfolio, network position, knowledge composition

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Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1 Background

Exploratory innovation, which refers to the generation and adoption of something novel and valuable by using unfamiliar knowledge obtained from exploration, has received considerable attention both in research and practice as an essential way to gain a competitive advantage while technologies and markets change rapidly (Phelps, Heidl, & Wadhwa, 2012; Wang, Rodan, Fruin, & Xu, 2014). However, the extant literature on exploratory innovation is in its early stage and still has room for further development. Until recently, many innovation studies have not clearly distinguished between exploratory and exploitative innovation while paying attention to the various attributes of innovation (e.g., Garriga, von Krogh, & Spaeth, 2013; Chatterji & Fabrizio, 2014). In addition, studies on exploratory innovation did not apply a comprehensive perspective enough to investigate the whole innovation process, including its antecedents, determinants, output, etc., but only the fragmentary aspect of innovation. This dissertation seeks to contribute to the research on exploratory innovation by focusing exclusively on exploratory innovation from a knowledge-based perspective, examining widely known but not systematized knowledge creation mechanisms, and investigating which factors firms need to consider comprehensively to facilitate exploratory innovation.

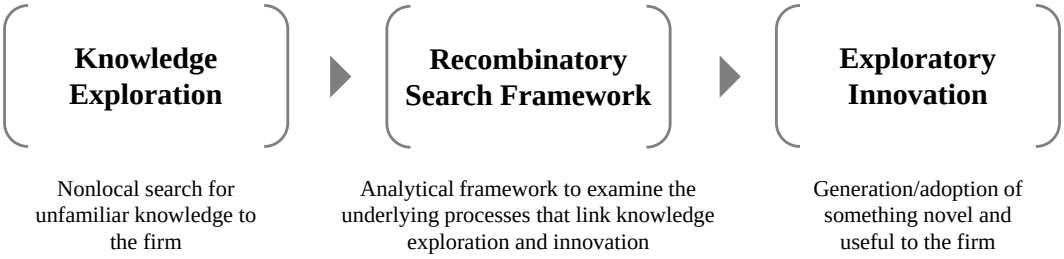


Figure 1-1. The processes of emerging exploratory innovation

Exploratory innovation emerges based on knowledge exploration and recombinatory search framework. Figure 1-1 exhibits the processes of emerging exploratory innovation. Knowledge exploration, which refers to the nonlocal search of new knowledge across technological or organizational boundaries beyond the firm's current expertise, is a prerequisite for exploratory innovation (Bierly, Damanpour, & Santoro, 2009; Luo, Lui, Liu, & Zhang, 2018; Rosenkopf & Nerkar, 2001). According to the seminal work of March (1991), exploration refers to “things captured by terms such as search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation”. From a knowledge-based view, the concept of exploration is presented diversely in innovation and knowledge management literature. It includes the pursuit of new knowledge and competence (Levinthal & March, 1993), gaining more absorptive capacity (Lavie & Rosenkopf, 2006), securing novel knowledge (Lin, Yang, & Demirkan, 2007), involving a shift to a different technological trajectory (Rosenkopf & Nerkar, 2001), departing entirely from prior firm knowledge (Mary J. Benner & Tushman, 2002), sharing tacit knowledge and developing new knowledge with partners (Frank T Rothaermel, 2001),

accessing new knowledge outside a firm's boundaries (Grant & Baden-Fuller, 2004). Additionally, the activity of knowledge exploration is described as collaboration concerning patenting (Mary J. Benner & Tushman, 2002; McNamara & Baden-Fuller, 2007), new product development (Danneels, 2003), alliances in upstream activities of the value chain, i.e., R&D alliances (Dittrich, Duysters, & de Man, 2007; Lin et al., 2007). Table 1-1 exhibits the concepts and activities of knowledge exploration described in the literature.

One more vital mechanism to explain exploratory innovation is the recombinatory search framework. It is an analytical framework to examine the underlying processes that link knowledge exploration to innovation (Luo et al., 2018). It has been an implicit premise in a large volume of innovation research and holds two critical assumptions. First, the invention is a function of combining knowledge elements. Specifically, new invention occurs as knowledge elements are (re)combined differently. Second, more valuable (re)combinations of knowledge elements, i.e., new inventions, lead to a higher level of innovation (Fleming, 2001; Fleming & Sorenson, 2004; Kogut & Zander, 1992; Nelson & Winter, 1982). Since knowledge elements can be external to the firm, its knowledge repertory can be enlarged by incorporating new knowledge elements from external sources, i.e., knowledge exploration. These new knowledge elements can be linked and used to form new knowledge combinations to create exploratory innovation (Ahuja & Lampert, 2001; Carnabuci & Operti, 2013; Laursen & Salter, 2006).

Table 1-1. Concepts of exploration in the literature (selective)

Authors (Year)	**Concepts of exploration in knowledge perspective**
March (1991)	Exploration includes search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation
Levinthal & March (1993)	**Pursuit of new knowledge/competence**
Koza & Lewin (1999)	Exploration alliances are identified as **knowledge-generating R&D alliances**
Rosenkopf & Nerkar (2001)	Exploratory innovation **involves a shift to a different technological trajectory**
Rothaermel (2001)	Exploration alliances occur in upstream activities of the value chain, **enabling partners to share tacit knowledge and develop new knowledge**
Vermeulen & Barkema (2001)	**Search for new knowledge**
Benner & Tushman (2002)	Exploratory patent category comprises **patents that depart entirely from a prior firm knowledge**
Danneels (2003)	New product development project that requires **competence the firms do not yet possess**
Grant & Baden-Fuller (2004)	Collaboration with partners facilitates learning **by accessing new knowledge outside a firm's boundaries**
Rothaermel & Deeds (2004)	Firms that cooperate with partners in R&D may **develop innovative technologies and applications**
Lavie & Rosenkopf (2006)	Alliances formed with new partners which encouraged to **gain more absorptive capacity**
Dittrich, Duysters, & Man (2007)	Explorative alliance network aimed at innovating and business development: **Non-equity alliances, partner with different technology**
Lin, Haibin, & Demirkan (2007)	Allocates resources to the development of new network relations **for securing novel knowledge**
Namara & Baden-Fuller (2007)	**R&D activities concern with patenting** and preclinical trials

By adopting those concepts and processes, previous research on exploratory innovation can be categorized into four viewpoints from the firm's internal and external aspects. First, from the internal focus, it is about the firm's knowledge stock (Brennecke & Rank, 2017; Carnabuci & Operti, 2013; Roper & Hewitt-Dundas, 2016; Wu & Shanley, 2009). Studies from this point of view pay attention to the characteristics of the knowledge stock accumulated within the firm. They focus on, for example, the size of the stock, diversity of its repertoire, structure of knowledge. Second, from the internal focus, it is about organizational learning (Renu Agarwal & Selen, 2013; Ahuja & Lampert, 2001; Fu, Diez, & Schiller, 2013). Studies from this perspective are concerned with the process by which firms accumulate a knowledge base. They pay attention to evolutionary processes through organizational learning, routines and inertia, path-dependent tendencies, and technology trajectories, and the like. Third, from the external focus, it is about the characteristics of external knowledge resources (Guan & Yan, 2016; Laursen & Salter, 2006; Phene, Fladmoe-Lindquist, & Marsh, 2006). Studies from this perspective are interested in firms expanding their external knowledge resources through external cooperation mode, i.e., alliance portfolio. They focus on the characteristics of the knowledge held by the affiliate partner, for example, its novelty, distance, diversity, breadth, and depth. Fourth, from the external focus, it is about the accessibility and appropriability of external knowledge resources (Laursen & Salter, 2014; Operti & Carnabuci, 2014; Zheng, Li, & Wu, 2013). Studies from this perspective are concerned with the influence of firms' relationships. The factors they pay attention to are the

characteristics of the social network's structural position and the firm's status formed on it. Table 1-2 categorizes previous studies into those four perspectives.

According to the classification of the previous studies, it is necessary to consider both firm's internal knowledge base and its external knowledge environment to understand the entire process by which a firm creates exploratory innovation. However, the research on exploratory innovation is still in its early stages and has room to develop the previous discussions by taking a closer look at this field. From the internal focus, because the knowledge base is embedded in the organization and exists in a complex form changing over time, it is necessary to consider it a dynamic collection that includes knowledge elements and their combinations rather than a simple repository of knowledge elements. From the external focus, when considering the external knowledge environment to promote exploratory innovation, it is necessary to understand not only the compositions of external knowledge resources but also the structural factors of interfirm networks, which affect accessibility and appropriability for external knowledge resources.

Table 1-2. Four perspectives of previous studies on exploratory innovation

Perspective		Concerning factor	Literature (selective)
Internal focus	a firm's knowledge stock	size, diversity, structure of internal knowledge	Wu & Shanley (2009) Carnabuci & Operti (2013) Roper & Hewitt-Dundas (2016) Brennecke & Rank (2017)
	knowledge accumulation by organizational learning	routine, a path-dependent tendency, tech. trajectory	Ahuja & Lampert (2001) Fu, Diez, & Schiller (2013) Renu Agarwal & Selen (2013)
External focus	characteristics of external knowledge resources	novelty, distance, diversity of external knowledge	Laursen & Salter (2006) Phene, Fladmoe-Lindquist, & Marsh (2006) Guan & Yan (2016)
	accessibility/appropriability of knowledge resources	focal firm's status, power among interfirm relationship	Zheng, Li, & Wu, (2013) Laursen & Salter (2014) Operti & Carnabuci (2014)

1.2 Research objectives

This dissertation aims to increase the academic understanding of the entire process by which a firm creates exploratory innovation and provides recommendations for firms to improve the benefits obtained from exploratory innovation. Recalling the previous discussion, i.e., how firms build knowledge base as a source of exploratory innovation and gain appropriate knowledge that is useful for the firm to create exploratory innovation, the research purpose of this dissertation can be described as following two fundamental questions. First, what characteristics of a firm's intrinsic and embedded knowledge base promote exploratory innovation? Second, what is the effective way to source external knowledge among partner firms to create exploratory innovation?

Starting by discussing the first question, a firm's knowledge base is an important factor in specifying the characteristics of a firm in the stream of innovation research. However, previous studies on firms' knowledge base as a source of innovation do not adequately investigate the characteristics and relationships between the firm's knowledge base and exploratory innovation from the following two aspects. First, although exploratory innovation incorporates creating new knowledge or finding new and different ways to use existing knowledge, most studies on the antecedents of the firm's exploratory innovation investigated only one side of exploratory innovation by focusing on creating new knowledge. Although some researchers recently started developing new ways to use existing knowledge as exploratory innovation, a comprehensive view covering both

dimensions of exploratory innovation is still underexplored. Second, prior studies overlooked the intrinsically dynamic nature of firms' knowledge base, which continuously changes over time through the absorption of subsequent exploratory innovation. Most of them considered the firm's knowledge base a static factor influencing its innovative outcome and conducted a cross-sectional analysis that examined the knowledge base as a snapshot. To overcome those limitations, I will illustrate a firm's knowledge base as a network composed of knowledge elements that are firm possess and their relationships formed through invention. Then I investigate how exploratory innovation, including new knowledge creation and new usage of existing knowledge, occurs among this knowledge network and how the knowledge network changes over time.

The second research topic is about the conditions and antecedents of the firm's effective knowledge sourcing for exploratory innovation, especially in the context of alliance portfolios. A firm trying to create exploratory innovation should consider expanding its knowledge base externally. Due to a firm's resource constraints and path-dependent tendencies, it is not easy to create exploratory innovation relying only on the internal knowledge base. Accordingly, many firms search, adopt and create new knowledge through external knowledge sourcing by establishing strategic alliances, forming an alliance portfolio. In alliance portfolio research, there are two viewpoints, i.e., structural aspects and partner characteristics aspects. The former is related to the social network theory, and the latter is related to the resource-based view, particularly the

knowledge-based theory. However, it is difficult to comprehensively observe from those two theoretical lenses simultaneously because factors related to the other theoretical lenses are considered constants when investigating by applying one theoretical lens. For example, some literature has assumed that firms in an equivalent network position can access and utilize the same quality of resources from their alliance partners. However, knowledge can differ between each firm's alliance partners, even though firms with the same position from a network structure perspective. Another literature assumes the same resource accessibility if firms have the same partners, regardless of any variance in their social network position. It also ignores the reality of structural differences among firms' network positions, even though they form alliances with the same partners. To overcome those limitations, I will employ these two perspectives, i.e., structural aspects and partner characteristics aspects together and investigate which combinations of a firm's position and the knowledge characteristics in alliance portfolio are beneficial for increasing the firm's exploratory innovation.

1.3 Research outline

The remainder of this dissertation consists of four chapters: the literature review, two different empirical studies; one focuses on the interaction of a firm's internal knowledge network and its subsequent exploratory innovation, and the other focuses on combinations of a firm's social network position and the knowledge characteristics of alliance partners which can be beneficial for increasing the firm's exploratory innovation, and the final chapter providing the overall conclusions of this research as well as limitations and some directions for future research.

Chapter 2 presents a literature review on the mechanisms of exploratory innovation. This chapter, first, summarizes some literature on exploratory innovation, considering the underlying mechanism by which a firm creates exploratory innovation. It also demonstrates the various factors influencing exploratory innovation. Moreover, Chapter 2 presents the extant literature on a firm's internal knowledge network as a source of innovation. It highlights the characteristics of a knowledge network that can explain the heterogeneity of a firm's innovation performance by focusing on how it is formed and evolves over time and how it affects the firm's subsequent exploratory innovation. Additionally, Chapter 2 introduces the primary conditions from a knowledge-based view to create exploratory innovation, i.e., uninterrupted knowledge flow and unconstrained search flexibility. In this regard, this chapter provides a literature review on alliance portfolio, specifically, how the focal firm is able to effectively discover and secure the

necessary knowledge in the alliance portfolio to create exploratory innovation.

The two empirical studies form the basis for Chapters 3 and 4. Figure 1-1 provides an overview of the two key questions answered by these chapters and how they help provide a comprehensive view of the origins and effects of exploratory innovation.

Chapter 3 examines the firm's internal knowledge network and its effects on the subsequent exploratory innovation. Previous research on exploratory innovation has primarily focused on investigating and explaining a firm's internal knowledge base as a simple repository of knowledge elements. Concerning the structure of knowledge, only recently has research begun to investigate characteristics of a knowledge base as a network of knowledge elements. In this regard, chapter 3 suggests a theoretical framework to express a firm's knowledge base as a single network composed of knowledge elements (nodes) and their combinations (ties), and to investigate the dynamics of such a knowledge network over time, accounting for the attributes and effects of knowledge accumulation. Chapter 3 distinguishes accumulated component and architectural knowledge, and investigates their impact on subsequent exploratory innovation, i.e., the creation of new elements and new combinations using patent data of 111 US semiconductor companies from 2000–2010. Chapter 3 empirically verifies an inverted U-shape relationship in creating knowledge combinations in a firm's knowledge network, as well as positive relationships between knowledge elements and knowledge combinations.

Chapter 4 investigates how the focal firm is able to effectively discover and secure the

necessary knowledge in the alliance portfolio to create exploratory innovation. Previous literature has primarily focused on examining the external knowledge environment for exploratory innovation, focusing on either the compositions of knowledge resources or the structural factors affecting firms' access to them. Chapter 4 propose a framework of knowledge flow and search flexibility to examine the effects of a firm's network position and knowledge composition of the alliance portfolio simultaneously. Using this framework, chapter 4 explores their interactions that create synergy and offset mutual disadvantages by using panel data of 142 pharmaceutical companies from 1996-2010. Chapter 4 empirically confirms that central and brokering positions have an inverted U-shape relationship with the creation of exploratory innovation. It also verifies two combinations of network position and knowledge composition advantageous for increasing exploratory innovation: a central position with partners' wide scope of new knowledge, and a brokering position with partners' wide scope of shared knowledge.

Finally, Chapter 5 summarizes the findings of the two empirical studies and provides managerial implications and academic contributions. Limitations and directions for future research are also provided in this chapter.

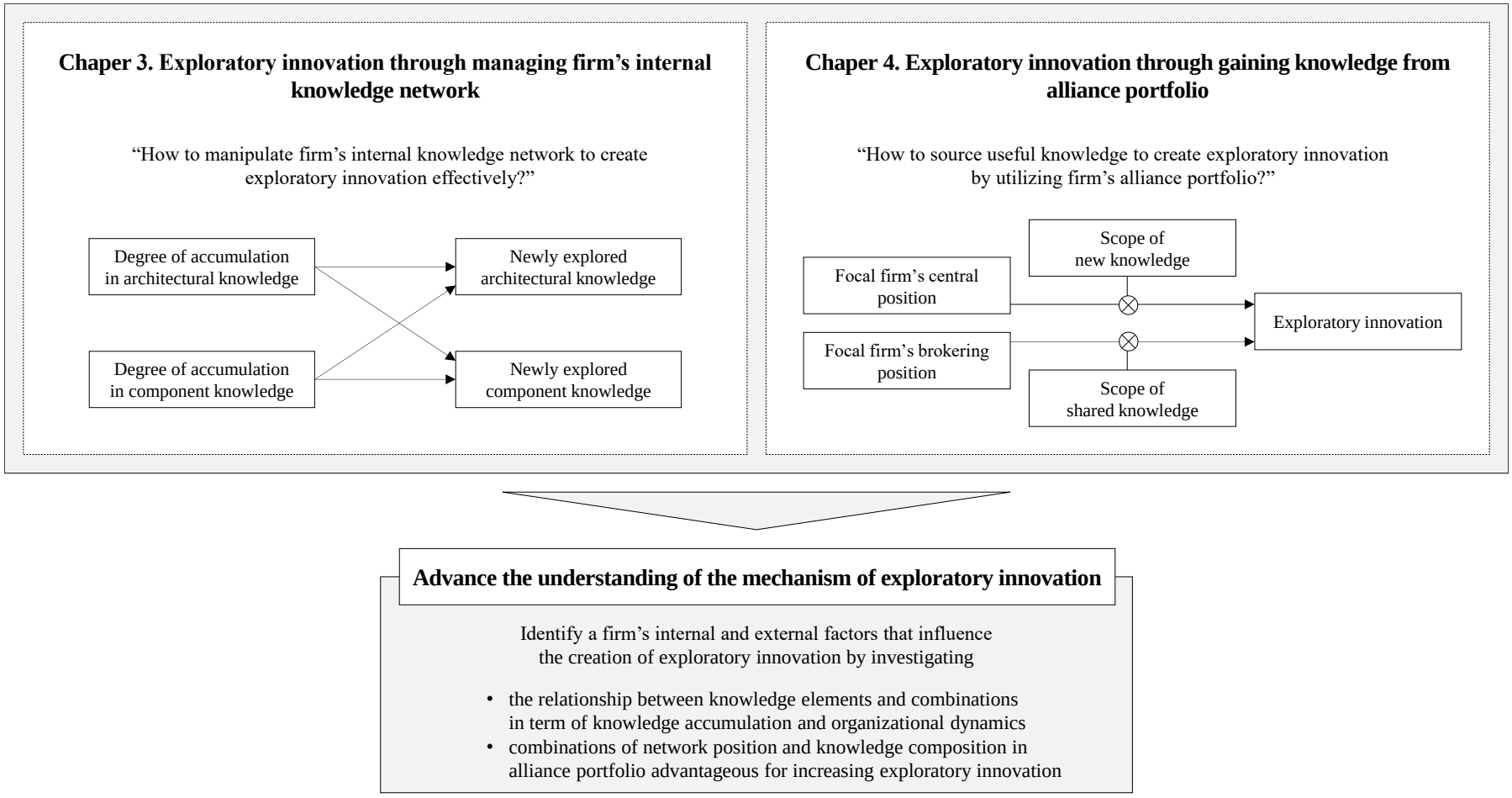


Figure 1-2. Research outline of the dissertation

Chapter 2. Literature review

2.1 Review on the literature on exploratory innovation

Since the seminal work of March (1991), the subject of exploratory innovation based on knowledge exploration and recombinatory search framework has been presented diversely in innovation and knowledge management literature. Table 2-1 summarizes 35 selected empirical studies focusing on exploratory innovation. Although this present review is not exhaustive, it provides various aspects to understand the whole process by which a firm creates exploratory innovation.

To explain the concepts and relationships between knowledge exploration, recombinatory search framework, and exploratory innovation, the knowledge-based view (Grant, 1996b) and organizational learning theory (Argote & Ingram, 2000; Argote & Miron-Spektor, 2011) are mainly applied. The knowledge-based view suggests that knowledge exploration is the nonlocal search of new knowledge across technological or organizational boundaries beyond the firm's current expertise (Rosenkopf & Nerkar, 2001). Organizational learning theory recognizes knowledge exploration as learning behavior, and learning occurs when knowledge external to an organization is assimilated and internalized for use (Argote & Ingram, 2000). By combining these two theoretical lenses, knowledge exploration involves a search and transfer process (Hansen, 1999) and

increases exploratory innovation through learning activities.

The results of empirical studies can generally support this argument. In many of the studies, although each author defines and measures particular aspects of knowledge exploration and innovation output to suit own research questions and empirical settings, knowledge exploration has been found to positively affect the output of exploratory innovation (Chatterji & Fabrizio, 2014; Frankort, 2016; Fu et al., 2013; Isaksson, Simeth, & Seifert, 2016; R. Katila & Ahuja, 2002; Y. Kim & Lui, 2015; Laursen & Salter, 2006; Li, Maggitti, Smith, Tesluk, & Katila, 2013; Love, Roper, & Vahter, 2014; Nerkar, 2003; Schilling & Green, 2011; Sidhu, Commandeur, & Volberda, 2007). However, based on the positive relationship between knowledge exploration and exploratory innovation output, some studies have investigated the cost sides of knowledge exploration and argued a nonlinear relationship between knowledge exploration and exploratory innovation (Ahuja & Katila, 2004; Ahuja & Lampert, 2001; Guan & Liu, 2016; Guan & Yan, 2016; Phene et al., 2006; Wu & Shanley, 2009; Yayavaram & Ahuja, 2008). Additionally, other studies have found mediators that link the effect of knowledge exploration to the performance of exploratory innovation and moderators that could potentially modify the relationship between knowledge exploration and exploratory innovation (Choi, Lee, & Kim, 2012; Laursen, Masciarelli, & Prencipe, 2012; Roper & Hewitt-Dundas, 2016; Xu, Li, & Zeng, 2017; Zheng et al., 2013). In Sum, it is necessary to consider various aspects, i.e., promoting or hindering factors, that influence knowledge exploration and organizational learning to understand exploratory innovation.

