Helsinki University of Technology
Institute of Strategy and International Business

Doctoral Dissertation Series 2006/4
Espoo 2006

Organizational Networks and Technological Change

Henri Schildt

Dissertation for the degree of Doctor in Science and Technology to be presented due permission of the Department of Industrial Engineering and Management for public examination and debate in Auditorium TU1 at Helsinki University of Technology (Epoo, Finland) on the 9th of December 2006 at 12.00.

Helsinki University of Technology

Department of Industrial Engineering and Management

Institute of Strategy and International Business

Teknillinen korkeakoulu

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Internet http://www.tuta.hut.fi/isib

ISBN 13 978-951-22-8500-6 (print)
ISBN 10 951-22-8500-2 (print)

ISBN 13 978-951-22-8501-3 (online)
ISBN 10 951-22-8501-0 (online)

ISSN 1459-7993 (print)
ISSN 1795-1453 (online)

http://lib.tkk.fi/Diss/2000/isbn9512285010/

The series deals with current issues in business strategy, technology management, marketing, and international business.

The cover picture "*States of Mind I: The Farewells*" (1911) is by Umberto Boccioni (Italian, 1882-1916). I am grateful for Mark Harden (www.artchive.com) for the digital scan.

Monikko

Espoo 2006

Abstract

Strategic networks and other external relationships of firms have become an eminent topic in strategic management. External relationships have been argued to provide firms knowledge and thereby foster inventiveness. This dissertation addresses the influence of organizational networks and pre-existing knowledge base on technological change in business firms through five publications describing independent empirical studies. This dissertation contributes to theory by developing and testing hypothesis that relate characteristics of network relationship to quantity, type, and timing of inventions.

The first research paper examines the creation of explorative and exploitative inventions from knowledge obtained through external relationship. The results support the predictions that tight integration, technological relatedness, and partner in customer industries decrease the likelihood of explorative outcomes. The findings are based on a logistic regression analysis of a longitudinal dataset, consisting of 110 largest U.S. public ICT companies and their external corporate ventures and patents.

The second paper investigates the timing of inventions in external relationships. A novel research setting shows that the industry-relatedness and form of external relationships influences the timing of inventions. Most importantly, high research and development spending enables the firm to exploit partner's knowledge more rapidly. Results are based on a data set derived from the first study and analyzed using a longitudinal negative binomial regression model.

The third paper links firms' external relationships to their rate of innovative output. The findings show systematic differences in the benefits accruing from different forms of relationship and levels of relatedness. Most importantly, partners in related industries provided greater benefits than intra-industry and unrelated partners. The analysis is based on negative binomial panel model and utilizes data derived from the first two studies.

The fourth paper examines the role of intra-industry social networks and technological specialization on the tendency to utilize proprietary knowledge as a basis for future inventions. Social centrality is associated with increased tendency for re-use of prior own knowledge in peripheral technological areas, while decreasing knowledge re-use in central technological areas. Inventions in more central technological areas are re-used more commonly. Contrary to earlier findings, I do not find a significant relationship between innovation team social centrality and the subsequent impact of the invention. The analysis is based on 450 innovation reports and related patents of a corporate R&D center. I use Tobit, linear, and negative binomial regression models.

The last paper applies the literature on local search to explain the choice of acquisition targets. As expected, the proximity of two companies in terms of alliances, country co-location, and technological similarity is associated with higher acquisition likelihood. However, these search contexts moderate one-other: companies tend to acquire technologically similar foreign firms and technologically dissimilar alliance partners. The analysis is conducted using on rare events logistic regression models with a dyadic longitudinal dataset based on 167 acquisitions in the global pharmaceuticals industry.

Tiivistelmä

Väitöskirjani koostuu viidestä erillisestä julkaisusta. Väitöskirjassani tarkastellaan yritysten ulkoisten ja sisäisten verkostojen vaikutusta yritysten teknologisen kehitystoiminnan ja yritysostokäyttäytymisen kannalta. Väitöstutkimus perustuu tilastollisiin analyyseihin kolmessa eri tutkimusasetelmassa. Kokonaisuudessaan tutkimukseni avaa yritysten ulkoisten suhteiden merkitystä organisaatioiden hakuprosessien ja muutoksen näkökulmasta.