Table 2-1. Literature review of empirical studies on exploratory innovation (in chronological and alphabetical order)

Authors (Year)	**Sample**	**Dependent Var (Y)**	**Independent Var (X)**	**X→Y**	**Moderator (Z)**	**Z→(X~Y)**
Ahuja & Lampert (2001)	97 Chemical firms over the period of 1980-1995	Creation of breakthrough invention	Exploration of novel/emerging/pioneering technologies	∩/∩/+		
Katila & Ahuja (2002)	124 industrial robotics companies in Europe, Japan, and North America, over the period of 1985-1996	Number of new product	Search scope	+	Search depth	+
Nerkar (2003)	15,345 patents of 33 pharmaceutical firms over the period of 1981–1987	Impact of innovations	Temporal knowledge exploration	+		
Ahuja & Katila (2004)	Leading US chemical firms over the period of 1979–1992	Innovativeness	Science/geography search	∩/∩		
Laursen & Salter (2006)	2,707 UK manufacturing firms in 2001	Radical innovation	External search depth	+		
Phene, Fladmoe-Lindquist, & Marsh (2006)	87 US biotechnology firms in 1988	Breakthrough innovation	Technologically distant/proximate knowledge exploration	∩/+		
Sidhu, Commandeur, & Volberda (2007)	155 Dutch metal and electrical engineering firms	Innovativeness	Nonlocal demand-side/geographic search	+/+	Environmental dynamism	-/n.s

Authors (Year)	Sample	Dependent Var (Y)	Independent Var (X)	X→Y	Moderator (Z)	Z→(X~Y)
Yayavaram & Ahuja (2008)	141 firms in the worldwide semiconductor industry over the period of 1984-1994	The usefulness of a firm's inventions/ The extent of changes in the structure of a firm's knowledge base	Level of decomposability of its knowledge base	∩/∩		
Wu & Shanley (2009)	139 US public electro medical device firms over the period of 1990–2000	Innovative performance	Knowledge exploration	∩	knowledge breadth	-
Schilling & Green (2011)	40 highest impact papers of the four disciplines: Economics, Management, Psychology, and Sociology	High impact	Search depth/Search scope/Atypical connections	+/+/+		
Choi, Lee, & Kim (2012)	1,228 Korean firms in the manufacturing sector over the period of 2002–2004	Innovative performance	Acquisition of external knowledge	+(through mediator)	(mediator) the in-house and joint R&D complementarity	+
Laursen, Masciarelli, & Prencipe (2012)	Firm level: ~ 7% of 4,900 Italian manufacturing firms over the period of 2001–2003 Region level: 21 Italian regions	Innovativeness	External R&D acquisition	n.s	social capital of the regions where the firms are located	+
Agarwal & Selen (2013)	449 respondents from a telecommunications service provider in Australia	Elevated service offering	Collaborative organizational learning	+		

Authors (Year)	Sample	Dependent Var (Y)	Independent Var (X)	X→Y	Moderator (Z)	Z→(X~Y)
Carnabuci & Operti (2013)	126 global semiconductor firms over the period of 1984-2003	Recombinant reuse/Recombinant creation	Collaborative integration/knowledge diversity	+/- +/-		
Fu, Diez, & Schiller (2013)	359 Chinese electronics firms in the Pearl River Delta	Product innovation performance	Interactive learning with business partners	+		
Garriga, von Krogh, & Spaeth (2013)	2,141 responding firms in Swiss Innovation Survey	Innovative performance	Constraints on the application of resources/Abundance of innovation-relevant external knowledge	-/+		
Li, Maggitti, Smith, Tesluk, & Katila (2013)	Australia and its partnering organizations 61 US public, high-technology companies	Number of new product introductions	Unfamiliar, distant and diverse top management team search selection	+	Search effort/persistence	-(distant), +(diverse) /-(diverse)
Zheng, Li, & Wu (2013)	A survey of 208 Chinese firms engaged in global production networks	Innovation performance	Embedded/accessed resources	+(through mediator)	(mediator) Technological capabilities/relative bargaining power	+
Chatterji & Fabrizio (2014)	128 US public medical device companies over the period of 1985-1997	Corporate innovative performance	Inventive collaborations with product users	+	newer technology areas/radical innovations	+/+

Authors (Year)	Sample	Dependent Var (Y)	Independent Var (X)	X→Y	Moderator (Z)	Z→(X~Y)
Dibiaggio, Nasiriyar, & Nesta (2014)	144 US semiconductor companies over the period of 1968-2002	Overall inventive performance/The rate of explorative inventions	Complementarity of knowledge elements/Substitutability of knowledge elements	+/- -/+		
Laursen & Salter (2014)	2,931 manufacturing firms in the UK (4th UK Innovation Survey)	external search breadth/Innovation collaboration breadth	appropriability strategy	∩/∩		
Love, Roper, & Vahter (2014)	1,064 Irish manufacturing innovation panels over the period of 1994–2008	Innovation performance	External knowledge linkages	+	previous openness experience	+
Wang, Rodan, Fruin, & Xu (2014)	844 researchers and their granted 2,836 patents in a leading, world-class microprocessor manufacturer in northern California	Number of new knowledge elements explore	Mean knowledge structural holes/Mean knowledge centrality/Collaboration network structural holes/Collaboration network degree centrality	-/∩/+/-		
Huang, Rice & Martin (2015)	2,374 Chinese firms	Innovation performance	Interfirm networking	n.s	firm size	-
Kim & Lui (2015)	283 Korean manufacturing firms responded to 2002 and 2005 surveys	Product innovation	Institutional network search	+		

Authors (Year)	Sample	Dependent Var (Y)	Independent Var (X)	X→Y	Moderator (Z)	Z→(X~Y)
Yayavaram & Chen (2015)	141 semiconductor firms across North America, Europe, and Asia and patents assigned to these firms over the period of 1984-1994	Firm innovation performance	Change in coupling among existing knowledge domains/Coupling between new and existing knowledge domains	-/+	Domain complexity	+/-
Yoon, Lee, & Song (2015)	85 firms in the biotech industry over the period of 2003-2007	Knowledge creation	Alliance network size/Alliance partner organizational diversity	∩/-		
Frankort (2016)	44 firms over the period of 1996–1999	New product development	Knowledge acquisition from R&D alliances	+	technological relatedness/product-market competition	+/-
Guan & Liu (2016)	919 innovative organizations located in North America, Europe, and Asia over the period of 2000–2013	Exploitative innovation/Explorative innovation	Mean knowledge direct ties/Mean knowledge indirect ties/Mean knowledge network efficiency/Direct ties in collaboration network/ Indirect ties in collaboration network/Collaboration network efficiency	∩/∩ ∩/∩ +/+ -/- -/+ +/+		
Guan & Yan (2016)	41,007 alternative energy patents granted in USPTO over the period of 1976-2012	Recombinative innovation	Technological proximity	∩	Geographic distance/Cultural distance	-/-

Authors (Year)	Sample	Dependent Var (Y)	Independent Var (X)	X→Y	Moderator (Z)	Z→(X~Y)
Isaksson, Simeth, & Seifert (2016)	230 suppliers over the period of 1990–2006	Supplier technological innovation	Knowledge exploration from buyer technological innovation	+	relationship duration	∩
Roper & Hewitt-Dundas (2016)	Irish innovation panel over the period of 1991–2008	Product innovation	Knowledge flows from external search	n.s	existing knowledge stocks/knowledge flows from R&D investment	+/-
Brennecke & Rank (2017)	Survey data on 135 inventors working in a German high-tech firm who have filed at least one patent over the period of 2009-2013	Transfer of advice among corporate inventors	knowledge diversity/uniqueness/combinatorial potential/combinatorial opportunities/knowledge proximity	+/-/-/+/+		
Xu, Li, & Zeng (2017)	738 Chinese automobile manufacturers over the period of 1990–2006	Explorative innovation	Network density/centralization	-/-	R&D collaborations	+

2.2 Exploratory innovation created from a firm's internal knowledge base

2.2.1 The concept of knowledge network

Researchers have studied a firm's knowledge base as a source of innovation. In recent studies, a firm's knowledge base is regarded as a network and its formation, development, expansion, and change are being explored. The concept of the knowledge network stems from the idea that scientific or technological knowledge elements can form relationships with each other[1], regarding each knowledge element as a node, and each relationship between two knowledge elements as a tie (Fleming, 2001). As every invention is made up of a (re)combination of different knowledge (Makri, Hitt, & Lane, 2010; Schumpeter, 1934; Weitzman, 1998), a knowledge element is the fundamental building block of an invention (Fleming & Sorenson, 2004). Wang et al. (2014) elucidate the knowledge element as a socially defined category derived from a group of scientific or technological knowledge in a particular subject matter, and characterize it as not atomistic but linked by joint application in previous inventions. Accordingly, prior empirical studies have

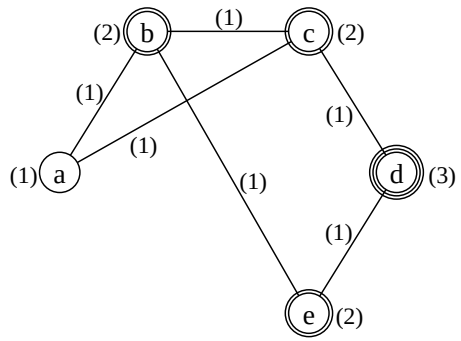
[1] A knowledge element is not a human actor or agency that has free will for action on social network perspective, so it is possible to raise the question whether they can bond with each other and form relationships. However, it a human that makes a successful invention by combining knowledge elements, so after all, it can be said that the relationship between knowledge elements is formed by human agency (Carnabuci & Bruggeman, 2009; Fleming & Sorenson, 2004; Paruchuri & Awate, 2017; Wang et al., 2014; Yayavaram & Ahuja, 2008).

considered a knowledge element to be a technological field, e.g., a detailed technology classification of the patent system, and a knowledge combination to be the relationship between those technological fields formed through an invention, e.g., a patent (Carnabuci & Operti, 2013; Fleming, Mingo, & Chen, 2007; Guan & Liu, 2016; Phelps, 2010). For example, an invention based on more than one technological field can be expressed as a collection of certain nodes and ties which represent technology classes (knowledge elements) and their relationships (knowledge combinations). If an invention is based on a single technological field, it can be expressed as a single node without ties. In this sense, a knowledge network can be created using the nodes and ties making up various inventions, e.g., all the inventions of a given researcher (Paruchuri & Awate, 2017; Wang et al., 2014). On the firm level, a knowledge network can be drawn as the sum of all the inventions made by the individual researchers employed by the firm. The nodes represent knowledge elements, in this case, the technology classes of the firm's patent. The ties represent knowledge combinations of technology classes formed by co-application in a single patent. The strength of a tie and the size of a node represent the level of frequent(repeated) usage of the knowledge combination/element. Through this network, I can examine the firm's knowledge resources. Because a firm's knowledge network reflects the firm's areas of expertise and how the firm combined them in their innovation process, it can represent the heterogeneity of knowledge characteristics between different firms. Figure 2-1 shows an example of a firm's knowledge network.

Firm's prior inventions

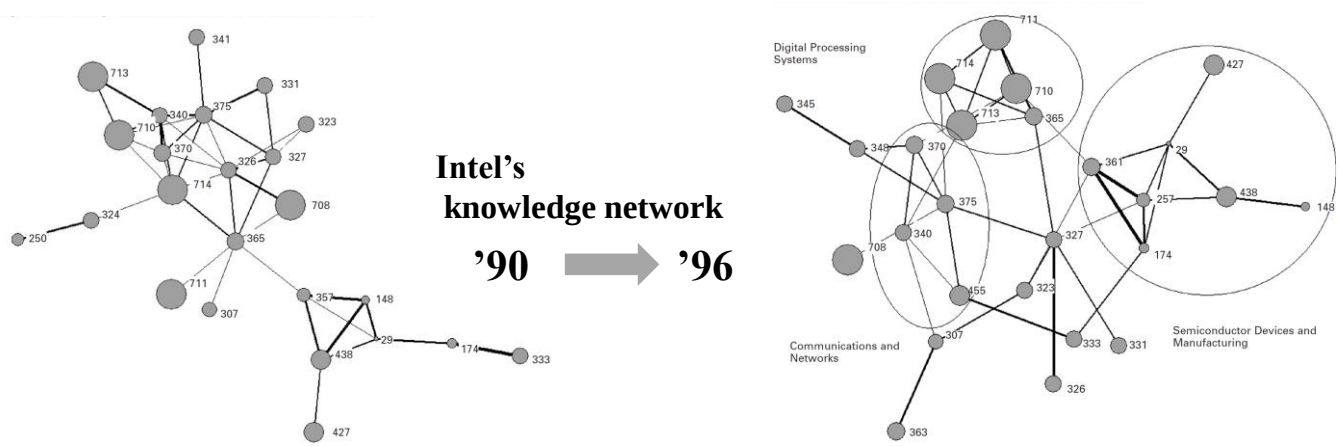
- Invention 1: a+b+c
- Invention 2: c+d
- Invention 3: d
- Invention 4: d+e
- Invention 5: b+e

Firm's valued knowledge network



※ a,b,c,d,e : Knowledge element, in this case, the technological field of a patent
——— : Knowledge combination, between technological fields cited in a single patent

Figure 2-1. Formation of the firm's knowledge network based on its prior inventions



- **Node**: individual knowledge elements
  e.g. detailed technology classification of the patent system
- **Tie**: connections of knowledge elements
  e.g. co-application of two or more knowledge elements within a single patent

Figure 2-2. An example of knowledge base depicted as a network (Yayavaram and Ahuja, 2008)

The knowledge stored in the elements and combinations of a knowledge network represents two different kinds of knowledge: component knowledge, which represents the knowledge itself as an ingredient of the invention, and architectural knowledge, which represents the structure of the invention and how its different components are brought together (Henderson & Clark, 1990). In a similar view, Argote and Ingram (2000) distinguished individual memory which is concerned with facts, skills and can be seen as "know-what", and transactive memory which is concerned with who is an expert for a certain case, what knowledge belongs to someone and can be summarized as "know-where" (Argote & Ingram, 2000; Argote & Miron-Spektor, 2011). In a knowledge network, nodes (=knowledge elements) are closely associated with the concepts of component knowledge and individual memory, while ties (=knowledge combinations) are associated with architectural knowledge and transactive memory.

Most prior studies on firms' knowledge resources have focused on knowledge elements, especially their attributes and compositions (Quintana-García & Benavides-Velasco, 2008; Srivastava & Gnyawali, 2011), but showed little concern for their combinations associated with learning, experience, capabilities (Carnabuci & Bruggeman, 2009). Considering a firm's knowledge resources as a bundle of knowledge elements without their combinations has limits in explaining the reason why firms that possess similar knowledge resources differ in their performance. In the real world, it is often found that firms, e.g., in the same industry, possess similar knowledge elements but exhibit heterogeneity in their performance. These performance differences might be

explained by the firm's different ways of leveraging the individual knowledge elements for their innovative outcomes. Knowledge networks are a suitable tool to examine the firm's knowledge resources and their application as well as their influence on the firm's performance.

2.2.2 Firm's innovation based on its knowledge network

From the perspective of the knowledge network, it is reasonable to draw the network on the firm level. Individual researchers find it hard to create inventions by themselves and without the support of the resources held by the firm. Generally, the more valuable an invention is, the more diversified knowledge is combined in the invention process. However, individual researchers possess only limited expertise, which encourages collaboration with others to combine the specialized knowledge held by numerous individuals to create a valuable invention. Thus, it is possible to see an invention as the output of the organic and collaborative work of researchers in the firm (Grant, 1996b). Additionally, the know-how learned from inventive activities is embedded in the firm's memory system, i.e., the member-tool-task network, and is transformed into the firm's unique capabilities (Argote & Ingram, 2000). It ultimately becomes the firm's foundation on which subsequent inventions are based. For these reasons, this study investigates the effects of the knowledge network on the subsequent invention at the firm level.

Every inventive activity is a series of search processes that determine which

knowledge elements should be combined (Fleming & Sorenson, 2001; Kauffman, Lobo, & Macready, 2000; Sorenson, Rivkin, & Fleming, 2006). Depending on the choice of knowledge elements, the resulting invention can either be exploratory or exploitative. Generally, exploration focuses on generating new knowledge to avoid obsolescence and to remain competitive, while exploitation pays attention to leveraging and refining existing knowledge to improve efficiency and to secure a firm's status (March, 1991; Stettner & Lavie, 2014). Exploration and exploitation rely on distinctive organizational routines (Dosi, Nelson, & Winter, 2000). Exploration routines facilitate flexibility, risk-taking, and experimentation (McGrath, 2001), while exploitation routines facilitate stability, control, and consistency (Mary J Benner & Tushman, 2003). In a knowledge network, exploitative invention, which is based on well-developed knowledge in a relatively familiar field, manifests itself as the repeated occurrence of existing knowledge elements or existing knowledge combinations. Exploratory invention, on the other hand, is the appearance of new knowledge elements and/or new knowledge combinations in the knowledge network. An exploratory invention can result in either the appearance of new nodes or ties or both of them at the same time. Figure 2-3 shows how the knowledge network of a firm changes in accordance with the firm's new exploitative and exploratory inventions. The formation of a new tie or a new node represents the creation of exploratory invention. For example, a tie formed between nodes e and d at time t+1 indicates a new invention created by co-application of the two technology classes e and d, which has not been conducted before. An isolated node f formed at time t+1 indicates a

new invention created by using a new, but single technology class f. On the other hand, increments in the strength of a tie or the size of a node at time t+1 represent exploitative invention, i.e., repeated usage of existing knowledge combinations and/or elements.

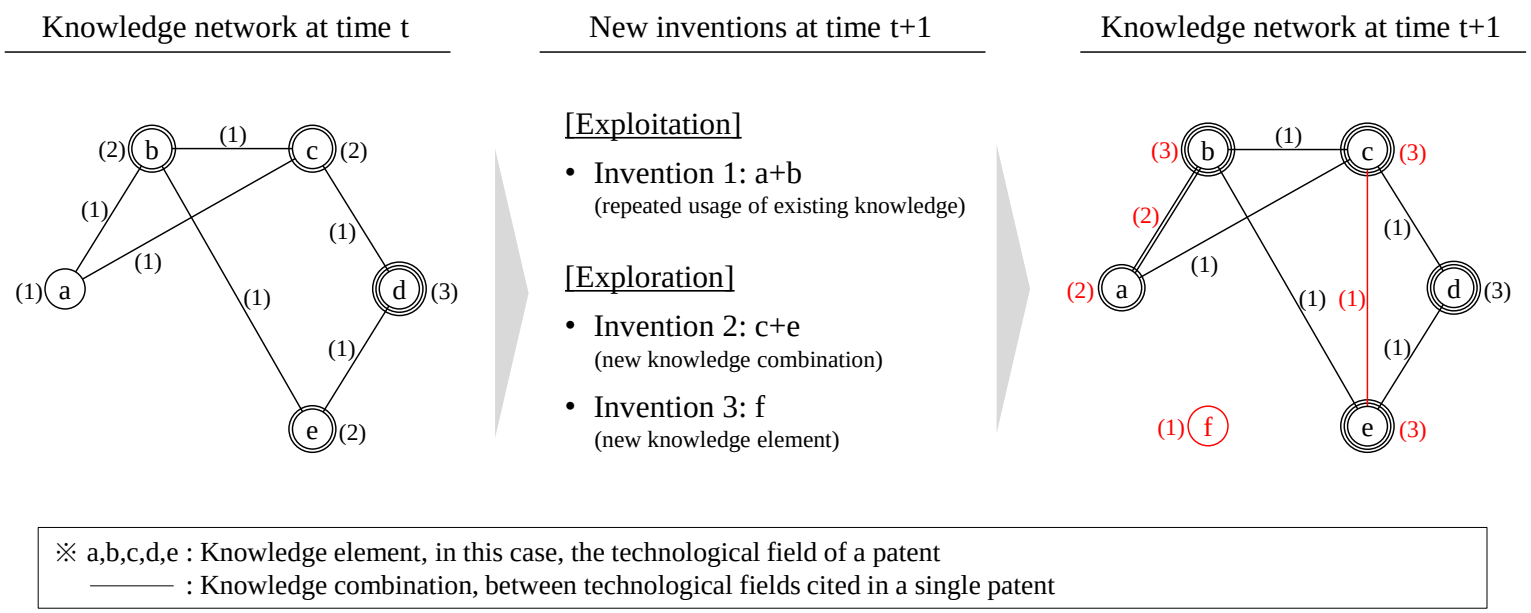


Figure 2-3. Changes in a firm's knowledge network due to new exploitative and exploratory inventions

As mentioned above, the firm's search process is influenced by organizational learning, which is routine-based and path-dependent (Cyert & March, 1963; Dosi, 1988; Levitt & March, 1988; Nelson & Winter, 1982; Vincenti, 1990). The search process in an organization can be described as a repeated trial and error experiment. If there are too many choice sets for researchers, it is hard to decide which combination will lead to a valuable invention, because it is almost impossible to understand all the attributes of the knowledge elements and their relationships at an individual level (March & Simon, 1958; Vincenti, 1990). Even at the firm level, it is hard to conduct an effective search since tacit and context-dependent knowledge is segmented and belongs to the different experts within the firm (Galunic & Rodan, 1998). Thus in that case, the easiest way is referring to prior experience of success (Fleming, 2001; Yayavaram & Ahuja, 2008). Yayavaram and Ahuja (2008) proposed that the more frequent a knowledge combination occurs, the stronger is the relationship between the two knowledge elements. Such a knowledge combination is an outcome of organizational learning and becomes organizational capability. A firm may try to create a new invention based on it and build up a logically consistent knowledge structure as collective references exist inside the firm (Nesta & Saviotti, 2005).

The know-how learned from inventive activities leads to a high success rate of new inventions through organizational learning. If a knowledge combination is based on past experience succeeds, it helps to more deeply understand the knowledge elements involved in that combination, thus these elements might be given priority in combinations

with new and yet unexplored knowledge elements. A successful new knowledge combination builds up a new tie in the firm's knowledge network. Knowledge elements with many ties can be expected to create a synergy effect when combined with others because of their demonstrated potential for application in different settings. In addition, firm's experience of knowledge combination can reduce the uncertainty related to new knowledge combinations and increases the chance of creating a successful new invention. Two elements which are not directly connected but have a relationship with the same third element, may have a substitutable or complementary relationship from the view of the shared element. Consequently, they increase the possibility of finding new ways of combining elements to create new inventions (Dibiaggio et al., 2014).

Accumulated knowledge from learning helps to create new inventions, but also increases the tendency of firms to keep doing things "the old way". Repetition of the same innovation processes gradually shapes strong norms and routines within the firm. Consequently, researchers are likely to resort to known and proven knowledge combinations without considering alternative solutions or adopting new knowledge from outside the firm. These phenomena are explained in prior literature using terms and concepts such as competency trap (Levitt & March, 1988), myopia of learning (Levinthal & March, 1993), group think (Janis, 1972), and NIH (not invented here) syndrome (Katz & Allen, 1982). Prior empirical studies in the petroleum industry (Helfat, 1994) and semiconductor industry (Stuart & Podolny, 1996) found that firms have a tendency to choose research projects from a familiar technological environment and tend to rely on

well-known knowledge combinations which are expected to perform well due to their fit with the firms' expertise and experience. In summary, a firm's knowledge network supports its search processes, but at the same time, makes it harder to adopt new ways of thinking due to increasing organizational inertia.

2.3 Exploratory innovation through external knowledge sourcing in alliance portfolio

2.3.1 Two theoretical lenses to examine the effects of a firm's alliance portfolio on its exploratory innovation

Exploratory innovation refers to innovation which is created through knowledge that is new to the firm, i.e., different from its extant stock of knowledge (Wang et al., 2014). However, owing to a firm's resource constraints and path-dependent tendencies, it is difficult to explore new knowledge relying only on internal R&D (Hagedoorn & Schakenraad, 1994). Accordingly, many firms search, adopt and create new knowledge through external knowledge sourcing (Fleming, 2001; Rosenkopf & Nerkar, 2001; Srivastava & Gnyawali, 2011). Establishing strategic alliances, which together form an alliance portfolio, is an external knowledge sourcing modes that has received large attention from both the managerial and academic fields (Duysters & Lokshin, 2011; Grant & Baden-Fuller, 2004; Hoffmann, 2007; Lavie, 2007; Powell, 1998; Van de Vrande, Lemmens, & Vanhaverbeke, 2006).

Previous literature has adopted social network theory and the knowledge-based view to examine the effects of a firm's alliance portfolio on its exploratory innovation (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008; Kogut & Zander, 1992; Phelps, 2010; Wassmer, 2010). Social network theory focuses on the characteristics of the

network structure, which may affect firms' access and utilization of social capital. Typically, central or brokering positions have been investigated to capture important aspects of network embeddedness (Gnyawali & Madhavan, 2001; Gulati & Gargiulo, 1999; Lin, Yang, & Arya, 2009). A central position refers to a high social status (Bonacich, 1987; Podolny, 1993, 2001), which allows a firm to directly access the knowledge of its alliance partners (Powell, 1998; Powell, Koput, & Smith-Doerr, 1996). At the same time, high-status firms face difficulties in exploring new ideas because of their close relationship with their partners (Locke, Noorderhaven, Cannon, Doney, & Mullen, 1999). A brokering position refers to a bridge of different and often unconnected groups, which may provide a potential source of novel ideas by accessing the different flows of information among separate groups (Burt, 2000; Zaheer & Bell, 2005). However, it may prevent a firm from accessing its partners' knowledge because of its loose connection (Burt, 2004).

The knowledge-based view focuses on the knowledge characteristics formed in a firm's alliance portfolio, e.g., new (or shared) knowledge breadth which refers to the scope of diverse new (or shared) knowledge that is available to the focal firm, to identify and capture the value of knowledge resources in alliance portfolio (Cui & O'Connor, 2012; Wuyts & Dutta, 2014). As exploratory innovation is created from recombination or reconfiguration of knowledge elements, a wide scope of new knowledge is an important source of exploratory innovation (Fleming, 2001; Marhold, Kim, & Kang, 2017). However, information overflow may arise if the scope of new knowledge is too wide

(Koput, 1997). While a wide scope of shared knowledge provides absorptive capacity to better understand a partner's knowledge (Cohen & Levinthal, 1990; Schildt, Keil, & Maula, 2012), the homogeneous knowledge may hinder the creation of exploratory innovation (Uzzi, 1996).

2.3.2 Two preconditions to absorb and create new knowledge for exploratory innovation

Many studies in the innovation stream adopted the perspective that innovation emerges through the process of knowledge creation, i.e., recombining and reconfiguring the knowledge resources which the innovator can reach and access (Fleming, 2001; Goerzen & Beamish, 2005; Grant, 1996a, 1996b; Hargadon & Sutton, 1997; Henderson & Clark, 1990; Nelson & Winter, 1982; Schumpeter, 1934; Weitzman, 1998). From this knowledge-driven innovation perspective, absorption and creation of new knowledge are necessary for exploratory innovation (Wang et al., 2014). However, prior studies have highlighted two difficulties in new knowledge absorption and creation (Lee, 2011): First, the absorption of new knowledge is difficult due to the intrinsic nature of knowledge. A knowledge that can bring a competitive advantage to the firm is generally complex, tacit, and interdependent (Grant, 1996b; Zander & Kogut, 1995). This type of knowledge is embedded in the members, tools, and tasks of an organization (Argote & Ingram, 2000).

These characteristics give rise to “stickiness” problems in transferring knowledge (Szulanski, 1996). Second, technology and market uncertainties make it difficult to create new knowledge. Developing the right knowledge is necessary to deal with these uncertainties, but it is hard to forecast which knowledge will help the firm gain a competitive advantage in the future (Becker & Lillemark, 2006). The past shows that many firms fail to cope with disruptive innovation and consequently cease to exist (Christensen, 1997; Christensen & Raynor, 2003).

For these reasons, firms that pursue exploratory innovation face two different needs: to effectively transfer complex, tacit, and interdependent knowledge and to maintain search flexibility for relevant knowledge in response to technological/market uncertainty. In other words, uninterrupted knowledge flow and unconstrained search flexibility are required for those firms (Hansen, 1999; Lee, 2011). Knowledge flow has been an important research subject in the knowledge management literature (Szulanski, 1996). According to prior studies, an effective knowledge transfer is realized in the presence of trust, a strong bonding with partners, a high level of collaboration, and a well-established communication channel (Heide, 1994; Powell & Smith-Doerr, 1994; Rindfleisch, 2000). In other words, the efforts for closely cooperating with partners facilitate an understanding of the partner’s intentions and the sharing and integration of knowledge resources (Dyer & Singh, 1998). Therefore, effective coordination with partners promotes an uninterrupted knowledge flow. Besides knowledge flow, also search flexibility has been considered as an influential factor to deal with technological uncertainty. In a fast-

changing environment, searching, contacting and cooperating with partners are required in order to create multiple alternatives and become agile and competitive (Uzzi, 1996). Because technology uncertainty, market uncertainty, and the fast-changing environment make it difficult to predict future developments, securing a variety of alternatives is necessary to cope with these uncertainties and environment (Moriarty & Kosnik, 1989). However, obtaining alternatives can be interrupted by, e.g., alliance partners when there is a conflict of interest (Folta, 1998; Folta & Miller, 2002). Accordingly, a firm needs to maintain autonomy in decision making to increase alternatives. Keeping a distance from their partners, i.e., lowering interdependence and maintaining weak interorganizational relationships, is required to retain unconstrained search flexibility. Because autonomy, which comes from the freedom of the constraint that accompanies partners, helps managers execute their various ongoing tasks and responsibilities (Burt, 2004; Moran, 2005; Shipilov, 2009).

In summary, effective coordination to retain uninterrupted knowledge flow and keeping a distance to promote unconstrained search flexibility for exploratory innovation are in a trade-off relationship, since they require different degrees of inter-organizational relationship.

Chapter 3. Exploratory innovation through managing firm's internal knowledge network[2]

3.1 Introduction

In today's fast-changing technological environment, firms are increasingly focusing on exploratory innovation which makes them more flexible and agile, and allows them to avoid obsolescence of their knowledge and remain competitive (Phelps, 2010; Wang et al., 2014). For this reason, firms have been building up strong knowledge resources which can serve as sources of innovation (Grant, 1996a, 1996b). Innovation is intrinsically linked to two key concepts: knowledge elements and their combinations. Specifically, exploratory innovation is associated with the creation of new knowledge elements or combinations (Fleming, 2001). Following the established framework of Henderson and Clark (1990), these correspond to component knowledge (knowledge elements) and architectural knowledge (knowledge combinations). Both these dimensions are captured in the concept of the knowledge network, which considers individual knowledge elements as nodes and their combinations as ties. Knowledge networks have been used and recognized as a useful tool to depict and describe a firm's existing knowledge elements

[2] An earlier version of Chapter 3 was published in *Innovation: Organization & Management, vol. 19, issue 4,* under the title "Linking the firm's knowledge network and subsequent exploratory innovation: a study based on semiconductor industry patent data."

and their applications (Sorenson & Fleming, 2004).

Although many researchers have studied the impacts of a firm's knowledge resources on its innovation performance, several important research gaps remain: First, among the many studies on the antecedents of firm's exploratory innovation, most investigated only one side of exploratory innovation by focusing on the creation of new knowledge elements[3] (e.g. Guan & Liu, 2016; Wang et al., 2014). Only recently, Dibiaggio et al. (2014) started to look at the creation of new knowledge combinations as exploratory innovation[4]. Due to their focus on the patent level, however, their research did not include newly created knowledge elements which may affect subsequent innovation. A comprehensive view that covers both dimensions of exploratory innovation by focusing on the creation of elements and combinations at the same time, is still underexplored. Second, prior literature has not fully explained the real world performance heterogeneity exhibited by firms operating in the same industry which often possess similar knowledge elements (D'Este, 2005; Patel & Pavitt, 1997). To explain this phenomena, Nesta and Dibiaggio (2003) stated that firms even in the same industry can show dissimilar ways of conducting their research activities and implementing their knowledge elements. This leads to the thought that not only different knowledge elements, but also the different ways of leveraging those elements result in dissimilar outputs of firms' inventive

[3] For example, Wang et al. (2014) studied the effects of degree centrality and structural holes in knowledge networks on gaining new elements at an individual level.

[4] Dibiaggio et al. (2014) examined the relationship of knowledge elements such as complementarity and substitutability, and their effects on creating new knowledge combinations.

activities. Thus, a framework that clearly distinguishes knowledge elements and combinations allows to look at their individual roles and characteristics in facilitating subsequent innovation, as well as to analyze their effects on each other. Last, prior studies considered the knowledge network as a static factor influencing the firm's innovative outcome and conducted a cross-sectional analysis that examined the knowledge network as a snap shot. This conflicts with the intrinsically dynamic nature of firms' knowledge networks which are continuously changing over time through the absorption of subsequent exploratory innovation, i.e., newly created elements and combinations.

The aim of this research is to overcome these limitations by linking the firm's knowledge network and its subsequent innovation in terms of knowledge elements and combinations, and at the same time capturing the dynamics of the knowledge network for which prior studies showed little concern. Specifically, I investigate how the accumulated knowledge elements and combinations affect the creation of new knowledge elements and combinations, which are key indicators for exploratory innovation, over time.

My hypotheses are tested on a panel of 111 US semiconductor companies from 2000-2010. Using patent data, I draw each firm's knowledge network during a 5-year period and employ a sliding window approach to look at the dynamic network as new knowledge elements and combinations are created while older elements become obsolete. I find evidence for an inverted U-shape relationship between the level of accumulated knowledge combinations and the creation of new knowledge combinations. In addition, I find positive relationships between the level of accumulated knowledge elements and the

creation of new knowledge combinations as well as between the level of accumulated knowledge combinations and the creation of new knowledge elements. These results suggest that both knowledge elements and combinations play an important role in facilitating subsequent exploratory innovation.

This study makes a number of important contributions: First of all, this study extends the theoretical background by uncovering the relationship between a firm's accumulated knowledge resources and the subsequent new exploratory innovation focusing on the dynamics of knowledge networks. Specifically, this study reveals the relationships between the two types of accumulated knowledge resources of the firm and two indicators of exploratory innovation using a framework distinguishing knowledge elements and combinations. From these links, this study explores the different roles and characteristics of the firm's dynamic knowledge network in facilitating subsequent innovation. Second, our research design suggests a new approach to capturing the process of knowledge accumulation. Unlike prior research which analyzed binary knowledge networks, our analysis of patent data allows us to express a firm's knowledge resources as a weighted network. This approach enables us to examine the effects of the strength of ties and the size of nodes, which reflect the firm's level of accumulated knowledge and experience. Last, from a practical perspective, this study advises managers to set up a suitable innovation strategy taking into account the relationship between knowledge elements and combinations. For firms with strong recombinant capabilities, it is recommended to establish an external knowledge sourcing strategy to gain access to new

knowledge elements. For firms with strong technological knowledge, it is advantageous to establish a knowledge leveraging strategy to combine existing knowledge elements in new ways.

3.2 Research Hypotheses

3.2.1 Degree of accumulation in architectural knowledge and newly explored component knowledge

A firm's knowledge network is expanded over time by acquiring and leveraging knowledge resources. At each moment, nodes represent the firm's knowledge elements and ties represent the combinations of these elements. The knowledge within the ties in the network represents the firm's architectural knowledge accumulated through the experience of combining knowledge resources in past inventions. From the understanding that a firm's innovation is based on its knowledge resources, I investigate the effects of the level of accumulated architectural knowledge on the two indicators of subsequent exploratory innovation: new knowledge combinations and new knowledge elements.

A firm's existing knowledge resources formed in the past influence the firm's present search process and help it decide which knowledge elements should be combined to create useful inventions. If the present level of architectural knowledge is low, the firm is lacking information on the relationship between the knowledge elements. In this situation, it is hard to create new successful innovation based on new knowledge combinations. As a firm accumulates architectural knowledge, it increases the recombinant capabilities that enhance internal knowledge exchange through connecting different technological fields and help to find new knowledge combinations (Carnabuci & Operti, 2013). In addition,

architectural knowledge increases the information on the relationship between knowledge elements that are only indirectly connected with each other. Dibiaggio et al. (2014) argued that these knowledge elements have a functional substitutability and are able to stimulate new knowledge combinations because they can become alternatives when researchers conduct an experiment to combine different kinds of knowledge elements. Similarly, as architectural knowledge helps to understand knowledge elements through their relational information, the potential for new knowledge combinations is increased (Wang et al., 2014).

Conversely, if the level of architectural knowledge reaches excessively high levels, path-dependency can reduce subsequent exploratory innovation. High levels of architectural knowledge allow the firm to enhance its exploitive inventions and reuse existing combinations. The efficiency of the search processes related to exploitative innovation is increased through various mechanisms including more concise search processes, decreasing uncertainty, or increasing resource efficiency (Levinthal & March, 1993; March, 1991). This efficiency of exploitative search raises the opportunity cost of exploration and makes the creation of new knowledge combinations unattractive when compared to reusing existing knowledge combinations. In addition, the accumulated experiences of the firm turn into complex organizational routines and tend to increase organizational inertia. The organizational inertia stiffens collective learning and gives rise to phenomena such as the competency trap, myopia of learning, group think or NIH syndrome (Janis, 1972; Katz & Allen, 1982; Levinthal & March, 1993; Levitt & March,

1988). With the occurrence of these phenomena, the firm finds it increasingly difficult to develop exploratory innovation composed of new knowledge combinations.

In summary, increasing levels of accumulated architectural knowledge in the firm's knowledge network help to form new knowledge combinations. At high levels, however, negative effects of inertia increasingly prevent the firm from creating exploratory innovation. Together, these positive and negative effects lead to the following hypothesis:

Hypothesis 1a: *In a firm's knowledge network, there is an inverted U-shape relationship between the level of accumulated architectural knowledge and the creation of exploratory (new) knowledge combinations.*

3.2.2 Accumulated architectural knowledge and new knowledge elements

Low levels of architectural knowledge in the knowledge network show that less focus was placed on forming combinations between existing knowledge elements. It implies that the firm does not know whether there are still lots of opportunities to combine the existing knowledge elements to create useful inventions. In this situation, the firm may perform an investigation of its existing knowledge elements to identify internal opportunities rather than focus on external knowledge sourcing, because searching for

new knowledge elements externally requires more resources such as time, costs and management efforts compared to learning existing knowledge elements more deeply (Srivastava & Gnyawali, 2011). If the firm with such an effort found chances to combine existing knowledge elements, researchers would not need to search for new knowledge from the outside, but would rather prefer to focus on activities using existing knowledge within the firm.

As the level of architectural knowledge is increasing, the remaining opportunities for knowledge combinations that have not yet been realized decreases. However, the information on the relationship between the knowledge elements is closely related with forming recombinant capability in organization that enables to identify a chance to match different knowledge elements (Fleming, 2001; Henderson & Clark, 1990; Srivastava & Laplume, 2014). Therefore, a firm with high levels of architectural knowledge is capable of seeking and distinguishing types of new knowledge elements which are appropriate for creating synergy effects with the existing knowledge elements. Consequently, the firm can aim at sourcing appropriate knowledge elements after exhausting the opportunities for combining existing knowledge elements. Additionally, high levels of architectural knowledge are also associated with exploitative invention relying on past experience and existing ways of combination, often resulting in diminishing marginal benefits of inventions (Henderson, 1995; D.-J. Kim & Kogut, 1996). In terms of the firm's motivation for new knowledge sourcing, the threat of gradually exhausting the firm's internal potential for inventive ideas fosters a sense of crisis inside the firm (Ahuja &

Lampert, 2001), and creates internal pressure to focus on exploratory innovation. As a result, the firm will turn to the outside world and introduce new knowledge elements through external knowledge sourcing.

In summary, low levels of accumulated architectural knowledge do not provide motivations for firms to acquire new knowledge elements. With increasing levels, however, firms' recombinant capabilities grow and the opportunities to combine the existing knowledge elements diminish, adding pressure to introduce new knowledge elements. This leads to the following hypothesis:

Hypothesis 1b: *In a firm's knowledge network, there is a positive relationship between the level of accumulated architectural knowledge and the creation of exploratory (new) knowledge elements.*

3.2.3 Accumulated component knowledge and new knowledge combinations

In a knowledge network, a node stands for each knowledge element the firm possesses, and the accumulated knowledge within nodes represents the component knowledge indicating the level of technological expertise of the firm. In this sense, a firm with a low level of component knowledge does not possess a large expertise in the technological fields it is involved in, while a firm with high levels of component

knowledge understands the technological knowledge resources it possesses to a large degree. In an extension of the argument that a firm's new innovations are affected by its accumulated knowledge, I hypothesize about the effects of the level of accumulated component knowledge on the two indicators of subsequent exploratory innovation: the new knowledge combinations and new knowledge elements.

At a low level of component knowledge, i.e., the firm has a shallow depth of technological knowledge, the chance of success in combining two or more of the existing knowledge elements is low because the firm does not have enough expertise to have a detailed knowledge and discover the potential areas of application. High uncertainty in finding which set of knowledge elements leads to a successful combination, resulting from poor understanding of technological knowledge, gives rise to a high failure rate in an experiment dealing with various knowledge elements. In addition, the chance of forming new knowledge combinations is further reduced in case there are already existing knowledge combinations which have succeeded in prior experiments utilizing the small amount of knowledge the firm assimilate. This is due to the possible number of combinations being limited among the firm's existing knowledge elements (D.-J. Kim & Kogut, 1996). Therefore, a firm with a low level of component knowledge finds it hard to pursue new knowledge combinations and is more likely to focus on refining and exploiting existing combinations.

Meanwhile, an increase of the firm's component knowledge, i.e., a deeper understanding of technological knowledge resources, decreases the uncertainties of

matching unclear elements and leads to a growth of recombinant potential by finding new areas of application that the firm did not pursue before. Expanding the existing applicability of each knowledge element provides new opportunities for a firm to utilize existing knowledge elements in different ways by connecting unmatched technological fields, leading to new knowledge combinations. In addition, a deeper understanding of knowledge elements helps to develop a firm's combinative capability to identify the related or well-matched attributes among the existing knowledge elements of the firm (Riitta Katila, 2002; R. Katila & Ahuja, 2002). It encourages a firm to find possible sets of knowledge elements in complementary relationships and create synergy effects by combining them, resulting in the creation of subsequent new knowledge combinations.

In summary, while low levels of accumulated component knowledge provide little potential for firms to combine the knowledge elements, the formation of new knowledge combinations increases with an increase in the level of the accumulated component knowledge. This leads to the following hypothesis:

Hypothesis 2a: *In a firm's knowledge network, there is a positive relationship between the level of accumulated component knowledge and the creation of exploratory (new) knowledge combinations.*

3.2.4 Accumulated component knowledge and new knowledge elements

In high-tech industries, which are fast-changing and where future trends are hard to predict, it is always possible for firms' technological knowledge resources to become obsolete. This makes the management of the firm's knowledge portfolio an important task as a firm with various knowledge elements, i.e., options for future use, is able to predict new technology and market trends and to act more flexible and agile in response to the changing environment. If a firm sticks to a particular technology, however, it might lose its ability to compete when technological discontinuities make the firm's technologies obsolete (R. Agarwal & Audretsch, 2001; Danneels, 2004; Henderson, 1993; Tripsas, 1997). For these reasons, firms are trying to explore new knowledge elements. However, at very low levels of component knowledge, because of the lack of deep understanding of specialized technologies resulting in an absence of forecasting capabilities, the scope of the firm's existing knowledge base will make it difficult to branch out into new fields. As the level of component knowledge increases, a deeper understanding of technological knowledge helps to increase a firm's absorptive capacity to seek and learn about related knowledge elements associated with the firm's existing knowledge resources (Cohen & Levinthal, 1990). It encourages a firm to expand its technological windows and broaden the areas of expertise, so the firm is able to rapidly identify the chance of finding relevant knowledge among different technological fields. Consequently, a deeper understanding of knowledge elements with a broad technological window will facilitate the acquisition or

creation of new technologies, resulting in an increasing level of subsequent new knowledge elements.