Ensimmäinen artikkeli tarkastelee ulkoisista suhteista saatuja hyötyjä teknologian kehityksessä. Erittelen yhteistyön tuloksena kehitetyn teknologian yrityksen tietoa hyödyntäviin ja kokeileviin keksintöihin. Tutkimuksessa käytetään laajaa tietokantaa 110 suurimman amerikkalaisen tietotekniikka- ja tietoliikenneteollisuuden yrityksen ulkoisista suhteista sisältäen allianssit, yhteisyritykset, yritysostot ja pääomasijoitukset. Tutkimustulokset osoittavat, että tiivis suhde, teknologinen läheisyys ja kumppanin sijaitseminen yrityksen asiakastoimialalla lisäävät aiempaa tietoa hyödyntävien keksintöjen syntyä suhteessa kokeilevampiin keksintöihin.

Toinen julkaisu tarkastelee ulkoisista suhteista saadun tiedon hyödyntämistä eri ajankohtina. Tutkimus erittelee tekijöitä, jotka vaikuttavat tiedon siirtoon yhteistyön eri vaiheissa. Tulokset osoittavat, että erityisesti korkeat tutkimus- ja tuotekehityspanostukset nopeuttavat oppimista suhteiden alkuvaiheessa, mutta suhteellinen hyöty vähenee ajan myötä. Lisäksi sama toimiala ja yhteistyösuhteen tyyppi vaikuttavat merkittävästi oppimishyötyjen ajoitukseen.

Kolmas julkaisu tutkii yritysostojen, allianssien, yhteisyritysten ja pääomasijoitusten vaikutusta yrityksen teknisten keksintöjen määrään. Tulosten mukaan läheisillä toimialoilla toimivat yhteistyökumppanit lisäävät merkittävästi teknologisten keksintöjen määrää. Samalla tai hyvin erilaisella toimialalla toimivat kumppanit eivät tulosten mukaan vaikuta yritysten kehitystoimintaan. Yritysostoissa puolestaan suurimmat hyödyt teknologian kehittämisen näkökulmasta saadaan kun kohde toimii samalla toimialalla.

Neljäs julkaisu tarkastelee sosiaalisten verkostojen ja teknologisen alueen merkitystä tutkimus- ja kehitystoiminnalle eräässä teollisessa tutkimusyksikössä. Tulokset osoittavat, että ryhmän sosiaalinen ja teknologinen keskeisyys lisää sen todennäköisyyttä hyödyntää yrityksen aiempia keksintöjä ulkopuolisen tiedon sijaan. Tutkimuksen perusteella suurin vaikutus yrityksen myöhempään kehitystoimintaan oli niillä keksinnöillä, joissa yhdistettiin sekä aiempi yrityksessä kehitetty tieto että yrityksen ulkopuolisten tahojen keksinnöt.

Viimeisessä artikkelissa tutkitaan yritysostokäyttäytymistä rajallisen informaation näkökulmasta. Rajallinen kyky tunnistaa ja arvioida yritysostokohteita saa aikaan ostojen keskittymisen läheisiin ja samankaltaisiin yrityksiin. Tilastollinen analyysi osoittaa, että yritysostot ovat erityisen todennäköisiä yritysten välillä, jotka toimivat samassa maassa, muistuttavat teknologisesti toisiaan tai ovat yhteistyökumppaneita. Nämä tekijät kuitenkin vähentävät toistensa vaikutusta siten, että yritykset ostavat pääosin teknologisesti erilaisia kotimaisia yrityksiä ja ulkomaalaisia yhteistyökumppaneita.

Acknowledgements

I am grateful to my colleagues and friends who made the process of writing dissertation so enjoyable, all in their own idiosyncratic way.

First, I would like to thank people who most concretely helped me during this project. These are the co-authors in the publications included in this dissertation. Professor Tomi Laamanen, the supervisor of my dissertation, went through great pains to comment my texts and largely taught me how to write scientific articles. Professor Markku Maula, who was my instructor, played a crucial role throughout the dissertation process. Markku originally recruited me to the project in which I made the dissertation, effectively securing financing for my endeavor. Even more importantly, Markku was invaluable help with methodological choices. The project Markku had organized also provided much of the data utilized in this dissertation. Thomas Keil has been a vital resource in the three papers I have co-authored with him. His excellent knowledge of corporate entrepreneurship has been valuable in the development of the papers.

I am indebted to my preliminary examiners, Professors Juha Laurila and Theresa Lant. Their insightful comments were useful in further improving the dissertation.

During the doctoral studies, I have been able to collaborate on other research projects and papers with a number of different people. These people include fellow doctoral students: Mikko Jääskeläinen, Juha Mattsson, and Doctor Antti Sillanpää. They also include several professors: Juha-Antti Lamberg, Saku Mantere, Shaker Zahra, and Raghu Garud. Moreover, I have had fascinating discussions with a number of fellow researchers at the Helsinki University of Technology, including e.g. Professor Annaleena Parhankangas, Doctors Jan Feller and Satu Teerikangas, as well as doctoral students Riikka-Leena Leskelä, Anna Ahola and Juha Uotila. I am indebted for Doctor Jukka-Pekka Salmenkaita for providing majority of the data I utilized in Appendix 5.