However, as the level of component knowledge exceeds a certain level, the large amount of knowledge resources becomes excessively complicated, shaping vast knowledge management processes and routines inside the firm (Srivastava & Gnyawali, 2011). Since a firm's resources and capabilities are limited, the interest in creating further knowledge elements decreases when managing the existing knowledge resources already requires the investment of a great amount of cost and effort. Previously secured elements also tend to primarily boost exploitative inventions as the existence of a large in-house knowledge stock diminishes the motivations and incentives for creating new knowledge elements. Moreover it is possible for previously formed elements to shape silos in organizations and bring about phenomena that hinder the exploration of new knowledge element from an unfamiliar context, e.g., group think or the NIH syndrome (Janis, 1972; Katz & Allen, 1982). For these reasons, the firm finds it increasingly difficult to create exploratory innovations composed of new knowledge elements.

In summary, while the level of accumulated component knowledge initially supports the creation of new knowledge elements, beyond a certain level, increasing internal costs and reduced benefits of managing a large amount of knowledge stock come into play and negatively affect the formation of new knowledge elements. Together, these positive and negative effects lead to the following hypothesis:

Hypothesis 2b: *In a firm's knowledge network, there is an inverted U-shape relationship between the level of accumulated component knowledge and the creation of exploratory (new) knowledge elements.*

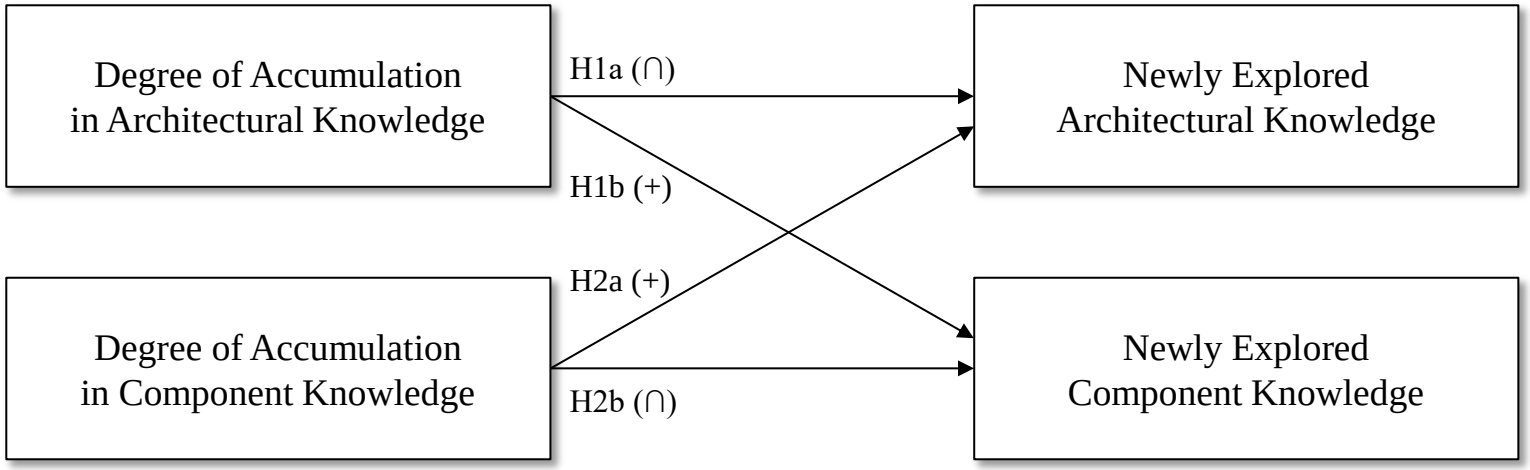


Figure 3-1. Conceptual diagram

3.3 Methods

3.3.1 Data and sample

The hypotheses of this study were tested on a dataset of firms operating in a high-tech industry. I constructed a panel of 111 global semiconductor companies (SIC 3674) for the 2000-2010 period using information on granted US patents listed in the database of the USPTO (United States Patent and Trademark Office) and financial information from the Compustat database provided by Thomson Reuters.

The semiconductor industry has several characteristics that make it a suitable setting for studying a firm's knowledge resources. First, the semiconductor industry is a typical high-tech sector in which building up a superb knowledge base is critical for gaining and holding a competitive advantage. Second, the industry is known for its high propensity to patent innovations which makes the use of patent data to track and measure knowledge and innovation possible (Hall & Ziedonis, 2001, 2007). Third, the fierce competition and the rapid technological process in the industry result in the constant emergence of new knowledge fields and elements, making it suitable for the study of knowledge and its combination in new inventions.

I used patent data to examine the characteristics of firm's knowledge resources. Patents are codified knowledge that represents the inventions made by the firm and enable objective observation of the output of the firm's R&D effort (Jaffe, Trajtenberg, &

Henderson, 1993). Patent data is reliable since every patent is documented and systematically classified by. It provides detailed information not only about the technological knowledge itself but also ancillary information such as the date of registration, the inventors involved in its creation, right holders, etc. In addition, being collected over long time frames, patent data allows to conduct longitudinal studies (Hall, Jaffe, & Trajtenberg, 2000). Patents are a typical example for explicit knowledge, but have a close relationship with the flow of tacit knowledge, making them suitable for investigating a firm's overall knowledge flow and stock (Mowery, Oxley, & Silverman, 1996; Song, Almeida, & Wu, 2003).

Patents serve as useful tools to distinguish individual knowledge elements as in addition to information related to application and grant date, inventor, owner and assignee of the patent, they include information on the technological classification of the invention. The USPTO has maintained and updated its technology classification standard composed of 400+ main classes and 100,000+ sub classes. Prior studies have considered technology classes as valid proxies for the knowledge elements which form the knowledge network (Carnabuci & Bruggeman, 2009; Dibiaggio et al., 2014; Fleming et al., 2007; Fleming & Sorenson, 2001; Wang et al., 2014; Yayavaram & Ahuja, 2008). If a patent has two or more technology classes listed, it shows that the invention contained in the patent is derived from the useful combination of each of these technology classes.

In this study, I set up a 5-year window to construct each firm's knowledge network by investigating all ultimately granted US patents that were applied for by the firm during

that period. I set up the observation window in order to reflect the change of the firm's knowledge network over time as it absorbs newly appearing nodes and ties, and old nodes and ties expire or lose their value. The 5-year period used also in many previous studies (Carnabuci & Operti, 2013; Dibiaggio et al., 2014; Guan & Liu, 2016; Wang et al., 2014) is chosen in accordance with the declining value of patented knowledge. A previous study has examined the technical knowledge depreciation rate in several industries and found it to reach up to 17% annually in high-tech sectors like computers and electronics (Gwangman Park, Shin, & Park, 2006). Another study focusing on the age of patent citations showed that the frequency of received citations is rapidly dropping about two years after the grant year. Including the typical delay between the application of the patent and it being granted, the relevant lifespan of a patent can be assumed to be about 5 years from the year of application (Mehta, Rysman, & Simcoe, 2010).

To arrive at the final dataset, I used the following procedure: At first, I extracted information on 103,787 granted patents of 157 global semiconductor companies (SIC3674) for the 2000-2014 time period from the USPTO database. This allowed us to verify whether the patents applied for in the period of interest (2000-2010) were ultimately granted or not. Next, I set up a 5-year window for each company to gather all the firm's granted patents filed in that period and, using the technology classes listed on each of the patents, identify the knowledge elements and their combinations. For example, if a firm's patent #1 is composed of technology classes A and B, then I generate nodes A and B with a value of 1 each, and connect them with a link of value 1 since they are

combined in a single patent. Next, if the same firm's patent #2 is composed of technology classes B and C, I generate node C with a value of 1 next to node B, which now has a value of 2 (1 added to the value it had received from patent #1), then link node B and C with the link being assigned a value of 1. In the same way, I cumulatively add all the nodes and ties derived from the firm's patents for the 5-year period. I constructed panel data of the firms by moving the 5-year window a total of six times, by a year each, creating the following observation windows: '00-'04, '01-'05, '02-'06, '03-'07, '04-'08, '05-'09. All independent variables and control variables are calculated from the observation period or at the last year of the observation period, however the dependent variables were lagged by a year to capture the causal relationship. Last, I added each firm's financial information from the Compustat database and removed entries with missing values. The final sample consists of 111 firms and 608 firm-year observations.

3.3.2 Dependent variable

This study focuses on the effects of a firm's accumulated knowledge on its subsequent exploratory innovation. To investigate different aspects of accumulated knowledge of a firm, I assemble the firm's knowledge network composed of knowledge elements (=nodes) and their combinations (=ties). Similarly, the firm's exploratory innovation can be separated into two types, one in terms of brand-new knowledge elements (=new

nodes) and the other one in terms of brand-new knowledge combinations (=new ties) (Fleming, 2001). Thus, the dependent variables of this study were chosen to represent these two key dimensions of exploratory innovation.

New knowledge combination indicates the extent to which a firm adopts new ways of knowledge application. It is measured by the number of new ties which appeared in focal firm i's knowledge network in year t, the lagged year from the observation period of the independent variables from t-5 to t-1. In a similar way, *New knowledge element* indicates the extent to which a firm adopts new knowledge elements, and is measured as the number of new nodes that appeared in focal firm i's knowledge network in year t. I use a simple count variable for two key reasons. First, the absolute number of new knowledge combinations or elements helps to understand a firm's exploration more intuitively. Second, it allows us to quantitatively measure the effects of a firm's accumulated knowledge at the knowledge level regardless of firms' different resources and capabilities.

3.3.3 Independent Variables

The independent variables of this study represent the level of accumulated knowledge within the two key dimensions of the knowledge network, i.e., previously formed knowledge elements and their combinations. As I mentioned before, I set up a 5-year observation window to construct the knowledge network of each firm from year t-5 to t-1,

and calculated the value of the knowledge elements (=nodes) and the knowledge combinations (=ties). *Accumulated architectural knowledge* is then defined as the mean value of the ties in focal firm i's knowledge network to indicate the extent to which the firm has accumulated knowledge related to the connection between different knowledge elements. In the same way, *Accumulated component knowledge* is defined as the mean value of the nodes in focal firm i's knowledge network to indicate the extent to which the firm has accumulated knowledge related to the knowledge elements themselves.

3.3.4 Control Variables

This study controls for the influence of other variables associated with the firm's knowledge network. I controlled for two representative measures of network cohesion: *Density* and *Degree Centrality* that may produce heterogeneity of the firm's knowledge network. *Density* indicates the overall valued network density in firm i's knowledge network, which is measured as the total value of ties divided by the total number of possible ties in knowledge network. *Degree Centrality* indicates how many relationships the nodes have, which is calculated at the network level by averaging each node's number of connections to other nodes in firm i's knowledge network (Wang et al., 2014). I also added *Number of clusters* which indicates the extent to which knowledge elements are connected together, because often a firm's knowledge network is composed of a few

disconnected clusters (Wang et al., 2014). From the network perspective, all nodes that belong to the same cluster are far more cohesive than a pair of nodes that are on separate clusters, so it may affect the tendency to explore new inventions. I measured it as the number of network clusters in focal firm i's knowledge network. I also added *Firm size* and *R&D intensity* to control the effects of scale and scope on technological search which may affect the firm's inventive activities (Dibiaggio et al., 2014; Henderson & Cockburn, 1994; Wang et al., 2014; Yayavaram & Ahuja, 2008). *Firm size* is defined as the number of employees of focal firm i in year t-1, the year before the observation year of the dependent variable (Yayavaram & Ahuja, 2008). *R&D intensity* is defined as the log-transformed value of total R&D expenses divided by total sales of focal firm i in year t-1 (Yayavaram & Ahuja, 2008). Last, I controlled for the *Number of alliance partners* which indicates the extent of a firm's external knowledge sourcing which may affect firm's exploratory activities (Srivastava & Gnyawali, 2011)

3.3.5 Empirical model specification

I use a negative binomial regression model because the dependent variables, the number of new knowledge combinations and new knowledge elements, are count variables. Negative binomial regression is used when the dependent variable's variance is bigger than its mean (Long, 1997). According to the result of the performed Hausman test,

I use a fixed-effect model which assumes that each entity's characteristics do not change over time (Hausman, 1978).

Table 3-1. Descriptive Statistics and Correlations

(obs=608)	Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) New knowledge combinations	13.10	22.96	0	213	1.00									
(2) New knowledge elements	3.34	3.83	0	44	0.69	1.00								
(3) Network density	0.33	0.39	0	4	-0.10	-0.13	1.00							
(4) Degree centrality	0.32	0.15	0	1	0.01	-0.06	0.28	1.00						
(5) Number of clusters	5.12	3.06	1	9	0.36	0.26	-0.38	-0.28	1.00					
(6) Firm size	5.25	11.52	0	99.9	0.75	0.40	-0.02	0.05	0.33	1.00				
(7) R&D intensity	0.30	1.07	0.01	24.06	-0.04	-0.06	-0.01	-0.04	-0.06	-0.07	1.00			
(8) Number of alliance partners	1.64	3.28	0	30	0.65	0.28	-0.05	0.11	0.30	0.64	-0.03	1.00		
(9) Accum. architectural knowledge	2.21	1.41	0	15	0.44	0.23	0.42	0.27	0.25	0.46	-0.05	0.41	1.00	
(10) Accum. component knowledge	9.39	11.25	1	75.10	0.76	0.36	0.08	0.17	0.34	0.67	-0.06	0.63	0.75	1.00

Table 3-2. Results of the Variance Inflation Factor (VIF) test

Variable	VIF	1/VIF
Network density	1.98	0.506
Degree centrality	1.27	0.790
Number of clusters	1.80	0.557
Firm size	2.18	0.458
R&D intensity	1.02	0.984
Number of alliance partners	2.00	0.500
Accum. architectural knowledge	3.72	0.269
Accum. component knowledge	3.95	0.253

Table 3-3. Results of Fixed-Effect Negative Binomial Regression Analysis for new knowledge combinations

	New knowledge combinations			
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Constant	0.709***	0.370	0.695***	0.452*
	(0.198)	(0.228)	(0.194)	(0.224)
Control Var.				
Network density	0.129	-0.412	-0.180	-0.467
	(0.233)	(0.287)	(0.263)	(0.305)
Degree centrality	-0.080	-0.534	-0.141	-0.377
	(0.368)	(0.401)	(0.377)	(0.407)
Number of clusters	0.033**	0.009	0.024*	0.012
	(0.014)	(0.014)	(0.013)	(0.014)
Firm size	0.036***	0.028***	0.025***	0.024***
	(0.005)	(0.005)	(0.006)	(0.006)
R&D intensity	0.184*	0.172*	0.189*	0.181*
	(0.098)	(0.093)	(0.098)	(0.096)
Number of alliance partners	0.002	-0.007	-0.022*	-0.019
	(0.011)	(0.012)	(0.012)	(0.012)
Independent Var.				
Accumulated architectural knowledge		0.466***		0.328**
		(0.131)		(0.140)
Accumulated architectural knowledge^2		-0.030**		-0.024*
		(0.013)		(0.013)
Accumulated component knowledge			0.032***	0.022**
			(0.006)	(0.009)
Year dummy included (all model)				
Number of observations	608	608	608	608
Number of firms	111	111	111	111
Log likelihood	-1248.211	-1238.543	-1239.151	-1236.213
Wald chi2	77.44	99.81	101.31	104.81
Prob > chi2	0.000	0.000	0.000	0.000

*p<0.10; **p<0.05; ***p<0.01 Standard errors are in parentheses.

Table 3-4. Results of Fixed-Effect Negative Binomial Regression Analysis for new knowledge elements

	New knowledge elements			
Variable	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Constant	2.089***	1.989***	2.131***	2.155***
	(0.294)	(0.296)	(0.321)	(0.332)
Control Var.				
Network density	0.428**	0.249	0.451**	0.229
	(0.211)	(0.234)	(0.219)	(0.230)
Degree centrality	0.159	0.025	0.175	0.000
	(0.370)	(0.386)	(0.372)	(0.384)
Number of clusters	-0.036**	-0.041**	-0.036**	-0.046**
	(0.018)	(0.018)	(0.018)	(0.018)
Firm size	0.012	0.010	0.013	0.015
	(0.009)	(0.009)	(0.010)	(0.009)
R&D intensity	0.043	0.042	0.043	0.043
	(0.069)	(0.069)	(0.069)	(0.069)
Number of alliance partners	-0.013	-0.020	-0.011	-0.010
	(0.017)	(0.018)	(0.021)	(0.020)
Independent Var.				
Accumulated architectural knowledge		0.097*		0.178**
		(0.059)		(0.075)
Accumulated component knowledge			-0.006	-0.033
			(0.018)	(0.021)
Accumulated component knowledge^2			0.000	0.000
			(0.000)	(0.000)
Year dummy included (all model)				
Number of observations	608	608	608	608
Number of firms	111	111	111	111
Log likelihood	-873.237	-871.917	-873.172	-870.424
Wald chi2	41.71	45.26	41.98	49.28
Prob > chi2	0.000	0.000	0.000	0.000

*p<0.10; **p<0.05; ***p<0.01 Standard errors are in parentheses.

3.4 Results

Table 3-1 provides descriptive statistics and correlations for all variables. The relationship between firm size and number of alliance partner is correlated, i.e., larger firms are more actively forming alliances with external partners. As the firm's alliance activity is closely associated with its external knowledge sourcing strategy, it may affect the focal firm's knowledge inputs. In addition, some of the variables associated with network properties may be correlated because they influence each other in a network context, e.g., the density of the network and the accumulation of ties. To check for the presence of possible multicollinearity problems, I conducted an additional variance inflation factor (VIF) test and the results showed low values (average of 2.04), which are small enough to ignore the multicollinearity problem (Kleinbaum, Kupper, Nizam, & Rosenberg, 2013; Myers, 1990).

Table 3-2 and 3-3 present the results. Table 3-2 (Models 1-4) presents the results of testing the hypotheses using the first dependent variable, *New knowledge combinations* while Table 3-3 (Models 5-8) presents results of testing the hypotheses related to the second dependent variable, *New knowledge elements*. I used a hierarchical approach to test the hypotheses by adding each of independent variables one by one into the baseline model which only contains the control variables.

In Table 3-2, Model 1 is the baseline model that includes the control variables *Network density*, *Degree centrality*, *Number of clusters*, *Firm size*, *R&D intensity*, *Number of*

alliance partners together with the dependent variable, *New knowledge combinations*. Model 2 adds the first independent variable: *Accumulated architectural knowledge* and its quadratic term to explore its impact on new knowledge combination. Model 3 adds the second independent variable: *Accumulated component knowledge* to Model 1. Model 4 is the full model that with both independent variables.

As shown in Table 3-2, positive effects of *Firm size* and *R&D intensity* on *New knowledge combinations* are found in Models 1-4. It shows that the scale and scope of technological search of the firm is positively affecting the firm's exploratory innovation. In addition, I found that the *Number of clusters* is positively associated with *New knowledge combinations* in Models 1 and 3. Following the study of Yayavaram and Ahuja (2008), this result can be interpreted that the more clusters are in the firm's knowledge network, the more opportunities are available for the firm to connect these different clusters with each other.

The testing of Hypothesis 1a, is performed using the results of Models 2 and 4. In Model 2, the coefficient of *Accumulated architectural knowledge* is positive and statistically significant (β=0.466, $p<.01$) while its quadratic term is negative and statistically significant (β=-0.030, $p<0.05$). In Model 4, the coefficient of *Accumulated architectural knowledge* is positive and statistically significant (β=0.328, $p<0.05$) while its quadratic term is negative and statistically significant (β=-0.024, $p<0.1$). These findings support Hypothesis 1a which predicted an inverted-U relationship between the level of accumulated architectural knowledge and the subsequent creation of new

knowledge combinations.

Models 3 and 4 are related to Hypothesis 2a. In Model 3, the coefficient of *Accumulated component knowledge* is positive and statistically significant (β=0.032, $p<0.01$). In Model 4, the coefficient of *Accumulated component knowledge* is positive and statistically significant (β=0.022, $p<0.05$) as well. These findings support Hypothesis 2a which predicted a positive relationship between the level of accumulated component knowledge and the subsequent creation of new knowledge combinations.

Table 3-3 follows the same pattern in presenting the results of testing the hypotheses related to the second dependent variable, *New knowledge element*. Models 5-8 find a negative effect of the *Number of clusters* on the *New knowledge elements*. It can be interpreted that as a firm's knowledge elements are clustered together, it may help the firm to bring a new knowledge element, which is the opposite result in terms of a new knowledge combination, so I may assume that the extent to which a firm's knowledge network clustered affects its creation of a new knowledge element or a new knowledge combination in a different way. Additionally, in Model 5 and 7, a positive effect of *Network density* on *New knowledge elements* is found which can be explained in that a cohesive knowledge network may boost innovation process by enhancing the exchange of information.

For testing Hypothesis 1b, I use the results of Models 6 and 8. In Model 6, the coefficient of *accumulated architectural knowledge* is positive and statistically significant (β=0.097, $p<0.1$). In Model 8, the coefficient of *Accumulated architectural knowledge* is

also positive and statistically significant (β=0.178, $p<0.05$). These findings support Hypothesis 1b which predicted a positive relationship between the level of accumulated architectural knowledge and the subsequent creation of new knowledge elements.