I feel the Institute of Strategy and International Business has been the perfect place for me to write my dissertation in. Many thanks go to the head of the institute, Professor Hannele Wallenius. The ever-helpful administration, Maria Tikka and Nina Henriksson also deserve my gratefulness.

Financial support is crucial for a project like this. Tekes and the Academy of Finland have provided project funding. I was fortunate to receive a salary while doing what I wanted to do. Additionally, a personal grant from Liikesivistyssäätiö has enabled me to travel to a number of conferences.

Finally, I doubt this book would have finished without the encouragement of my parents, Leena and Jaakko Schildt. The support Sini Jämsén provided during the four years of my doctoral studies was beyond significant.

Helsinki, November 2006

Henri Schildt

Table of contents

"There is no man," he began, "however wise, who has not at some period of his youth said things, or lived in a way the consciousness of which is so unpleasant to him in later life that he would gladly, if he could, expunge it from his memory. And yet he ought not entirely to regret it, because he cannot be certain that he has indeed become a wise man—so far as it is possible for any of us to be wise—unless he has passed through all the fatuous or unwholesome incarnations by which that ultimate stage must be preceded. I know that there are young fellows, the sons and grandsons of famous men, whose masters have instilled into them nobility of mind and moral refinement in their schooldays. They have, perhaps, when they look back upon their past lives, nothing to retract; they can, if they choose, publish a signed account of everything they have ever said or done; but they are poor creatures, feeble descendants of doctrinaires, and their wisdom is negative and sterile. We are not provided with wisdom, we must discover it for ourselves, after a journey through the wilderness which no one else can take for us, an effort which no one can spare us, for our wisdom is the point of view from which we come at last to regard the world.

Marcel Proust, 1919. Remembrance of Things Past, Vol. 2: Within a Budding Grove. Translated from the French by C. K. Scott Moncrieff in 1924.

INTRODUCTION TO THE DISSERTATION

1 BACKGROUND

Organizations evolve through gradual adjustments of existing routines, serendipitous innovation, and problem-driven search in response to performance problems (Cohen & Levinthal, 1994; Cyert & March, 1963/1992; Gavetti & Levinthal, 2000; Nelson & Winter, 1982). Strategic decisions driving organizational changes are commonly bounded by the existing repertoire of organizational routines (Nelson & Winter, 1982; Winter, 2006) and severely limited by imperfect knowledge regarding the attractiveness of alternative postures (March & Simon, 1958/1993). Given the inherent limits to managerial foresight, we need to investigate how new alternative patterns of organizing come about (Levinthal, 2005).

Researchers have suggested that although organizational capabilities commonly evolve through gradual variations in existing operations (Feldman & Pentland, 2003), companies create new capabilities also by innovating – recombining existing knowledge in a novel way (Nelson and Winter 1982). The benefit of recombination is that the result is non-incremental yet conservative variation (Levinthal, 2006). In order to gain insight into the processes leading to the creation of new organizational capabilities, it is useful to focus on a subset of capabilities. In this dissertation, I chose to focus on technological capabilities. Technology forms a particularly suitable part of operations to study, since technological inventions have economic importance and they are empirically tractable (Cattani, 2006; Podolny, Stuart, & Hannan, 1996).

The ability to innovate hinges greatly on access to new knowledge that can be recombined usefully. A large body of research has suggested that the access to knowledge and thus the ability to innovate can derive from informal social networks (Aiken, Bacharach, & French, 1980; Allen, 1977; Burt, 2004) and inter-firm relationships (Dodgson, 1993; Hargadon & Sutton, 1997; Powell, Koput, & SmithDoerr, 1996). Recent studies suggest that inter-firm networks increase the novelty of inventions relative to existing knowledge-base of the firm (Rosenkopf & Almeida, 2003). Prior literature has examined the quantitative outcomes of inter-firm relationships on innovative output (Ahuja, 2000; Ahuja & Katila, 2001; Stuart, 2000)

Despite the breadth of research on organizational networks, there is considerable room for more research on the dynamics of technological evolution. Specifically,

comparative effects of alternative forms of inter-firm relationships have not been thoroughly investigated, nor has the earlier research fully attended to factors that influence novelty and timing of knowledge flows within relationships. The first three studies of this dissertation examine how inter-organizational network relations together with pre-existing technological knowledge-base influence technological change within the firm in terms of the novelty (Appendix 1), timing (Appendix 2), and volume (Appendix 3) of technological invention. The two subsequent studies extend my investigation of organizational evolution to the effects intra-organizational networks have on technology development (Appendix 4) and to the effects of inter-organizational relations on the choice of acquisitions targets (Appendix 5).