Hypothesis 2b is tested using the results of Models 7 and 8. In Model 7, the coefficient of *Accumulated component knowledge* is negative and statistically insignificant (β=-0.006, $p>0.1$) while its quadratic term is not found to have any effect (β=0.000, $p>0.1$). In Model 8, the coefficient of *Accumulated component knowledge* is negative and statistically insignificant (β=-0.033, $p>0.1$) as well as its quadratic term (β=0.000, $p>0.1$). These findings do not support Hypothesis 2b which predicted an inverted-U relationship between the level of accumulated component knowledge and the subsequent creation of new knowledge elements.

3.5 Discussion

The main idea of this study is that the accumulated knowledge within a firm's knowledge network influences subsequent exploratory innovation. A firm's knowledge network is a set of knowledge elements which indicate the areas of technological expertise and their combinations which indicate ways of knowledge application. I focused on the different characteristics of a firm's accumulated knowledge within elements and combinations, i.e., the component and architectural knowledge, and distinguished their impacts on the subsequently emerging new knowledge elements and combinations. The uncovered relationships between the two types of accumulated knowledge and the two types of exploratory innovations, help us comprehend the dynamics of the firm's knowledge network.

In terms of knowledge combination, I confirmed an inverted U-shape relationship between the level of accumulated architectural knowledge and subsequent new knowledge combinations. New ways of knowledge application occur more frequently as the firm accumulates experience of combining knowledge resources, however, it slows down after reaching a certain level. It indicates that accumulated architectural knowledge helps organizational learning and broadens knowledge applicability to foster exploratory innovation, but because of path-dependent attributes, knowledge application becomes increasingly rigid, creating inertia that makes it harder for the firm to seek new ways of doing things.

Next, the relationships between accumulated component knowledge and new knowledge combinations, and between accumulated architectural knowledge and new knowledge elements, were found to be positive. This shows that both knowledge elements and knowledge combinations in the knowledge network can be seen as positively influencing each other. The accumulation of component knowledge can be essential for creating new knowledge combinations, and the inverse relationship, i.e., the accumulation of architectural knowledge helps to form new knowledge elements, was proven as well. In other words, learning about elements as basis for new inventions should preceded the creation of new inventions by combining elements. Additionally, accumulating knowledge from the experience of combining various elements is important to extend a firm's area of expertise by gaining new knowledge elements. These results may help a firm to understand how the two key dimensions of knowledge resources are able to enhance each other despite the exploratory innovation may not be created automatically without managerial efforts, and to seek an exploration strategy tailored to the firm's present situation.

In summary, a firm seeking exploratory innovation should be conscious about the path-dependent attributes of its knowledge resources, which have the nature of becoming rigid over time. In addition, by understanding the relationship between architectural and component knowledge, this study drew two managerial implications: First, if a firm tries to create new knowledge combinations, it is helpful to adopt knowledge elements in advance and apply this component knowledge. Second, if a firm tries to gain a new

knowledge element, it is useful to have an experience of combining its existing elements as this allows the firm to better identify which new knowledge elements are suitable for the firm. To extend these arguments, obtaining new knowledge elements is associated with a firm's activities for expanding the areas of technological expertise through various knowledge sourcing modes, and combining knowledge elements is associated with a firm's activities for developing new ways of knowledge application by utilizing its stock of knowledge. Thus, I can draw a conclusion that a firm's knowledge sourcing activities and knowledge utilizing activities may have positive effects on boosting and enhancing each other to build a strong foundation for subsequent innovation.

Chapter 4. Exploratory innovation through gaining knowledge from alliance portfolio[5]

4.1 Introduction

Exploratory innovation, which refers to the generation of something valuable by using unfamiliar knowledge obtained from exploration, has received considerable attention as an important way to gain a competitive advantage and achieve sustainable growth (Ali, 2021; Gilsing et al., 2008; Luo et al., 2018; Rothaermel & Deeds, 2004). However, owing to a firm's resource constraints and path-dependent tendencies, it is not easy to explore new knowledge relying only on internal R&D (Hagedoorn & Schakenraad, 1994). Accordingly, establishing strategic alliances, which together form an alliance portfolio, become a vital external knowledge-sourcing strategy that firms can search for, adopt, and create new knowledge (Duysters & Lokshin, 2011; Grant & Baden-Fuller, 2004; McConnell & Cross, 2019; Powell, 1998; Rosenkopf & Nerkar, 2001; Slavova & Jong, 2021; Srivastava & Gnyawali, 2011; Van de Vrande et al., 2006). This study aims to reveal the effective way to source external knowledge among alliance partners to create exploratory innovation. Specifically, I examine the effects of a firm's external knowledge

[5] An earlier version of Chapter 4 was published in the *International Journal of Innovation Management, advance online publication* under the title "Exploratory Innovation through Gaining Knowledge from Alliance Portfolio: Interplay between Network Structure and Knowledge Composition."

environment, i.e., the configuration of the alliance portfolio, on its creation of exploratory innovation.

Previous literature has adopted the social network theory and the knowledge-based view as the primary theoretical lenses in consideration of the structural factors affecting firms' access to external knowledge resources or the compositions of knowledge that the alliance partners possess (Cao, Xing, & Zhang, 2021; Gilsing et al., 2008; Kogut & Zander, 1992; Luyun, Deming, & Yunsheng, 2019; Phelps, 2010; Wassmer, 2010; Yu & Chen, 2020). From social network theory, central or brokering positions have been investigated to capture important aspects of network embeddedness (Gnyawali & Madhavan, 2001; Gulati & Gargiulo, 1999; Lin et al., 2009; Ma, Zhang, & Zhang, 2020). A central position refers to a high social status, which allows a firm to directly access the knowledge of its alliance partners (Bonacich, 1987; Podolny, 1993, 2001; Powell, 1998; Powell et al., 1996). At the same time, high-status firms face difficulties in exploring new ideas because of their close relationship with their partners (Locke et al., 1999). A brokering position refers to a bridge of different and often unconnected groups, which may provide a potential source of novel ideas by accessing the different flows of information among separate groups (Burt, 2000; Zaheer & Bell, 2005). However, it may prevent a firm from accessing its partners' knowledge because of its loose connection (Burt, 2004).

The knowledge-based view focuses on the knowledge characteristics, e.g., the scope of new (or shared) knowledge available to the focal firm, to identify and capture the value

of knowledge resources in alliance portfolio (Cui & O'Connor, 2012; Wuyts & Dutta, 2014). As exploratory innovation is created from recombination or reconfiguration of knowledge elements, a wide scope of new knowledge is an important source of exploratory innovation (Crescenzi & Gagliardi, 2018; Fleming, 2001; Marhold et al., 2017). However, if the scope of new knowledge is too wide, information overflow may arise (Koput, 1997). While a wide scope of shared knowledge provides the absorptive capacity, i.e., a firm's ability to value, assimilate, and apply external knowledge (Cohen & Levinthal, 1990; Schildt et al., 2012; Zahra & George, 2002), homogeneous knowledge may hinder the creation of exploratory innovation (Uzzi, 1996).

Although many prior studies on alliance portfolios have employed these two theoretical lenses, important research gaps remain: First, from the viewpoint of social network theory, previous literature has assumed that firms in an equivalent network position can access and utilize the same quality of resources from their alliance partners. However, in reality, knowledge differs between each firm's alliance partners, even though firms occupy the same position from a network structure perspective. Second, from the viewpoint of knowledge-based theories, previous literature assumes the same resource accessibility if firms have the same partners, regardless of any variance in their social network position. This assumption also ignores the reality of structural differences among firms' network positions, even though they form alliances with the same partners. The difference between these implicit assumptions and reality leads an incomplete understanding of alliance portfolio characteristics and their effects on subsequent

exploratory innovation. To overcome this limitation, it is necessary to employ these two theoretical lenses together and investigate the interaction effects between structural and nodal properties, i.e., a firm's position among its alliance partners and the knowledge characteristics of the surrounding partners. Following the objective, this research investigates which combinations of network positions and knowledge composition in the alliance portfolio are beneficial for increasing the focal firm's exploratory innovation.

To this end, I develop four hypotheses to identify both the individual effects of central and brokering positions, and the interaction effects between those network positions and the knowledge compositions on exploratory innovation. I start by drafting a framework considering the two key factors of knowledge flow and search flexibility to deal with the two fundamental challenges that firms may face, i.e., the search and transfer problems in the creation of exploratory innovation (Hansen, 1999; Lee, 2011). Using this framework, I hypothesize that both network positions facilitate knowledge flow or search flexibility, but hinder the other factor as their positional effects increase beyond a certain level. In addition, I presume that the effects of both the network position and knowledge composition complementarily interact with each other. Accordingly, the potential negative effect on either knowledge flow or search flexibility from a network position can be compensated by the effects stemming from the knowledge composition in the alliance portfolio.

The empirical analysis on a panel dataset of 145 international pharmaceutical companies confirms the proposed inverted U-shape relationship between both central and

brokering network positions and the creation of exploratory innovation. I find that a central position promotes smooth knowledge flow with partners, however, beyond a certain level, it may decrease search flexibility. These findings also clarify that a brokering position increases search flexibility, however, it may decrease knowledge flow when exceeding a certain level. Furthermore, the results of this study confirm that two combinations of network position and knowledge composition have positive interaction effects on exploratory innovation: a central position with partners possessing a wide scope of new knowledge, and a brokering position with partners possessing a wide scope of shared knowledge. Specifically, the results confirm that new knowledge breadth can help to mitigate the low search flexibility resulting from being in a central position, and shared knowledge breadth can increase absorptive capacity, which helps to understand each other and to increase the knowledge flow that is typically insufficient in a brokering position.

This study makes three important contributions: First, this study provides new theoretical insights by establishing a comprehensive view combining both social network theory and the knowledge-based view. Specifically, this study highlights the inter-relationship between the effects of network position and knowledge composition in the alliance portfolio, and claims that potential negative effects resulting from the network position can be compensated when the knowledge composition is well-matched. Second, this study suggests two key factors for the creation of exploratory innovation, i.e., uninterrupted knowledge flow and unconstrained search flexibility, and uncover the

conditions that satisfy both key factors at the same time. Although the extant studies have considered them to be in a trade-off relationship, this study identifies combinations between network position and knowledge composition in the alliance portfolio which allows them to compensate each other's weak point, ultimately fostering both knowledge flow and search flexibility at the same time. Last, from a practical perspective, this study advises managers to set up a suitable alliance strategy for exploratory innovation taking into account the network position and knowledge composition at the same time. Specifically, this paper reveal that both central and brokering network positions possess advantages and disadvantages in creating exploratory innovation, and suggest solutions to overcome those disadvantages by utilizing appropriate knowledge resources from the alliance portfolio to increase exploratory innovation.

4.2 Research Hypothesis

As I mentioned earlier, effective coordination to retain uninterrupted knowledge flow and keeping a distance to promote unconstrained search flexibility for exploratory innovation are in a trade-off relationship since they require different degrees of inter-organizational relationship. However, I suppose that appropriate combinations of the network position and knowledge composition can solve this problem from a trade-off relationship because they have different effects on knowledge flow and search flexibility. Based on this train of thought, I developed a series of hypotheses. First, I investigate the effects of the network position on the firm's exploratory innovation in terms of knowledge flow and search flexibility. Second, I build hypotheses on appropriate combinations of network position and knowledge composition for overcoming this problem.

4.2.1 Central position and exploratory innovation

The central position in an alliance network indicates the extent of connectedness among members of an alliance network (Freeman, 1979). A central firm can gain a "high social status" and "technological prestige" among the alliance partners through having accumulated broad or in-depth knowledge (Ahuja, 2000; Podolny, 1993; Stuart, 1998). Thus, potential partner firms want to build a strong relationship with the firm. These

characteristics of firms in a central position may have effects on knowledge flow and search flexibility.

The central position facilitates the inter-firm knowledge flow, which has positive effects on the creation of exploratory innovation. A firm in a central position is able to access more closely guarded information through its direct contact with multiple partners (Koka & Prescott, 2008). The partners try to interact with a central firm to benefit from its accumulated knowledge. Frequent interaction with partners increases partners' resource commitments and makes them interdependent with each other (Rowley, Behrens, & Krackhardt, 2000). Accordingly, partner firms share more knowledge that is not opened to other firms with a central firm. Throughout this process, a firm in a central position can establish well-developed communication channels with fewer intermediaries. It helps the firm to receive the tacit and complex knowledge of the partners (Larson, 1992). Also, a large number of partners would increase the quantity of knowledge flow to the firm. In addition, a central firm can take advantage of benefits arising from control over its R&D partners using its high prestige (Podolny, 1993) and can mobilize support from its partners to integrate knowledge resources more easily (Stuart, 1998). Furthermore, the central firm can allow its partners to filter and clarify the relevant knowledge benefits to the central firm and informed risk to be avoided (Wang et al., 2014).

Conversely, if a firm is located too close to a central position, increased negative influences on the search flexibility would reduce the firm's exploratory innovation. A central firm is regarded as an expert on extant knowledge who have accumulated its

technological prestige. Searching and adopting knowledge totally different from the extant knowledge may result in the central firm losing reputation and a rearrangement of the status order within the alliance portfolio (Burkhardt & Brass, 1990; Wang et al., 2014). This reduces the incentive of the central firm to explore new ideas and encourage it to stay focused on its existing knowledge base while narrowing the scope of the search (March, 1991). Additionally, a central firm is tightly connected to its partners with a strong sense of belonging. In this situation, it is difficult to establish new partnerships without the existing partners' consent, since these new alliances might have strong effects on the existing relationships (Gunno Park, Kim, & Kang, 2015). These concerns may constrain the central firm from searching and developing new partnerships. Moreover, because of the central firm's tightly connected relationships, its every move, including its intentions, strategies, behaviors, can be known to its partners. This 'hard to conceal', 'information-sharing' situation constraints the central firm in finding new knowledge that does not belong to the existing partners, even if the central firm has strong motivations and capabilities for exploration. Lastly, the central firm having more interaction with its direct partners can increase the density of the interfirm network, resulting in a high degree of redundancy of partners' knowledge resources (Wassmer, 2010). Since exploratory innovation is created by combining new/different knowledge elements, this resource redundancy can degrade opportunities for knowledge search and combination activities.

In summary, as the firm is more close to the central position in the alliance network, increasing positive effects on the knowledge flow result in leading a successful

exploratory innovation. Too close to the central position, however, negative effects on the search flexibility arise and overwhelm the positive effects and as a result, hinder from creating exploratory innovation. Together, these positive and negative effects lead us to the following hypothesis:

Hypothesis 1: *There is an inverted-U shape relationship between the firm's level of central position in its alliance network and the creation of exploratory innovation.*

4.2.2 Brokering position and exploratory innovation

The brokering position among the alliance partners refers to a position linking different and often unconnected groups of firms following the concept of structural holes (Burt, 1992). This position may be closely associated with search flexibility which positively influences the creation of exploratory innovation. A firm in a brokering position may be located between different strategic groups which have dissimilar expertise and resources (Koka & Prescott, 2002, 2008). Thus, the firm in the brokering position can act as a bridge between them and take advantage of the information flow, e.g., by receiving different knowledge from separate groups (Burt, 2004; Ozer & Zhang, 2019; Rhee, 2004; J. Wen, Qualls, & Zeng, 2021; Zang, 2018). This helps the firm to broaden its technological window to search and track novel technologies that will lead to

a possible technological change. The brokering position also provides information benefits that increase the possibility of discovering knowledge elements which are from unrelated or distant fields (Zaheer & Bell, 2005). In the course of combining these knowledge elements, the firm can increase inventive opportunities which lead to the creation of exploratory innovation. In addition, if the firm is close to a brokering position, the firm is likely to have autonomy in decision making since the firm typically is unaffiliated with the neighbouring groups of firms (Shipilov & Li, 2008). This results in the firm having fewer constraint in exploring new ideas and allows it to ally with new partners more easily if they possess novel technology.

Meanwhile, if the firm is too close to the brokering position, allowing the firm not to belong to any particular group of firms, negative effects on the knowledge flow will arise. Assuming the opposite case, i.e., firms within a group, they can share the same context; for examples, the same interests, objectives, culture, and background knowledge (Rindfleisch, 2000). They can communicate with each other based on a comprehensive understanding with a shared context, which increases the absorptive capacity that is important to understand tacit and complex knowledge (Cohen & Levinthal, 1990). On the other hand, a firm that does not belong to a certain group faces difficulties in communicating with the firms within the group because they do not share the knowledge that is the foundation of absorptive capacity. Without absorptive capacity, the firm is not able to understand tacit, complex, and interdependent knowledge. In a similar vein, a firm in a brokering position is likely to be unaffiliated with any group of firms, so it may suffer

from a lack of a strong sense of fellowship. Therefore, a firm in a brokering position will have a hard time mobilizing support from its partners to integrate knowledge resources and to create exploratory innovation.

In summary, while the level of brokering position in an alliance network initially increases search flexibility, beyond a certain level, increasing negative effects on the knowledge flow outweigh the positive effects of search flexibility and prevent the firm from creating exploratory innovation. Together, these positive and negative effects lead us to the following hypothesis:

Hypothesis 2: *There is an inverted U-shape relationship between the firm's level of brokering position in its alliance network and the creation of exploratory innovation.*

4.2.3 Central position with partners' wide scope of new knowledge and exploratory innovation

The effects of the network position can be affected by the partner's knowledge composition. The interaction effect can be viewed from two sides: the effect of new knowledge breadth on the central position, and vice versa.

As mentioned above, the central position benefits knowledge flow, which is essential for a firm to create exploratory innovation. A wide scope of new knowledge, in this case,

can boost this positive effect of the knowledge flow in a central position on the creation of exploratory innovation. First, a central firm usually established high technological prestige through long-term collaborations with its partners. Through such a collaborative process, they can set up well-developed communication channels, which allow them to share large amounts of knowledge and experience to increase absorptive capacity (Stuart, 1998) and help them understand their partners' tacit and complex knowledge (Larson, 1992). If the partners possess a wide scope of new knowledge, the central firm can learn and absorb novel ideas beyond its knowledge stock more easily, which can help to increase the central firm's exploratory innovation. Second, a central firm has better control over its partners in order to filter and clarify the relevant knowledge beneficial to it (Wang et al., 2014). If the partners possess a wide scope of new knowledge, they can provide more potential but refined knowledge, which may result in the central firm creating exploratory innovation. Overall, a wide scope of new knowledge strengthens the positive relationship between the central position and the creation of exploratory innovation.

In terms of search flexibility, however, the central position has a weakness resulting from the tightly connected relationships with a strong sense of belonging. These could hamper the creation of alternatives, i.e., seeking new partners with relevant technology and building collaborative relationships. In this situation, a wide scope of new knowledge can compensate this negative effect of the insufficient search flexibility. The central firm can take advantage of its position, which allows it to identify and access the new

technologies held by its surrounding partners (Powell et al., 1996). If those partners possess diverse knowledge, the focal firm is exposed to the diverse scope of knowledge and finds it easier to discover new technologies among them. Put together, a wide scope of new knowledge in an alliance portfolio can boost the positive effect, as well as mitigate the negative effect of the central position on the creation of exploratory innovation.

From another point of view, the central position may affect the influence of new knowledge breadth as well. Prior studies have confirmed that new knowledge breadth helps to provide possible sets of knowledge combinations, however, if the scope of new knowledge exceeds a certain level, it may cause an information overflow problem (Koput, 1997). This leads to a management problem that incurs a cost and effort to identify and assess the value of each combination (Srivastava & Gnyawali, 2011). A centrally located firm, however, may overcome this management problem more easily compared to firms located outside the center. The central position provides the advantage of being able to monitor and control the surrounding partners, so a focal firm can prevent its partners from providing irrelevant knowledge in advance and calibrate the knowledge to meet the focal firm's requirement (Koka & Prescott, 2008). Consequently, this reduces the management problems resulting from the information overflow.

In summary, a wide scope of new knowledge positively influences both the knowledge flow and the search flexibility in a central position. At the same time, the central position can help to solve the management issues which arise from increased new

knowledge breadth. Together, these effects lead to the following hypothesis:

Hypothesis 3: *The new knowledge breadth of the firm's alliance portfolio has positive interaction effects on the relationship between the central position and subsequent exploratory innovation.*

(Graphically, the new knowledge breadth will shift the turning point of the inverted-U shape relationship between the central position and subsequent exploratory innovation to the left-upside direction and flatten its curve.)

4.2.4 Brokering position with partners' wide scope of shared knowledge and exploratory innovation

The interaction effect of the brokering position and the shared knowledge breadth of the alliance portfolio can be seen as the effect of shared knowledge breadth on the brokering position, and vice versa.

The brokering position is advantageous for search flexibility, which is an important factor for a firm to create exploratory innovation. A wide scope of shared knowledge can boost this positive effect of the brokering position's search flexibility on the creation of exploratory innovation. First, a brokering position allows intercepting the information flow among separate groups (Burt, 2004; Rhee, 2004). Therefore, a brokering firm can broaden its search window to recognize and track novel ideas that will lead to

opportunities for innovation. If the separate groups share a wide scope of knowledge with the focal firm, the shared knowledge can help to become more aware of each partner's inside story and provide further information on which knowledge of each firm is most valuable. Consequently, it may help to more easily capture useful knowledge to increase inventive opportunities which lead to exploratory innovation. Second, a brokering firm can increase its possibility of discovering knowledge elements which are from unrelated or distant fields (Zaheer & Bell, 2005). In this situation, if there is a wide scope of shared knowledge among firms in the alliance portfolio, it may help to identify and match useful combinations of different knowledge elements even though they originated from the unfamiliar field. This is because the shared knowledge provides various experiences of trial and error in the R&D experiments and guides to successful inventions which help the creation of exploratory innovation. Overall, a wide scope of shared knowledge further increases the positive relationship between the brokering position and the creation of exploratory innovation.