Together, the findings of this dissertation provide support for the proposition that technological evolution, though exhibiting local search behavior, is importantly influenced by networks. The rate and type of changes in technological capabilities depend on the number and characteristics of a firm's inter-organizational relationships (Stuart & Podolny, 1996). The studies reported here illuminate how strategic actions, such as alliances and acquisitions, influence technological search, and how managerial search for acquisition targets is influenced by inter-organizational networks, contributing to our knowledge of these empirical relationships. In general, the studies suggest a view of network ties as metaphorical "bridges" through technological and managerial cognitive search spaces. This notion contributes an improved theoretical understanding of relationships between a firm's network ties and its innovative activities.

Research on the development of new technological inventions sheds light to dynamics of organizational evolution more generally. Specifically, the model of recombinant search processes (Fleming & Sorenson, 2001) is complementary to the contemporary models of evolution through optimizing search processes (Gavetti, 2005; Levinthal, 1997). In this introductory chapter I propose that a more accurate concept of organizational evolution could be reached by integrating the models of recombinatory and optimizing search into a system of intertwined search processes.

2 RESEARCH QUESTIONS

As the overarching question, my dissertation examines how pre-existing technological capabilities and organizational networks influence the search for technological and managerial solutions in firms. The research question is motivated by the view of firms as bounded rational entities (March & Simon, 1958/1993), which tend to solve problems by drawing on their pre-existing capabilities while creating new capabilities that are predominantly similar to those already possessed (Nelson & Winter, 1982). Prior research suggests that networks may mitigate both tendencies. Social and inter-firm networks allow vicarious learning of new decision alternatives and enable the creation of technological capabilities required to pursue new alternatives (Ahuja, 2000; Allen, 1977; Hansen, 1999; Stuart, 2000).

The main empirical domain of the dissertation lies within the intersection of new technological inventions and inter-firm networks (see Figure 1). Within this domain, I examine how relationships and firm characteristics influence the ability of companies to rapidly create novel technological inventions. Although inventions in general could be seen as path-breaking or boundary-spanning, some inventions are more 'local' than others (Rosenkopf & Nerkar, 2001). I attend specifically the conditions that influence the novelty of firms' technological inventions. I extend the focus from inter-organizational networks and technological solutions to the dynamics of invention and local search related to inter-personal networks within a single organization and the effects of inter-firm alliances on managerial search processes related to the choice of acquisition targets.

External relationships are commonplace, and take many forms. Examples from the telecommunication industry include a high-profile joint venture between Ericsson and Sony, Nokia's acquisition of Symbian, a company that had developed an operating system for mobile phones, investments by Nokia Venture Partners to mobile start-ups such as Riot-E, and alliances across mobile phone companies in the area of 3G standards. Arguably, all of these relationships have the potential to facilitate knowledge exchange and creation.

A considerable stream of research on the effects of inter-firm networks on technological innovation exists. These studies focus mainly on explaining patent rates (Ahuja, 2000; Ahuja & Katila, 2001; Stuart, 2000) and knowledge diffusion (Mowery, Oxley, & Silverman, 1996; Stuart & Podolny, 1996). This dissertation builds on and

extends the existing research by focusing on the effects external relations have on technological search. The research questions addressed here are as follows:

Q1: How do external relationship characteristics influence the tendency for explorative or exploitative learning outcomes?

Complementing earlier studies with focus on the level of innovativeness, this question addresses on the type of learning outcomes accomplished through external relationships. The topic is important, as novel technological inventions can help companies renew their knowledge-base. Moreover, there is no prior quantitative research on how different relationship characteristics relate to the novelty of technological inventions.

Q2: How do the characteristics of the focal firm and its partner influence the time required for the company to develop new inventions?

This question addresses the issue of time in organizational learning. In part this question answers recent calls for researchers to better specify and explain the timing of events (Mitchell & James, 2001). While literature has paid great attention to firm-level ability to absorb and exploit of knowledge from external relationships (Zahra & George, 2002) and scholars have investigated the average time required for benefits to materialize from external relationships (Ahuja & Katila, 2001), there is no systematic research on the factors that influence the time required. This question has particularly high practical relevance as rapid changes in external environment force firms to create new technological capabilities rapidly to address strategic opportunities perceived by the management (Teece, Pisano, & Shuen, 1997; Volberda, 1996).