On the other hand, firms in a brokering position often have a disadvantage in terms of knowledge flow, which requires a certain level of absorptive capacity between knowledge donors and recipients (Cohen & Levinthal, 1990; Easterby-Smith, Lyles, & Tsang, 2008). A firm in a brokering position may be located between different groups, finding it hard to achieve a strong social cohesion and to build communication channels for stable knowledge flow. This non-affiliation results in the brokering firm become isolated from sharing knowledge and experience with its partners, resulting in a lack of absorptive

capacity. Under this condition, if a focal firm shares common knowledge with its alliance partners, it can increase its absorptive capacity, which is essential to understand the partners' knowledge base and to improve communication with each other. Thus, a firm in a brokering position with shared knowledge breadth is likely to perform better in its messenger role and more effectively deliver information and knowledge between different groups. Consequently, a wide scope of shared knowledge in an alliance portfolio can boost the positive effects as well as mitigate the negative effect of the brokering position on the creation of exploratory innovation.

From a different point of view, a brokering position also affects the effect of the shared knowledge breadth. If the scope of knowledge shared by a group is high, the group is likely to become more homogeneous. As the firms from the homogeneous group possess the same way of thinking, the methods of knowledge application become rigid, and the increasing inertia prevents firms from exploring new ideas. It also gives rise to the negative effects of the competency trap, myopia of learning, group think or NIH syndrome (Janis, 1972; Katz & Allen, 1982; Levinthal & March, 1993; Levitt & March, 1988). However, a firm in a brokering position is not likely to belong to a group even though it is sharing a large extent of knowledge with surrounding partners since this position intrinsically enjoys autonomy (Shipilov, 2009). The different groups have a different culture, norms, routines, and ways of doing things, which prevents them from becoming homogeneous. Thus, a firm in a brokering position might not be caught in a rigidity trap which would impede the adoption of new knowledge.

In summary, a wide scope of shared knowledge provides positive effects on both the knowledge flow and the search flexibility in a brokering position. At the same time, the brokering position can prevent firms sharing knowledge with partners from becoming homogeneous which would hinder their creation of exploratory innovation. Together, lead us to the following hypothesis:

Hypothesis 4: *The shared knowledge breadth between the focal firm and its alliance portfolio has positive interaction effects on the relationship between the brokering position and subsequent exploratory innovation.*

(Graphically, the shared knowledge breadth will shift the turning point of the inverted-U shape relationship between the brokering position and subsequent exploratory innovation to the left-upside direction and flatten its curve.)

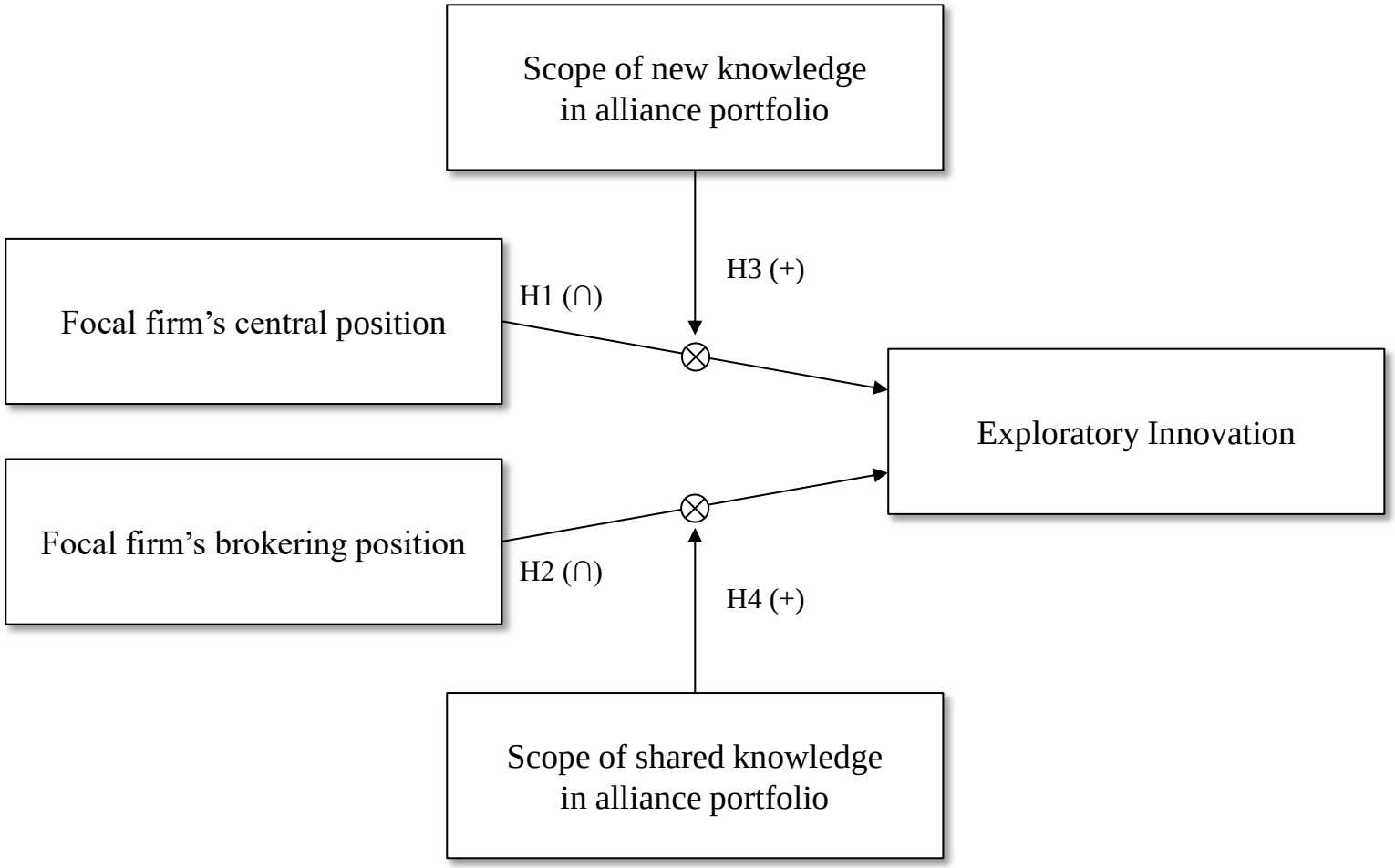


Figure 4-1. Conceptual diagram

4.3 Methods

4.3.1 Data and sample

For the empirical testing of hypotheses, I constructed a panel dataset of 145 international pharmaceutical companies in the bio-pharmaceutical industry (SIC 2833-2836) from 1996-2010. The bio-pharmaceutical industry is selected as a suitable setting for this study for the following reasons: First, it is a high-tech industry in which constant exploratory innovation, e.g., the change from basic chemistry to molecular genetics as the key method for developing new drugs, is critical for firms to gain and defend a competitive advantage (Rothaermel & Deeds, 2004; Rothaermel & Hess, 2007). Second, interfirm R&D alliances are frequently used to share the large cost and risks related to drug development (Grant & Baden-Fuller, 2004; Hagedoorn, 1993). Third, this industry has a high propensity to patent its inventions, which enables us to employ patents to objectively measure their knowledge base and technological expertise (Wuyts & Dutta, 2014).

The dataset is compiled from the Thomson Reuters SDC Platinum, Compustat, and the United States Patent and Trademark Office (USPTO) databases. I have performed several steps to connect the alliance data, financial data, and granted patent data using CUSIP, Fung Institute's firm-patent matching data (Fierro, 2014), and a fuzzy name match. To construct the firms' alliance portfolios, I collected information on all

announced R&D alliance deals conducted by firms in the bio-pharmaceutical industry from 1996-2010 from the Thomson Reuters SDC Platinum database. During these years, the 145 focal firms concluded strategic alliances with 611 different partner firms. The industrial background of partner firms is as follows: 5 firms in the research, development and testing services (SIC 8732, 8733, 8734), 382 firms in the biopharmaceutical services (SIC 2834-2836), 5 firms in the manufacturing of chemicals (SIC 2844, 2899, 2911), 20 firms in the biopharmaceutical and biomedical suppliers (SIC 3841, 3674, 5047, 5049), 65 firms in the commercial research & management services (SIC 8731, 8741, 7839), 2 firms in the distribution & promotion services (SIC 5122, 4226), 5 firms in the medical laboratories & hospitals (SIC 8071), 1 firm in the non-for-profit & government sector (SIC 8641, 8399, 9999), 126 firms in the others (Caner, Bruyaka, & Prescott, 2018).

This information on the alliance deals was used to construct the firms' alliance portfolios and alliance network. Since for most alliances, no information on the termination date is available, I need to assume a typical alliance duration. F. T. Rothaermel (2001) stated that the average duration of alliances in the bio-pharmaceutical industry is more than 3 years. I follow previous literature (Kogut, 1988; Lavie, 2007; Lin et al., 2009) in setting up a 5-year window for including alliance deals into each firm's alliance portfolio. I then shift this 5-year window portfolio by one year at a time and construct ten observation samples from '96-'00 to '05-'09 for each firm.

To identify the knowledge composition, I calculated the knowledge base of each focal firm and the corresponding alliance portfolio using patent data. Using the same 5-year

window, I collected information on the patent classes listed in all patents applied by the focal firm to describe its knowledge base. Similarly, I collected the same information for all the firms in the firm's alliance portfolio for the same observation window. I repeated this process by shifting the 5-year observation window by a year, for a total of ten times. I then used patent data to calculate the focal firms' exploratory innovation and supplemented the dataset with firm-level information such as annual sales, R&D expenses, and the number of employees from the Compustat database. The final panel dataset of this study consists of 145 focal firms and 792 firm-year observations.

4.3.2 Dependent variable

This study focuses on the effects of a firm's network position and alliance partner's knowledge composition on the creation of exploratory innovation. While the literature on exploratory innovation reached a consensus about the concept of exploratory innovation, i.e., explored, advanced, and impactful innovation which is created from knowledge new to the firm's extant stock of knowledge, the measurement of this concept varies among researchers. Wang et al. (2014) operationalized exploratory innovation as the number of patents including at least one technology class that is new to the firm's extant stock of knowledge. Guan and Liu (2016) measured exploratory innovation as the sum of the family size-weighted patents instantiated by at least one technology class new to the focal

organization. Dibiaggio et al. (2014) defined exploratory innovation as any invention that introduces a new technological combination to the firm, i.e., a patent including more than two technology classes that originate from the firm's extant knowledge stock but had not been previously listed in the same patent. In this paper, I define exploratory innovation as an innovation which is created by new to the firm according to the concepts found in previous literature, but add the constraint that the new innovation must have been created under the influence of the firm's external knowledge sourcing, i.e., influenced by the firm's alliance portfolio. Thus, I generalize that a firm pursuing exploratory innovation should seek new knowledge from its alliance partners and make an internal effort to assimilate their knowledge and transform it into the firm's own expertise (Mazloomi Khamseh & Nasiriyar, 2014; S. H. Wen & Chuang, 2010). Consequently, *Exploratory innovation*, the dependent variable of this study, was selected to represent a firm's innovation created from unfamiliar technological fields which are obtained from the firms in the alliance portfolio. It is measured by the number of new patents which include a technology class that was not a part of the focal firm's knowledge base during the preceding five years. The dependent variable is calculated in year t, lagged from the observation window of the independent variables (from year t-5 to t-1) to capture the causal relationship (Guan & Liu, 2016; Wang et al., 2014). To confirm that the creation of a firm's innovation is influenced by the firm's alliance portfolio, I only considered cases in which the technology class listed in a new patent appears in the knowledge base of the alliance portfolio.

4.3.3 Independent variables

The independent variables of this study represent the structural properties associated with the network position and the nodal properties related to knowledge composition. First, the two network position variables are *Central position* and *Brokering position*. Prior studies have employed several centrality measures, e.g., degree centrality, representing the number of actors tied to a focal firm, between centrality representing the extent to which a focal firm lies on paths between other actors, and closeness centrality which is defined by the average distances to all other actors and shows the extent of clustering in a network. In this study, *Central position* indicates the extent of connectedness to the surrounding R&D partners. Consequently, I selected degree centrality as the most suitable measure to capture the concept of the variable (Wang et al., 2014). *Brokering position* refers to a location which can act as a bridge between separate groups. This concept can be captured using the concept of structural holes, which indicates the extent of disconnectedness among actors (Burt, 1992). Following many prior studies, I employ the structural hole measure as a proxy of *Brokering position* (Koka & Prescott, 2008). Both network position variables are calculated based on the alliance network formed by all sample firms and their partners from t-5 to t-1 using UCINET6 (Borgatti, Everett, & Freeman, 2002). By following Burt's measure of structural holes, the ratio of nonredundant contacts to total contacts for the ith firm is computed as

$$\left[\sum_{j}\left[1-\sum_{q} p_{iq} m_{jq}\right]\right] \Big/ C_i$$

where piq is the proportion of i's relations in connection with contact q, mjq is the marginal strength of the relationship between contact j and q, and Ci is the total number of contacts for firm i. The index range is from 0 to 1; the higher value reflects that the firm's ego networks are rich in structural holes. If all of a firm's partners are unconnected to each other, the index takes a value of 1, indicating that none of the firm's contacts are redundant. Similarly, a lower value for this index reflects higher redundancy and fewer structural holes.

The two variables associated with knowledge composition are *New knowledge breadth* and *Shared knowledge breadth*. The measurement of knowledge breadth in prior literature can be categorized into entropy measurement (Schildt et al., 2012; Wu & Shanley, 2009) and the total number of patent classes in which a firm applied for patents (Kotha, Zheng, & George, 2011; J. Zhang & Baden-Fuller, 2010). Each measurement represents a different dimension of knowledge breadth. Entropy measurements are more frequently used and indicate how the knowledge base of a firm is dispersed over diverse patent classes. In other words, they only capture the distribution of the knowledge base. The alternative, i.e., measuring the total number of patent classes allows capturing the absolute amount of dispersion. Accordingly, the latter measurement is more appropriate for this study and allows us to deliver the exact meaning of the framework. *New*

knowledge breadth indicates the scope of new technological knowledge in the alliance portfolio that serves as the focal firm's external knowledge pool. It is measured as the number of technology classes found in the patents granted to the firms in the alliance portfolio, that are not found in the focal firm's knowledge base from year t-5 to t-1. *Shared knowledge breadth* represents the degree of shared knowledge between a focal firm and its partners in the alliance portfolio. Similar to the operationalization of *New knowledge breadth*, it is measured as the number of technology classes which are shared between the focal firm and at least one firm in the alliance portfolio in patents granted from year t-5 to t-1 and captures the degree to which the focal firm and its partners are sharing technological expertise.

4.3.4 Control variables

I controlled for effects from factors associated with the knowledge base, alliance portfolio, and firm which may affect exploratory innovation. First, I controlled for the size and scope of the focal firm's knowledge base which may affect its technological search and innovative capabilities (Henderson & Cockburn, 1994). *Technology classes in knowledge base* refers to the scope of the focal firm's knowledge base, which is measured by the number of the technology classes listed in the patents the firm applied for from year t-5 to t-1. Similarly, *Patent stock in knowledge base* indicates the size of the focal

firm's knowledge base, which is defined as the number of patents the firm applied for from year t-5 to t-1 (Wuyts & Dutta, 2014). Next, I controlled for variations between the sample firms in terms of their alliance experience and configuration of their alliance portfolio (Hoang & Rothaermel, 2005). *Alliance portfolio experience* indicates how many alliances the firm concluded in the past, which can affect the performance outcomes of the alliance portfolio. It is defined as the number of R&D alliance deals conducted by each focal firm as recorded in the SDC platinum database from 1984 to the year t-1. I also include the variable *Ratio of biopharmaceutical firms in alliance portfolio* which indicates the proportion of horizontal alliances which may affect the competitive strength and the distribution of shared knowledge (Lavie, 2007; Wassmer & Dussauge, 2012). It is measured by the number of biopharmaceutical firms divided by the number of all partners in the focal firm's alliance portfolio. I also added *Ratio of marketing(manufacturing) deals in alliance portfolio* because I covered only R&D alliance deals to construct the alliance portfolio, but my dataset includes the multi-functional deals covering marketing and manufacturing activities (Lavie, 2007). In addition, I controlled for the effects of *Firm size*, which might affect the firm's innovation performance due to availability or constraints of resources (Yayavaram & Ahuja, 2008). It is measured as the log-transformed number of employees of the focal firm in the year t-1. The investment in R&D activities is an important source of innovation (Cohen & Levinthal, 1990) and thus has the potential to affect the firm's exploratory innovation outcomes. Consequently, I control for the focal firm's *R&D intensity*, which is defined as the total R&D expenses

divided by the total sales of the focal firm in the year t-1. Finally, year dummy variables are included to control for possible changes of the environment over time.

4.3.5 Empirical model specification

As the dependent variable, *Exploratory innovation*, is a count variable that takes only non-negative integer values, a negative binomial regression model is employed. As the variable's variance is larger than its mean, a negative binomial regression, rather than Poisson regression is used (Long, 1997). Following the result of a Hausman test, I applied a fixed-effect model to my panel data, which assumes a strict heterogeneity, i.e., the unobserved attributes of each entity may not change over time (Hausman, 1978).

To test the interaction effects proposed in Hypotheses 3 and 4, I followed the suggestion by Haans, Pieters, and He (2016). Haans et al. (2016) state that one should be aware of separating a linear benefit and a convex cost curve benefit while testing interaction effects. A turning point shift occurs when interaction effects have a linear benefit, but flattening or steepening occurs when the interaction effects have a convex cost curve benefit. Thus, a test method should be modified in accordance with the author's prediction of the inverted U-shape change. Because both Hypotheses 3 and 4 imply that both a turning point shift and flattening occur, I multiplied the interaction term with both the linear and squared terms of the independent variables.

Table 4-1. Descriptive Statistics and Correlations

(obs=792)	Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Exploratory innovations	1.93	6.49	0	143	1.00											
(2) Technology classes in knowledge base	14.80	15.50	1	108	-0.03	1.00										
(3) Patent stock in knowledge base	647.95	1,148.76	2	7,793	0.01	0.78	1.00									
(4) AP experience	12.60	16.59	1	88	0.02	0.58	0.76	1.00								
(5) Ratio of biopharmaceutical firms in AP	0.82	0.30	0	1	-0.05	-0.12	-0.08	0.00	1.00							
(6) Ratio of marketing deals in AP	0.23	0.34	0	1	-0.03	0.10	0.03	0.00	0.06	1.00						
(7) Ratio of manufacturing deals in AP	0.14	0.30	0	1	-0.03	-0.01	-0.09	-0.14	0.06	0.84	1.00					
(8) Firm size*	-0.65	2.46	-6.91	4.80	0.00	0.67	0.63	0.61	-0.11	0.05	-0.06	1.00				
(9) R&D intensity	418.22	5,128.38	0	109,670	0.05	-0.03	-0.03	-0.05	0.05	-0.02	-0.02	-0.06	1.00			
(10) Central position	3.03	3.26	1	21	0.06	0.50	0.65	0.78	-0.05	-0.02	-0.20	0.51	-0.04	1.00		
(11) Brokering position	0.38	0.35	0	1	0.08	0.33	0.41	0.56	-0.09	-0.06	-0.28	0.46	-0.06	0.73	1.00	
(12) New knowledge breadth	25.35	26.18	0	196	0.15	-0.07	0.03	0.04	-0.02	0.01	-0.02	-0.09	0.04	0.26	0.30	1.00
(13) Shared knowledge breadth	8.48	8.05	0	47	0.02	0.77	0.76	0.67	0.01	0.06	-0.09	0.57	-0.01	0.70	0.51	0.23

* Log-transformed

Table 4-2. Results of the Variance Inflation Factor (VIF) test

Variable	VIF	1/VIF
Technology classes in knowledge base	4.36	0.229
Patent stock in knowledge base	4.33	0.231
AP experience	3.99	0.251
Ratio of biopharmaceutical firms in AP	1.13	0.888
Ratio of marketing deals in AP	4.03	0.248
Ratio of manufacturing deals in AP	4.30	0.233
Firm size*	2.34	0.427
R&D intensity	1.03	0.974
Central position	4.52	0.221
Brokering position	2.65	0.377
New knowledge breadth	1.47	0.679
Shared knowledge breadth	4.65	0.215

Table 4-3. Results of Fixed-Effect Negative Binomial Regression Analysis

	Exploratory innovations				
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Constant	-1.118***	-1.759***	-2.003***	-2.588***	-2.214***
	(0.324)	(0.382)	(0.407)	(0.453)	(0.477)
Control Var.					
Technology classes in knowledge base	-0.022**	-0.022**	-0.022**	-0.021**	-0.020
	(0.010)	(0.010)	(0.011)	(0.011)	(0.014)
Patent stock in knowledge base	2.1E-04	1.9E-04	2.0E-04	1.7E-04	5.1E-05
	(1.5E-04)	(1.5E-04)	(1.5E-04)	(1.5E-04)	(1.5E-04)
AP experience	0.012	-0.007	-0.005	0.005	0.012
	(0.009)	(0.011)	(0.011)	(0.011)	(0.011)
Ratio of biopharmaceutical firms in AP	-0.211	-0.180	-0.218	-0.351	-0.284
	(0.270)	(0.286)	(0.289)	(0.299)	(0.304)
Ratio of marketing deals in AP	0.110	-0.151	-0.282	-0.354	-0.478
	(0.400)	(0.419)	(0.434)	(0.479)	(0.455)
Ratio of manufacturing deals in AP	0.145	0.641	0.867*	0.736	0.835
	(0.468)	(0.493)	(0.524)	(0.578)	(0.551)
Firm size	0.117***	0.096	0.096	0.140**	0.165***
	(0.057)	(0.059)	(0.060)	(0.063)	(0.064)
R&D intensity	9.6E-06	1.1E-05	1.3E-05	1.0E-05	1.3E-05
	(8.9E-06)	(8.9E-06)	(9.0E-06)	(9.0E-06)	(9.0E-06)
Independent Var.					
Central position		0.274***	0.388**	0.514**	0.395*
		(0.074)	(0.187)	(0.224)	(0.233)
Central position^2		-0.009**	-0.012*	-0.023**	-0.026**
		(0.004)	(0.007)	(0.011)	(0.011)
Brokering position			2.403**	1.851*	3.543**
			(1.066)	(1.104)	(1.496)
Brokering position^2			-3.572*	-3.445*	-5.996***
			(2.036)	(2.074)	(2.290)
New knowledge breadth				0.032***	0.041***
				(0.007)	(0.008)
Central position x New knowledge breadth				-0.006**	-0.007**
				(0.003)	(0.003)
Central position^2 x New knowledge breadth				3.7E-04**	4.2E-04**
				(1.8E-04)	(1.9E-04)

	Exploratory innovations				
Variable	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Shared knowledge breadth					-0.099**
					(0.043)
Brokering position x Shared knowledge breadth					-0.122
					(0.168)
Brokering position^2 x Shared knowledge breadth					0.332*
					(0.178)
Year (Dummy)			*~ Included ~*		
Number of observations	792	792	792	792	792
Number of firms	145	145	145	145	145
Log likelihood	-726.816	-718.652	-716.036	-701.280	-693.198
Wald chi2	41.54	58.11	61.44	86.13	106.34
Prob > chi2	0.000	0.000	0.000	0.000	0.000

*p<0.10; **p<0.05; ***p<0.01 Standard errors are in parentheses.