Q3: How do various forms of external relationships and the relatedness of partner companies influence the overall magnitude of invention in firms?

Learning is an important motivation for alliances, acquisitions, and other external relationships. Also, prior research has found external relations to increase firm innovativeness (Ahuja, 2000; Ahuja & Katila, 2001; Dushnitsky & Lenox, 2005; Stuart, 2000). This question complements the existing studies by accounting simultaneously for the complete portfolio of external ties, as well as providing evidence on the relative benefits of alternative forms for relationships.

In order to complement the research questions related to inter-organizational networks, I investigate how intra-organizational networks influence the novelty and impact of technological inventions.

Q4: How do intra-organizational technological and social networks influence the path-dependent development of new technologies?

This question complements the knowledge on technological search processes by examining how accumulated social networks and distinct areas of technological specialization within a firm influence the creation of new technology. The question is also motivated by earlier studies, which have linked firm-level local search behavior with innovativeness (Ahuja & Lampert, 2001; Katila & Ahuja, 2002; Rosenkopf & Nerkar, 2001). By investigating local search on the level of individual inventions and innovation teams, I shed light on dynamics which influence knowledge re-use in teams.

Finally, I shift the focus from invention and extent the concept of local search to managerial search processes related to the choice of acquisition targets.

Q5: How do technological and alliance networks together with national boundaries influence firm's choices of acquisition targets?

This question applies the concept of local search behavior to the domain of strategic decisions. So far, only very few studies have examined empirically how local search tendency in strategic decisions is influenced by inter-organizational networks and firm characteristics (Baum, Li, & Usher, 2000).

By answering these five questions, the publications together provide insight into the evolutionary processes through which firms expand their domain of operations. As depicted in Figure 1, the study of search processes is separated to two domains, technological and managerial, and two antecedents of boundary-spanning search are investigated, inter-organizational and intra-organizational networks.

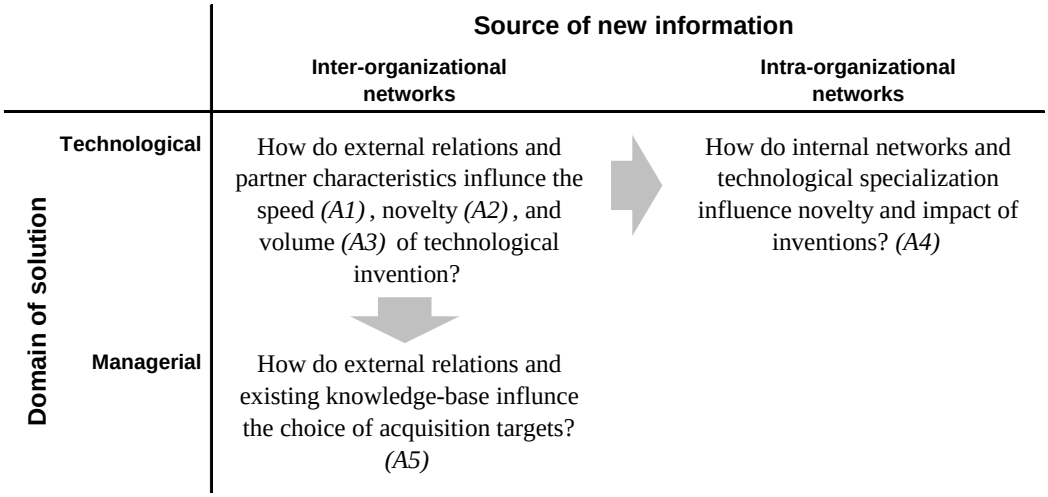

Figure 1: The empirical research domains in of the individual publications

3 THEORETICAL BACKGROUND

I examine how networks influence firm-level search processes. Given the broad tenet that organizations evolve only gradually through local search (Cyert & March, 1963/1992; Nelson & Winter, 1982), the key question is when and how are novel capabilities created, and when do organizations simply follow and reproduce a limited repertoire of prior strategies and behaviors (Garud & Karnoe, 2001). By examining how companies construct "path-breaking" competencies beyond their existing knowledge domain, we can better understand how firms evolve. Such knowledge may help us understand and predict likely evolution of firms and industries, as well as provide insight into managerial activities that can foster organizational renewal.

As each individual study reported here includes a review of relevant literature, I focus here on the overarching areas of prior theory. First, I introduce the concept of local search, originating from the behavioral decision making theory and evolutionary economics. Second, I provide an overview of the literature on technological space, which provides a model of firms' technological capabilities using patent data. These two concepts are also related, as firms have been proposed to exhibit local search behavior within the technological space (Stuart & Podolny, 1996).

3.1 Behavioral Decision Making and Local Search

Local search behavior denotes the tendency of decision makers to utilize prior models of the world up to a point where they are no longer acceptable (Cyert & March, 1963/1992: 126). At that point, individuals start to search for new solutions in the neighborhood of the problem symptom and of the current solution alternative (Cyert & March, 1963/1992: 170). Local search (called *simple-minded search* at the time) was originally related to individual decision-makers (Cyert & March, 1963/1992).

The focus shifted away from individuals was once the evolutionary economists took up the concept and concentrated on the aggregate organizational behaviors (Nelson & Winter, 1982). In this more abstract and aggregate form, the concept of local search corresponds to, for example, technological paradigms and trajectories (Dosi, 1988). Generally, the evolutionary tradition has deemed individuals unimportant and little interest is typically paid to micro-level dynamics.

Empirical studies have provided evidence that firms tend to "initiate new R&D projects that share technological content with the outcomes of their prior searches" (Stuart & Podolny, 1996: 21), and different performance implications from local and "boundary-spanning" search have been identified (Katila, 2002; Rosenkopf & Nerkar, 2001). Whereas early theory was concentrated on the characteristics of solutions (Cyert & March, 1992), recent studies on local search extend the concept to the likely sources of solutions (Rosenkopf & Almeida, 2003; Rosenkopf & Nerkar, 2001). Although innovation and local search could be understood as opposites, it is now customary to treat technological inventions as exhibiting local search behavior when they build on pre-existing knowledge-base of the firm.

3.2 Technological spaces

Building on Schumpeter's notion of invention as a novel recombination (Schumpeter, 1934), several authors have depicted invention activities as being localized within a distinct domain of pre-existing "technological space" (Podolny & Stuart, 1995; Stuart & Podolny, 1996).[1] Technological space is a methodological framework that captures prior technological knowledge. Each position in a hypothetical technological space, defined through the pre-existing technological inventions, resembles a spot for new technological solutions to emerge (Fleming & Sorenson, 2004; Podolny et al., 1996). Such methodological formulation is enticing as the framework allows the technological position of companies and shifts in those positions to be compared. Also, it is possible to theorize and examine how the position of a new invention in the space influences its value.

Recently, Lee Fleming and Olav Sorenson have applied the concept of *fitness landscapes* (Wright, 1932) to understand the creation of new technological inventions (Fleming, 2001; Fleming & Sorenson, 2001). This formulation draws on Levinthal's conceptualization of managerial decision making as localized search process within an organizational fitness landscape (Levinthal, 1997). A fitness landscape is a multi-dimensional space, in which each position is associated with a "fitness" value. Typically, fitness values change gradually, so that specific areas of the space provide

[1] The notion that new ideas are created by recombining existing knowledge has been attributed to Plato (Kogut & Zander, 1992: 392).

superior fitness values. In case of technological landscapes, the fitness is typically associated with the subsequent impact (or value) of an invention.

However, I feel reluctant to call technological spaces *fitness* landscapes, as individual positions do not resemble complete configurations (like in organizational fitness landscapes) but rather areas in which creative new solutions could potentially be produced. Unlike in biological combination of genes (or traits), the outcome of creative activities in a new position is not pre-determined. Therefore, positions in a technological space cannot be readily assigned "fitness values". Moreover, the concept of fitness landscapes is strongly related to optimization of returns in a fixed environment, whereas recombinant search is generative and largely unpredictable.

Technological space is defined through patent data. Each prior patent represents a binary dimension in the search space. A typical operationalization of technological space consists of either tens of thousands (Stuart, 1998) or millions (Fleming & Sorenson, 2001) of dimensions. The position of a new patent is positive on a dimension if the new patent cites the respective prior patent that defines the dimension. This relationship is captured by the presence of citations from the new patent to prior patents. In all other dimensions, the new patent occupies a zero-position. The position of a firm in technological space is often defined as the sum of the positions occupied by its patents filed in a given number of preceding years (Stuart & Podolny, 1996). Typical studies examine how an organization's past and present search efforts, conceptualized as complexity, coupling, familiarity, and competition, probabilistically influence the performance of the firm or the particular patent (Fleming & Sorenson, 2004; Podolny & Stuart, 1995).