4.4 Results

Table 4-1 presents a summary of the descriptive statistics and correlations among the variables used in the empirical analysis. Some variables show relatively high correlations (higher than 0.6). However, this unavoidable correlations can be explained by the natural relatedness of the variables and was also observed in prior literature (Dibiaggio et al., 2014; Wang et al., 2014; Yayavaram & Ahuja, 2008). A variance inflation factor (VIF) analysis was conducted to check for the existence of a multicollinearity problem. The results of the VIF test show low values (below 10) and indicate that our sample does not suffer from a multicollinearity problem (Kleinbaum et al., 2013; Myers, 1990). Table 4-2 contains the analysis results using negative binomial regression. The effects of the control variables are reflected in Models 1-5. Two control variables show significant results, *Firm size* shows significant results in all models and *Technology classes in knowledge base* shows significant results, not just in Model 5.

Models 2 to 5 test Hypothesis 1, which predicts an inverted U-shape relationship between the level of the central position of the firm in the alliance network and the creation of exploratory innovation. In Models 2-5, the coefficient of the linear term *Central position* is positive and statistically significant while the quadratic term *Central position squared* is negative and significant. Therefore, Hypothesis 1 is supported. In addition, I adopt the procedure by Lind and Mehlum (2010) to properly test for the presence of an inverted U-shape relationship. The result confirms that Hypothesis 1 meets

all three steps (testing of the coefficient of the square term, steep slopes at the extremes of the data range, and the location of the turning point within the data range).

Hypothesis 2 predicted an inverted U-shape relationship between the focal firm's brokering position and the creation of exploratory innovation. In Models 3-5, the coefficient of *Brokering position* is positive and statistically significant while its quadratic term is negative and statistically significant. These results support Hypothesis 2. The results also pass the test suggested by Lind and Mehlum (2010).

In Model 4, I test Hypothesis 3 which predicted a positive moderating effect of new knowledge breadth on the relationship between the focal firm's central position and exploratory innovation. *Central position* x *New knowledge breadth* and *Central position squared* x *New knowledge breadth* are both significant and follow the predicted direction of the effect, thereby confirming Hypothesis 3. This moderation effect of *New knowledge breadth* is plotted in Figure 4-2 and Figure 4-3. The moderation effect of an inverted U-shape relationship results in a turning point shift and/or a flattening or steepening of the curve (Haans et al., 2016). One can see that the curve shifts up-left and its shape flattens. This means that the moderation effect of *New knowledge breadth* increases overall exploratory innovation. In other words, *New knowledge breadth* boosts the positive effects and mitigates the negative effects of *Central position* on the creation of exploratory innovation.

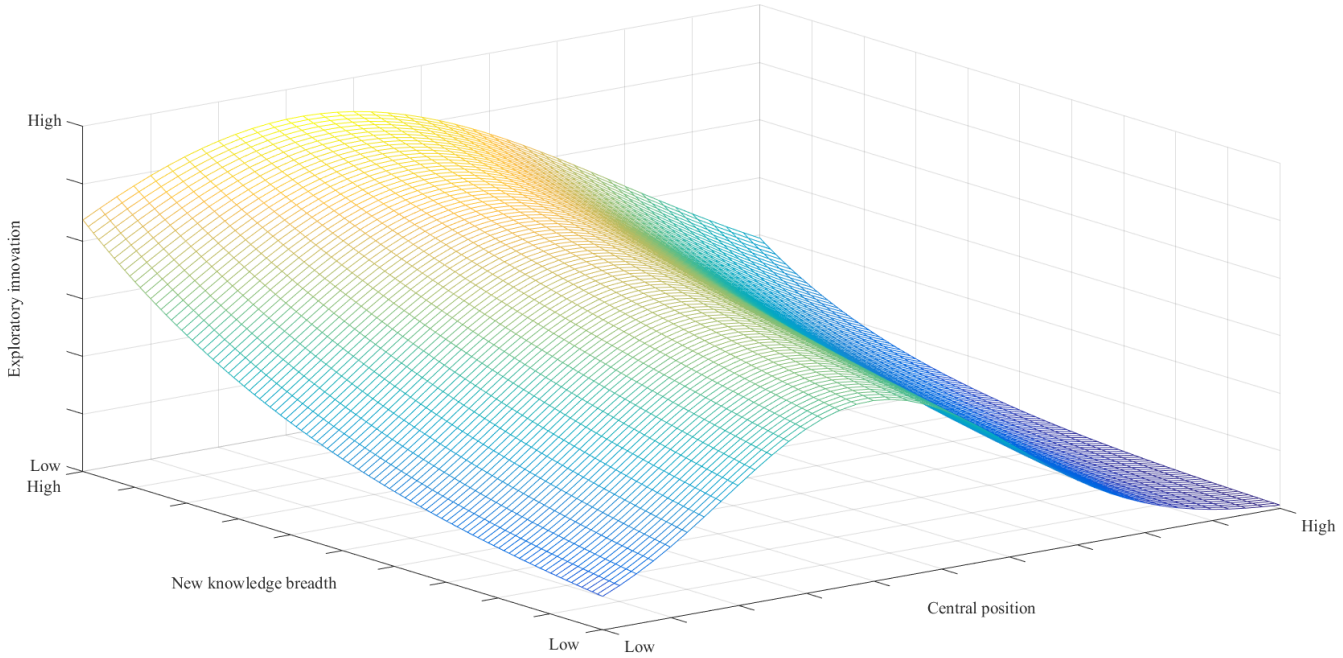


Figure 4-2. The interaction effects of central position and new knowledge breadth on the firm's exploratory innovation (3D)

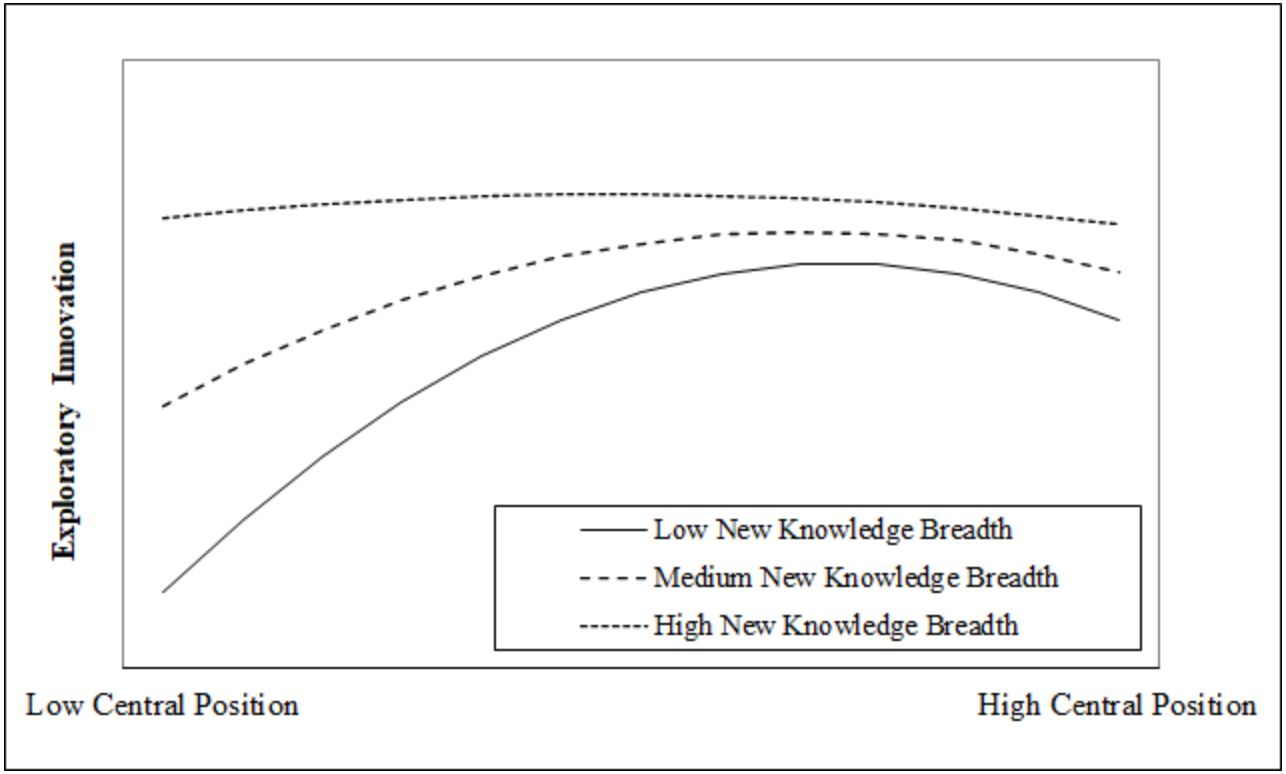


Figure 4-3. The interaction effects of central position and new knowledge breadth on the firm's exploratory innovation (2D)

Model 5 is the full Model and tests Hypothesis 4, which predicted a positive moderating effect of *Shared knowledge breadth* on the relationship between the focal firm's brokering position and exploratory innovation. As can be seen in Table 4-2, the coefficient for *Brokering position* x *Shared knowledge breadth* is statistically insignificant. However, the coefficient for *Brokering position squared* x *Shared knowledge breadth* is positive and significant. Summarizing the results for *Brokering position* x *Shared knowledge breadth* and *Brokering position squared* x *Shared knowledge breadth*, I find statistical support for Hypothesis 4. The moderation effect of *Shared knowledge breadth* is also plotted in Figure 4-4 and Figure 4-5. According to Figure 4-4 and Figure 4-5, the phenomenon of "shape-flip" occurs. This is interesting because "the fundamental nature of the relationship between independent variable and dependent variable now depends on the moderator" (Haans et al., 2016: 1190). In other words, it implies that the effect of the moderator is extremely strong. Theoretically, this can be interpreted as follows: the positive moderating effect of *Shared knowledge breadth* alleviates the negative effect of a high *Brokering position* and rather changes the negative effect to a positive. One should be aware that the inverted U-shape relationship turns into a U-shape relationship as *Shared knowledge breadth* increases. This change results from the negative direct effects of *Shared knowledge breadth*. In other words, a too large scope of shared knowledge, solely, gives rise to overall negative effects on exploratory innovation. Therefore, to exploit the positive effects of shared knowledge breadth, a high brokering position and an appropriate level of shared knowledge breadth are required.

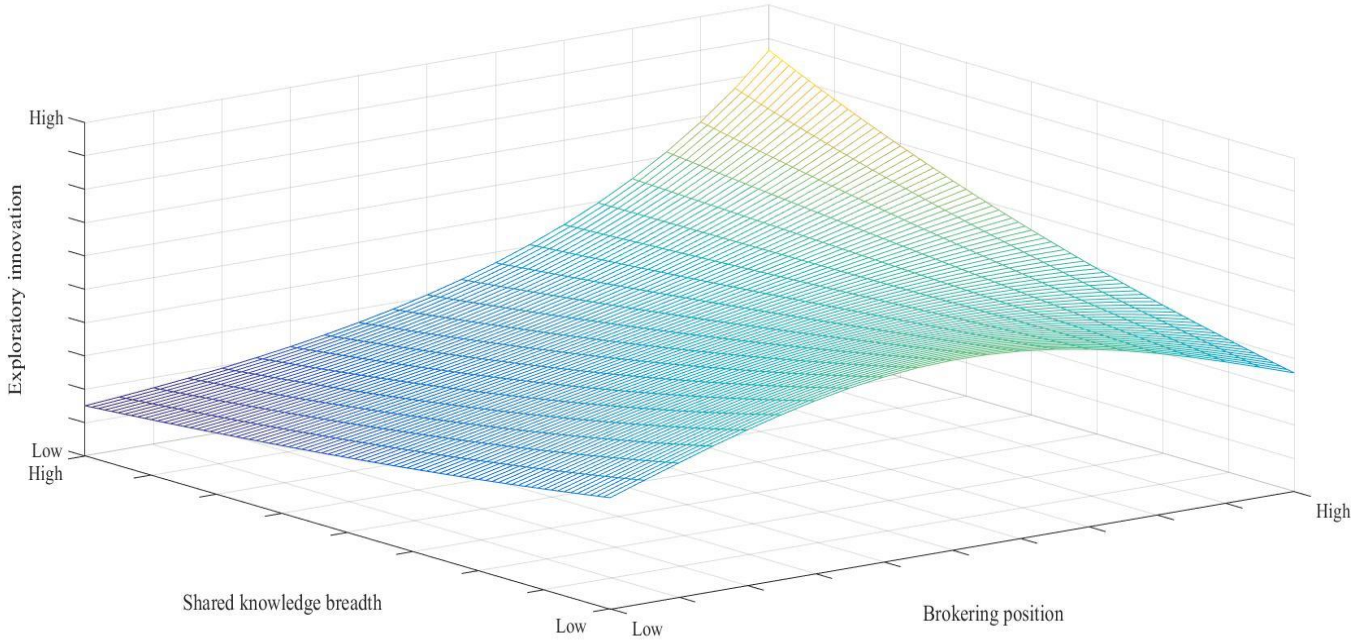


Figure 4-4. The interaction effects of brokering position and shared knowledge breadth on the firm's exploratory innovation (3D)

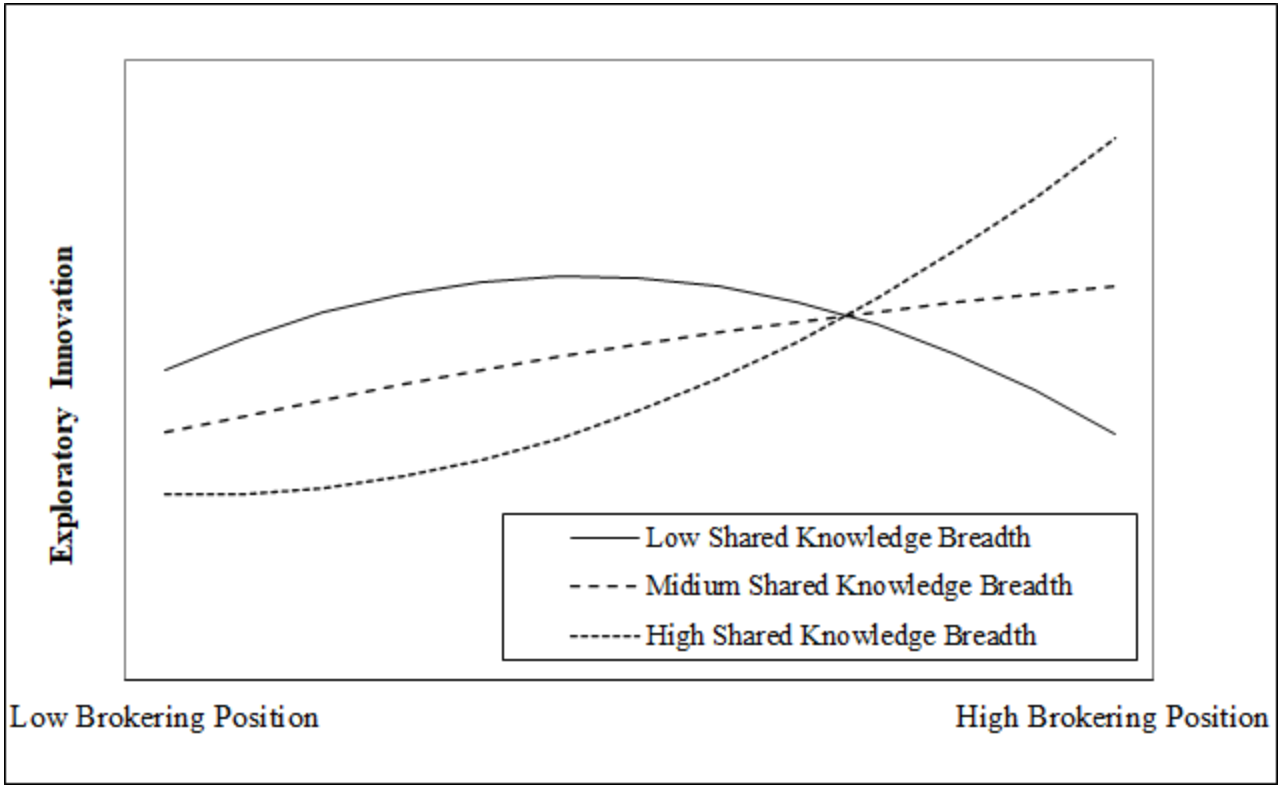


Figure 4-5. The interaction effects of brokering position and shared knowledge breadth on the firm's exploratory innovation (2D)

4.5 Discussion

Prior studies examining alliance portfolios as a source of external knowledge have recognized two key factors affecting the creation of exploratory innovation: First, from the social network theory perspective, they highlighted the role of a firm's network position. Second, from the perspective of the knowledge-based view, they highlighted the role of knowledge resources. These factors influence exploratory innovation individually as well as simultaneously. Consequently, the inclusion of both of these factors in the present study results in a comprehensive view that enables us to investigate also the interaction effects of both network and knowledge factors. In this regard, I first suggested two hypotheses on the individual effect of two characteristics of network position, i.e., central and brokering positions, on exploratory innovation. I then proposed two additional hypotheses which focus on the interaction effects of network position and knowledge composition in an alliance portfolio. The interaction effects focus on the complementary nature of the central position with a wide scope of new knowledge and the brokering position with a wide scope of shared knowledge.

The empirical analysis on a panel dataset of 145 pharmaceutical companies reveals the proposed inverted U-shape relationship between both network positions and the creation of exploratory innovation (Hypotheses 1 and 2). These results confirm that although the effects of a central and a brokering position are different, they influence a firm's exploratory innovation in both positive and negative ways. To explain these

double-sided effects, I propose a new research framework based on two factors, knowledge flow and search flexibility, important for the creation of exploratory innovation. Using this framework, I explain that both network positions positively affect one of the two factors but negatively affect the other factor if their positional effects grow excessively. Specifically, I confirm that a central position promotes smooth knowledge flow with partners due to the focal firm's high social status which allows it to access valuable knowledge from its partners in terms of both quantity and quality. However, beyond a certain level, the central position decreases search flexibility due to the constraint on decision making caused by strong relationships. Findings also clarify that a brokering position fosters search flexibility as it allows the focal firm to control information flows. However, exceeding a certain level, the lack of absorptive capacity negatively influences knowledge flow.

Furthermore, the results of this study confirm that two combinations of network position and knowledge composition in the alliance portfolio lead to positive interaction effects: a central position among partners who possess a diverse scope of technological knowledge, and a brokering position between partners who share a large extent of knowledge with the firm (Hypotheses 3 and 4). These results support my argument that the effects of network position and knowledge composition can complementarily interact with each other, thus potentially compensating the negative effects on either knowledge flow or search flexibility. The outcomes of the analysis also reveal that the interaction effects of the brokering position and shared knowledge breadth even contribute to

changing the negative slope to a positive one beyond a certain level of brokering position. Specifically, the results confirm that new knowledge breadth can contribute to increasing the low search flexibility resulting from the effect of a central position, and the central position allows firms to better deal with the information overflow that is often associated with large increases of new knowledge breadth. The results also confirm that the shared knowledge breadth with partners can increase absorptive capacity, which helps the firms to better understand each other and ultimately increases the knowledge flow that is often insufficient for firms at a brokering position. At the same time, the brokering position can prevent firms from becoming too similar to its partners, which would harm the exploration of new ideas.

Chapter 5. Conclusive remarks

5.1 Contributions and implications

This dissertation makes a number of important contributions. Based on the findings of Chapter 3, this dissertaion provides several theoretical and empirical implications. First, Chapter 3 extends the theoretical background of prior studies by revealing the relationship between knowledge elements and combinations. To this effect, I separated the viewpoint of the firm's knowledge resources into accumulated knowledge elements and combinations, and explored their roles and characteristics respectively. I also applied these two knowledge dimensions to the firm's exploratory innovation, i.e., the creation of new knowledge elements and combinations. This approach allowed us to uncover the inverted U-shape relationship between the level of accumulated architectural knowledge and subsequent knowledge combination. The positive effects of increasing the level of accumulated architectural knowledge diminish when the level becomes so high that path dependency and increasing inertia reduce the ability of the firm to create new knowledge combinations. I also found the mutually supporting relationship between component knowledge and architectural knowledge as they help to create each other in innovation process. These results contribute to the research on the antecedents of (exploratory) innovation. Furthermore, by linking the firm's previously formed knowledge network and

its subsequent innovation, these relationships allowed us to explore the dynamics of a knowledge network in which existing elements and combinations are influencing each other to form new knowledge elements and combinations over time.

Second, my research design suggests a new approach to analyze the process of knowledge accumulation. Although some prior studies have applied the concept of the knowledge network, they fell short of capturing the attributes of accumulation. I expressed the firm's knowledge resources using a weighted network which enables us to capture the levels of knowledge accumulation by examining the strength of ties and the size of nodes. From this approach, I explored the differences of firms' innovation performance depending of the level of accumulated knowledge which can help to understand inter-firm differences within the same industry.