It is possible to expand the idea of technological space theoretically and empirically. First, although the studies mentioned above all concentrate on patented new inventions, their basic framework and theoretical argumentation applies to all new routines or practices in general, although these capabilities do not leave traces as patents and patent citations do. Indeed, I suggest that one can meaningfully conceptualize any processes through which companies either create or evaluate new capabilities or routines as a process of technological search: recombining prior material artifacts, knowledge, and practices to create valuable new solutions. There are thus conceptual grounds to expect certain findings regarding patterns of

technological invention to apply to, for example, new administrative and marketing practices.

Second, it is possible to conceive of *cognitive search spaces*, defined through perceptions rather than objective patent data, related to technological search. Such a formulation is based on the expectation that employees relate potential new capabilities to existing ones along a variety of dimensions. Although there are an infinite number of possible dimensions through which new technology can vary from, or relate to, pre-existing solutions, organizations are likely to concentrate on a relatively small number of salient features (Levinthal & March, 1993). In effect, the idea of cognitive search spaces assumes that every researcher or technologist holds certain theories–of scientific or lay origin–regarding their problem area. These theories provide them with dimensions through which the new solutions can differ from or resemble prior solution. Such a cognitive formulation would allow us to examine the recent suggestion that the departmentalization of organizations affects the employee attention, and thus the search for new capabilities (Jacobides, 2006).

In this dissertation, I examine technological spaces through retrospective patent data, without attending to technologists' cognitions. Although actors may perceive the technological solutions along the lines of technological areas measured here through patents, little empirical research exists on the actual patterns of cognitive search for technological solutions. The concept of *search* as applied in the evolutionary literature, and especially in technological context, should thus be understood as a metaphorical ex-post explanation for complex and potentially heterogeneous processes through which new solutions are created. The extent to which our ex-post models of actor's search processes resemble generative mechanisms of technological change is a subject for further research.

4 KEY CONTRIBUTIONS

The studies reported in the dissertation indicate that external networks can be sources of both path-dependence and change. Importantly, networks appear to help companies to bridge into new technological domains and thereby increase the rate and novelty of innovative outputs. I conclude this section by contrasting the model of recombinant search underlying the study of technological invention with models of optimizing search that have become popular among evolutionary economists. I suggest that a framework connecting the two models of search processes could provide an improved explanation of organizational evolution.

4.1 Contributions to Literature

I will summarize the contributions made by the independent publications here. I will emphasize and explicate the contributions of studies reported in Appendices 2 and 3, as the studies were published as abbreviated versions of more thorough research papers.

Appendix 1 makes an empirical contribution by inspecting the conditions under which external networks lead to explorative or exploitative inventions. I find support for the prediction that characteristics of network partners and relationships influence the ability to overcome path-dependence. Tight relationships with similar local companies tend to provide less exploratory learning outcomes, although such relationships have been found to be the easiest and most efficient means to create new inventions and technological learning (Lane & Lubatkin, 1998; Mowery et al., 1996). I also find empirical support for an earlier proposition that allying with customers tends to decrease the novelty of inventions (Christensen & Bower, 1996).

Appendix 2 investigates how the relational ability to utilize partner's knowledge develops over time. Recent work on hypercompetitive environments and emphasis on the ability to build new capabilities rapidly (Teece et al., 1997; Volberda, 1996) suggest that ability to rapidly assimilate and exploit external knowledge can be an important source of competitive advantage. Prior literature has focused mainly on overall learning outcomes and thus largely overlooked this dimension. This paper contributes importantly to the literature on inter-organizational organizational learning (Cohen & Levinthal, 1989; 1990) by underlining the dynamic, temporal dimension of firm-level absorptive capacity.

The empirical analysis provided support for the prediction that innovativeness ininterorganizational relationships over time represents an inverted U-shape. I also provide strong support for the relationship of firm-level absorptive capacity on the timing of inventions. Firms with high R&D spending (and presumably, firm-level absorptive capacity) appear to excel in the early absorption of knowledge from a relationship. The benefits of R&D intensity decline over time, although high R&D investments do provide a sustained advantage in knowledge absorption even when controlling for overall patent rate. Surprisingly, we found that the learning benefits from intra-industry relationships tend to be timed in the middle of the relationship. This finding suggests that the relative absorptive capacity resulting from firm similarity (Lane & Lubatkin, 1998) cannot be overcome by developing partner-specific routines, as we had assumed. Instead, the benefits of intra-industry relationships appear to be greatest once the companies develop partner-specific relational absorptive capacity. The effects of industry relatedness should be approached prudently, as a robustness tests with zero-inflated model failed to replicate the finding. Finally, the study suggests different forms of external relationships to lead to different temporal patterns of knowledge flow. Specifically, alliances and joint ventures differed in their early and late learning benefits. In contrast to predictions, alliances have both higher early and late knowledge benefits in comparison to joint ventures. This relationship could be caused by different underlying strategic motives between the two types of relationships. Recent findings relating higher degree of integration to more strictly defined contractual agreements (Poppo & Zenger, 2002), suggests that joint ventures may have a systematically more narrowly defined scope.