In addition, Chapter 3 suggest the following managerial implications that a firm seeking exploratory innovation should consider the dynamics of its knowledge network, and set up a suitable innovation strategy to take advantage of the relationship between knowledge elements and their combinations. To be specific, if a firm has insufficient technological expertise but many experiences of collaborative research, it is recommended for the firm to establish an external knowledge sourcing strategy to gain new technological elements which enables to utilize the firm's strength of collaborative capabilities. If a firm accumulated technological knowledge resources through its former knowledge sourcing strategies, then it will be helpful to establish a knowledge leveraging strategy to create synergy effects by connecting and collaborating with different

technological fields.

Chapter 4 makes two important theoretical contributions. First, this study extends the literature on alliance portfolios by clearly distinguishing viewpoints from social network theory and the knowledge-based view, which were loosely connected in the prior literature on exploratory innovation. Many prior studies investigated alliance portfolios as a source of external knowledge by focusing on structural properties, such as a firm's network position (Podolny, 2001; Zaheer & Bell, 2005), or by focusing on nodal properties, such as a firm's knowledge base(Srivastava & Gnyawali, 2011; Wuyts & Dutta, 2014). This led to the emergence of two distinct streams of research on alliance portfolios originating from social network theory and the knowledge-based view. However, those viewpoints were applied in a mixture to infer both structural and nodal properties, and each consequence was inconsistent in the extant literature on innovation. I linked those two viewpoints to alliance portfolios' structural/nodal properties, respectively, and opened up opportunities to elucidate each viewpoint's independent and inter-relational effects on exploratory innovation.

Second, this study contributes to innovation literature by proposing ways to overcome the 'search and transfer' trade-off relationship, which has long been a subject in the knowledge-creating relationship. The theoretical basis was presented by proposing two key factors corresponding to the search and transfer problem to better understand the mechanisms of creating exploratory innovation. By analysing the effects of those two key

factors, I claim that potential negative effects from a firm's network position can be overcome under specific conditions through a suitable knowledge composition. Prior studies state that knowledge flow corresponds with strong relationships, while search flexibility is associated with weak relationships. As both knowledge flow and search flexibility are required for exploration, prior studies focused on finding the optimum level of organizational integration (Folta, 1998) or the relevant strategic choice contingent on the firm's situation (Ghosh & John, 2005). However, I reveal that a particular combination between a firm's network position and the knowledge composition of its alliance portfolio can complement both factors' shortcomings, ultimately presenting the possibilities to overcome the search and transfer problem.

In addition, Chapter 4 provides two key managerial implications for firms trying to create exploratory innovation through their alliance portfolios. First, firms in the central position need to find a partner firm with a wide range of heterogeneous knowledge to make good use of the benefits of the central position in creating exploratory innovation. For managers in this situation, efforts to find a partner who expands the breadth of new knowledge in various dimensions, such as different business domains, functions, and attributes, are necessary.

Second, firms in the brokering position need to find a partner firm with a common knowledge base to take advantage of the brokering position that helps exploratory innovation. For managers in this situation, efforts to check whether the partner firm has a denominator to the focal firm in terms of knowledge base, such as business domains and

functions, and to create a common knowledge base to better understand a partner's knowledge are necessary. Those two suggestions are derived from the finding that certain network positions possess advantages and disadvantages in creating exploratory innovation. Those disadvantages can be overcome through the partners' knowledge resources, which helps the firm increase its search flexibility and knowledge flow with its alliance partners. These findings suggest managers care about network position and knowledge composition in configuring their firms' alliance portfolios.

Overall, this dissertation aims to enhance understanding of the mechanism of exploratory innovation by investigating the firm's internal and external factors that promote the creation of exploratory innovation. To this end, I raised questions about what characteristics of the knowledge base inherent in the firm facilitate exploratory innovation and what effective ways to obtain external knowledge among partner firms to create exploratory innovation, and analyzed them separately in chapters 3 and 4. Chapter 3 shows that the firm's knowledge base is established by organizational learning and that knowledge elements and combinations play different roles in creating exploratory innovation. Chapter 4 reveals that effective external knowledge sourcing requires consideration of both access to and value for knowledge resources, and can maximize exploratory innovation through a combination of specific network positions and knowledge compositions. I believe this dissertation meets the purpose of exploring the firm's internal and external knowledge environment that promotes the creation of

exploratory innovation by enhancing academic understanding of the whole process of creating exploratory innovation and suggesting how the firm can boost exploratory innovation performance.

5.2 Limitations and future research

Despite making important contributions, this dissertation has several limitations which provide a set of promising future research opportunities.

Chapter 3, while providing insights into the concept of firm's accumulated knowledge resources, has several limitations. First, this study uses a dataset comprised of firms from the semiconductor industry. While the semiconductor industry has served as the setting for several prior studies (Carnabuci & Operti, 2013; Dibiaggio et al., 2014; Wang et al., 2014; Yayavaram & Ahuja, 2008) on patent-based knowledge networks, and is known for its propensity to patent (Hall & Ziedonis, 2001, 2007), it is also reported that semiconductor companies exhibit very similar knowledge profiles (Patel & Pavitt, 1997). While this provides an interesting research setting to study performance heterogeneities of firms with similar knowledge bases, it might limit the generalization and application of the results to other industries. For these reasons, I expect future research to test my hypotheses using datasets covering a broad range of industries.

Second, this study focused on the nodes and ties of the knowledge network, but could not reflect other complex structural features from a social network perspective. Though I controlled for key variables including degree centrality, density, and number of clusters, additional effects from other network features such as network structure or core-periphery disparities need to be explored. I hope to see follow-up studies take full advantage of the possibilities offered by network analysis.

Third, this study focused on the conditions that facilitate subsequent exploratory innovation from a knowledge perspective, but could not consider the role of managerial intervention. Even though intra-industry firms face similar knowledge conditions, performance heterogeneity may arise due to their unique characteristics of top management team, different strategy establishment and implementation. I expect future studies to account for the impacts of different forms of managerial intervention.

Last, this study makes use of patent data. Patent data suffers from a range of known shortcomings (Kleinknecht, Van Montfort, & Brouwer, 2002; Pavitt, 1985), the effect of some of which could be reduced due to focus on a single industry. Future studies might supplement the patent data with data from other sources or try overcoming its limitations, e.g., by using patent measurements based on received citations to allow for a better distinction of inventions in terms of their usefulness and contribution.

Chapter 4, while providing important contributions and implications on exploratory innovation and alliance portfolio context, has several limitations. First, this study focuses on the bio-pharmaceutical industry to test its hypotheses, which limit the generalization of its results to other industries. Although the bio-pharmaceutical industry has been frequently used to investigate cooperative R&D activities among firms (Hess & Rothaermel, 2011; Hoang & Rothaermel, 2005; Powell et al., 1996), the characteristics of this industrial context may influence the firm's alliance activities and the process of innovation. For this reason, I look forward to seeing future research attempt similar

research using datasets from other industries.

Second, focus on capturing firms' exploratory innovation created from knowledge gained from its alliance partners. However, depending on the research context, different concepts and measures of exploratory innovation can be employed. For example, S. H. Wen and Chuang (2010) categorized exploratory innovation through inter-firm collaboration into two types: learning new knowledge from partners and transforming it to the firm's own knowledge, and "co-exploration" which is creating new knowledge new to both the focal firm and its partners. It is also possible to consider the two distinct types of knowledge, i.e., component knowledge and architectural knowledge, which were mentioned in Chapter 3. In the research setting of chapter 4, I did not consider architectural knowledge as a type of knowledge subject to external knowledge sourcing due to the ambiguity of knowledge origin. Future research can employ such categorizations to capture various dimensions of exploratory innovation.

Third, this study relies on patent data for its measure of exploratory innovation. Following innovation literature, this study defines exploratory innovation as new patents emerging from technological fields new to the focal firm. Patents are a useful tool to make objective observations of the output of a firm's R&D efforts. However, not all innovations are patented wither due to the stringent regulations on what constitutes a patentable innovation or for other reasons. I hope that future research attempts to employ measurements to try and capture non-patented ideas and inventions derived from the knowledge in the alliance portfolio.

Fourth, this study focuses on the positions of an individual firm in the alliance network, not on the entire network's characteristics, e.g., the degree of centrality of the entire alliance network. Different results and implications can be derived if the network's overall characteristics are applied to research from a different level of analysis, i.e., industry-level perspective. For instance, in the case of a (de)centralized network, the effects of centrally located firms with many contacts on innovation and the effects of firms in peripheral parts of the network on innovation are different but present simultaneously. Thus, the degree of (de)centrality of the entire network should reasonably lead to the network's overall innovative efficiency being positively or negatively affected (Cummings & Cross, 2003; Grund, 2012; Krackhardt & Stern, 1988; Sparrowe, Liden, Wayne, & Kraimer, 2001). I hope future researchers apply a different level of analysis to topics I dealt with to open up wider research opportunities.

Fifth, I suggest some other approaches and subjects for conducting more diverse research. Different types of work, for instance, collecting different primary data or conducting a qualitative study, can bring new perspectives and confirm (or not) the findings of this work. In addition, different aspects of network structures, e.g., tie strength (Yang, Zeng, Zhang, & Dai, 2022), network density (Tian, Su, & Yang, 2022), an indirect network effect (G. Zhang, Wang, & Duan, 2020), and phenomena referred to recent innovation research, e.g., innovation readiness (Ojiako, AlRaeesi, Chipulu, Marshall, & Bashir, 2022; Orozco & Grundmann, 2022), level of absorptive capacity (Crescenzi & Gagliardi, 2018; Horvat, Dreher, & Som, 2019; Solís-Molina, Hernández-Espallardo, &

Rodríguez-Orejuela, 2018; Vlačić, Dabić, Daim, & Vlajčić, 2019), knowledge co-creation (Abbate, Codini, & Aquilani, 2019), digitalization (Agostini, Galati, & Gastaldi, 2020; Gobble, 2018; Kraus, Roig-Tierno, & Bouncken, 2019), organizational slack (Hu, Chen, Zhou, Liu, & Qu, 2021), strongly impact the firm's ability to innovate using external knowledge. I hope these possible lines of investigation will be valuable to the other researchers.

Finally, I would suggest that future research can extend the concept of resource combinations by applying a higher perspective. This study focused only on the knowledge combination contained in the patent from a knowledge elements level. However, if future research focuses on the combination of isolated resources within a firm, e.g., human resources, physical resources, knowledge resources, etc, it will be possible to examine the formation of routines that become the firm's capabilities, which is a fundamental concept in organizational theory. If a higher level of analysis is applied rather than staying on patent-based research, it can be reformed as better research on organizational learning and the firm’s capabilities.

In addition, I would like to advise on the discovery of new dependent variables which able to capture the essential meaning of exploratory innovation. At the corporate level, exploratory innovation means ‘finding new ways of doing things’, ‘developing new ways of utilizing existing resources’, and ‘adopting whole new processes’, and so on. If dependent variables that can measure these meanings are developed, meaningful research

can be conducted from a strategic management perspective beyond the knowledge-based view.

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Abstract (Korean)

탐험적 혁신을 촉진하는 기업의 내·외부적 지식요인에 대한 연구

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탐험적 지식을 활용해 가치 있는 것을 만들어내는 탐험적 혁신은 경쟁 우위를 확보하고 지속 가능한 성장을 이룰 수 있는 중요한 방법으로 상당한 관심을 받아왔다. 탐험적 혁신의 중요성이 높아짐에 따라 지식 탐험과 재조합 검색 프레임워크와 같은 혁신의 기본 메커니즘에 대한 관심이 높아지고 있으며 최근에는 이러한 혁신 메커니즘을 바탕으로 탐험적 혁신을 촉진하는데 필요한 기업의 지식 환경에 초점을 맞춘 연구가 등장하고 있다. 그러나 탐험적 혁신에 대한 연구는 아직 초기 단계에 있으며 기업이 탐험적 혁신을 창출하는 전체 과정을 분석하기보다는 개별 주제에 초점을 맞추고 있다. 그런 점에서 이 분야는 좀 더 면밀한 연구를 통해 기존 문헌의 논의를 발전시킬 여지가 있다. 본 논문은 다음 두 가지 핵심 질문을 제시함으로써 탐험적 혁신 메커니즘에 대한 학문적 이해를 높이는 것을 목표로 한다. 첫째, "기업에 내재된 지식 기반의 어떤 특징이 탐험적 혁신을 촉진하는가?"; 기업의 지식 기반은 조직, 시스템, 사람 등에 내재되어 복잡한 형태로 존재하고 시간이 지남에 따

라 변화하기 때문에 단순한 지식 요소의 저장소가 아닌 지식 요소 및 이들의 조합을 포함하는 동적 집합체라고 간주할 필요가 있다. 둘째, "탐험적 혁신을 창출하기 위해 제휴 파트너 기업들 사이에서 그들이 가진 지식을 얻는 효과적인 방법은 무엇인가?"; 탐험적 혁신을 촉진하기 위해 외부 지식 환경을 고려할 때, 외부 지식 자원의 구성뿐 아니라 외부 지식 자원의 접근성과 전유성에 영향을 미치는 기업 간 네트워크의 구조적 요인도 이해할 필요가 있다.

내부적 관점에서, 탐험적 혁신에 대한 기존 연구는 기업의 내부 지식 기반을 주로 단순한 지식 요소의 저장소로 조사하고 설명하는 데 초점을 맞추었으며 최근에서야 지식 요소의 구조적 특성을 조사하기 위한 연구가 시작되었다. 이와 관련하여 본 논문은 기업의 내부 지식 네트워크가 탐험적 혁신에 미치는 영향을 살펴본다. 제3장은 기업의 지식 기반을 요소 지식(=component knowledge)과 이들의 조합(구조 지식=architectural knowledge)으로 구성된 네트워크로 표현하고 이러한 지식 네트워크가 시간에 따라 어떻게 변화해 가는지 조사하기 위한 이론적 프레임워크를 제안한다. 구체적으로, 제3장에서는 축적된 요소 지식 및 구조 지식을 구별하고, 이로 인해 발생하는 탐험적 혁신, 즉 새로운 요소 지식 및 새로운 구조 지식(요소 지식간 새로운 조합)에 미치는 영향을 조사한다. 두 가지 유형의 축적된 지식과 두 가지 유형의 탐험적 혁신 사이의 드러나지 않은 관계는 회사의 지식 네트워크의 동적 특성을 이해하는 데 도움이 된다. 제3장에서는 2000~2010년 미국 111개 반도체 기업의 특허자료를 이용하여 축적된 구조 지식의 수준과

그에 따른 새로운 구조 지식 간의 역 U자형 관계를 실증적으로 검증한다. 기업이 지식 결합 경험을 축적함에 따라 새로운 지식 적용 방법을 발견하며, 이렇게 축적된 구조 지식은 조직 학습 및 지식 적용 가능성을 확장하여 탐험적 혁신(구조 지식의 발생)을 촉진한다. 그러나 구조 지식이 축적될수록 조직 학습의 경로 의존적 속성에 따른 경직된 관성이 생기게 되고 새로운 지식 응용 방법을 모색하는 것이 어렵게 된다. 한편으로, 축적된 요소 지식과 새로운 구조 지식, 그리고 축적된 구조 지식과 새로운 요소 지식 간의 관계는 양(+)의 방향으로 나타났다. 이는 요소 지식 축적이 새로운 지식 조합(구조 지식)을 만드는 데 필수적일 수 있으며, 구조 지식 축적이 새로운 요소 지식을 형성하는 데 도움이 된다는 것을 말해준다. 즉, 새로운 발명(지식 요소의 결합)을 하기 위해서는 개별 지식 요소에 대한 학습이 선행되어야 하며, 반대로 새로운 요소 지식을 획득함으로써 기업의 전문 영역을 확장하려면 다양한 요소 지식 결합 경험이 중요하다는 결과를 도출하였다. 이 결과는 기업이 축적한 지식 자원이 탐험적 혁신 창출에 미치는 영향을 강조하고 기존 탐험적 혁신에 대한 문헌 연구에 기여한다.

외부적 관점에서는, 어떻게 포컬 기업이 탐험적 혁신을 창출하기 위해 제휴 포트폴리오에서 필요한 지식을 효과적으로 발굴하고 확보할 수 있는지 조사한다. 기존 문헌은 탐험적 혁신을 위한 외부 지식 환경을 설명하기 위해 주로 지식 자원의 구성 또는 지식 자원 접근에 영향을 미치는 구조적 요인에 초점을 맞추어 조사하였다. 통합적 접근방식을 위해, 제4장은 기업의 네트워

크 위치와 제휴 포트폴리오의 지식 구성 영향을 동시에 조사하기 위해 탐험적 혁신에 필수적인 두 가지 요소, 즉, 지식 흐름(knowledge flow)과 검색 유연성(search flexibility) 프레임워크를 제안한다. 제4장은 이러한 틀을 이용하여 1996~2010년 142개 제약회사의 패널 자료를 통해 중심 위치 및 중개 위치가 탐험적 혁신의 창출과 역 U자형 관계를 맺고 있음을 실증적으로 확인한다. 중심 위치는 높은 사회적 지위로 인해 원활한 지식 흐름을 촉진하여 파트너로부터 귀중한 지식을 접할 수 있도록 돕는다. 그러나 일정한 수준을 넘어서면 중심 위치는 강한 관계에서 발생하는 의사 결정 제약으로 인해 검색 유연성을 떨어뜨린다. 중개 위치는 포컬 기업이 정보 흐름을 제어할 수 있도록 하기 때문에 검색 유연성을 높인다. 그러나 일정 수준을 넘어서는 경우 흡수능력 부족으로 지식 흐름에 부정적인 영향을 미치게 된다. 제4장에서는 또한 탐험적 혁신을 증가시키는데 유리한 네트워크 위치와 지식 구성의 두 가지 조합, 즉 중심 위치와 넓은 범위의 새로운 지식을 보유한 파트너, 중개 위치와 넓은 범위의 공유 지식을 보유한 파트너 사이의 관계를 검증한다. 이러한 결과는 네트워크 위치와 지식 구성의 영향이 상호 보완적으로 상호 작용하여 지식 흐름 또는 검색 유연성에 대한 부정적인 영향을 잠재적으로 보상할 수 있다는 주장을 뒷받침한다. 넓은 범위의 새로운 지식은 중심 위치에서 기인하는 낮은 검색 유연성을 증가시킬 수 있다. 중심 위치의 구조적 장점을 이용해 포컬 기업은 새로운 지식의 범위가 증가할 때 발생할 수 있는 정보의 범람을 극복할 수 있다. 파트너와 넓은 범위의 지식을 공유할 경우 상대적인 흡수 능력을 증가시켜 기업이 서로를 이해하는 데 도움이 되고 중개 위치에 있는 기

업에게 종종 부족한 지식 흐름을 증가시킨다. 동시에, 중개 위치는 포컬 기업이 파트너들과 너무 비슷해지는 것을 막아줌으로써 새로운 아이디어 탐구에 미칠 수 있는 부정적 영향을 줄인다. 이러한 결과로부터, 제4장은 소셜 네트워크 이론과 지식 기반 관점의 상호작용 효과를 확인함으로써 기존 문헌 연구에 기여하고 기업의 제휴 전략 설계에 대한 시사점을 제시한다.

종합하면, 본 논문은 탐험적 혁신 창출에 영향을 미치는 기업의 대내외적 지식 요인을 조사함으로써 탐험적 혁신 메커니즘에 대한 이해를 높이고 다음과 같은 시사점을 도출한다. 첫째, 본 논문은 제3장의 연구결과를 바탕으로 지식 요소와 지식 결합의 관계를 밝히고 혁신의 원천으로서의 지식 자원에 대한 기존 문헌을 확장한다. 헨더슨과 클라크(1990)의 프레임워크를 적용하면, 회사의 지식 네트워크와 탐험적 혁신은 축적된 요소 지식 및 구조 지식과 새로 발생하는 요소 지식 및 구조 지식으로 묘사될 수 있다. 이러한 관계를 통해 형성된 기업의 지식 네트워크와 혁신 창출을 연계함으로써 시간이 지남에 따라 기존 요소 지식과 구조 지식이 서로 영향을 미쳐 새로운 요소 지식 및 구조 지식을 형성하는 지식 네트워크의 동적 특성을 탐색할 수 있었다. 둘째, 본 논문은 제4장의 연구결과를 바탕으로 소셜 네트워크 이론과 지식기반 관점을 동시에 적용하여 제휴 포트폴리오에 대한 기존 문헌을 확장한다. 많은 선행 연구는 행위자의 네트워크 위치와 같은 구조적 특성에 초점을 맞추거나 행위자의 지식 자원과 같은 노드적 특성에 초점을 맞추어 제휴 포트폴리오 특성을 조사하였다. 그러나 제휴 포트폴리오에서 네트워크 위치와 지식 구성 간

상호 관계에 대한 연구는 제한적이었다. 본 연구는 이러한 상호 관계를 초점을 맞추고, 특정 조건 하에서는 기업의 네트워크 위치에서 비롯되는 부정적 영향을 적절한 파트너의 지식 구성을 통해 극복할 수 있음을 시사한다. 셋째, 본 논문은 탐험적 혁신 창출을 위한 두 가지 핵심 요소, 지식 흐름과 검색 유연성을 만족시켜야 한다는 새로운 논의를 제안함으로써 기존 혁신 문헌연구에 기여한다. 이전 연구에서 지식 흐름은 강한 관계에서 발현하기 쉽고 검색 유연성은 약한 관계에 비롯된다고 말한다. 탐험적 혁신을 위해서는 지식 흐름과 검색 유연성이 모두 요구되기 때문에 선행연구는 최적의 조직통합 수준이나 적절한 전략적 선택을 찾는 데 초점을 맞췄다. 그러나 본 논문은 제휴 포트폴리오에서 포컬 기업의 네트워크 위치와 파트너 지식 구성 간 특정 조합이 두 요소의 단점을 보완하여 궁극적으로 두 가지 핵심 요소를 동시에 만족시킬 수 있음을 밝힌다.

주요어 : 탐험적 혁신, 지식 네트워크, 요소 지식, 구조 지식, 제휴 포트폴리오, 네트워크 위치, 지식 구성

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