Appendix 3 provides evidence that external relations provide knowledge and increase firm innovative output. The impact on innovativeness depends on the form of relationships and the relatedness of the partner company. We find that of four alternative forms of external relations, only joint ventures show an aggregate positive relationship with innovative performance. This finding is interesting as prior studies that have typically suggested positive effects for all forms of relations when they are analyzed in isolation. Focusing on one form of relationships at a time, may have lead to an omitted variable bias. Our analysis of intra-industry, related, and unrelated partners provides a more in-depth picture of innovative performance.

We found that related (middle category of relatedness) CVC investments have significant positive effect on innovative performance. This suggests that CVC can be an instrument to tap external innovation if the firm focuses on external ventures that have a clear relationship with the current core business of the firm. However, literature on CVC investments often highlights the technology and market monitoring function of these investments. In line with this, the majority of the investments of firms in our sample were in unrelated industries, indicating that corporations might use these investments less to gain short and medium term benefits from patentable inventions and instead to monitor longer term trends that might not be well captured by our measures. Intra-industry alliances did not provide significant innovation benefits, whereas less related alliances did. We speculate that intra-industry alliances might provide mainly scale benefits for the corporation, related e.g. to improvement of existing operations. Related and unrelated alliances might provide the learning benefits typical for link alliances and therefore positively influence innovative performance. The results also indicate that acquisitions might be most beneficial for innovative performance when the firm acquires other firms within its existing industry. Acquisitions in related or unrelated industries seem to contribute less to innovative performance despite some widely held beliefs about their learning benefits. Our finding is in line with earlier studies (Haleblian & Finkelstein, 1999).

Overall, our results suggest that form of external relationships can be used to stimulate a company's innovative performance, but that their influence on innovative performance depends on the relatedness of partners. For each external relationship form, only some of the relatedness groups we formed appeared to enhance innovative performance. Although the differences may be largely caused by the heterogeneity of underlying strategic intent in various corporate relationships, this systematic difference in the outcomes is nonetheless interesting. This study thus contributed to three areas of research: determinants of innovative performance, alternative forms of interorganizational relationships, and the impact of external networks. Further, the study contributed to research on governance mode choices of corporations (Villalonga & McGahan, 2005) by demonstrating the relevance of knowledge-based arguments in the choice of the governance mode. Research on governance mode choice has predominantly advanced arguments based on transaction cost economics (Vanhaverbeke, Duysters, & Noorderhaven, 2002) and to a lesser extent from the

knowledge-based view of strategy. Finally, the study adds further detail to the benefits of external corporate venturing and extending prior research that has explored different governance modes in isolation.

Appendix 4 contributes to the study of technological local search processes. The study differs from prior organization-level studies by focusing on innovation teams and strong social network ties within a research and development (R&D) unit. I find that in a corporate R&D unit I studied, social networks tended to increase local search behavior in marginal technological areas, while enabling exploration in the most central technological areas. I argue that this novel finding is explained by two opposite effects of networks: on the one hand they enable innovation teams to identify and compose novel solutions, while on the other hand they provide access to a broad range of pre-existing solutions thus decreasing incentives for more risky and troublesome exploration. As a minor contribution, the study also replicates and fails to find support for an earlier proposition that social network centrality influences the internal impact of inventions.

Finally, Appendix 5 bridges the literatures on acquisitions and local search behavior. I contribute by expanding the use of local search behavior to the domain of strategic decisions making. The article shows that companies are more likely to acquire companies that are localized in the same country, connected through alliance ties, or related through the development of similar technologies. However, the search contexts through which firms gain information interact. Instead of maximizing the overall proximity of their acquisition targets, companies acquire technologically similar foreign companies and technologically dissimilar alliance partners.

Together, the individual publications provide two major contributions. First, the dissertation sheds light on the probabilistic effects of the number and characteristics of network ties of firms on firm-level technological change. Second, the dissertation demonstrates the use of local search framework to examine the systemic influences of networks on likely evolutionary paths of firms.

Table 1: Key findings from Appendices 1-3: The effects of inter-organizational relationship characters on innovative output.

	Knowledge creation outcomes		
Properties of external relationships	**Novelty of the Inventions** ***(Appendix 1)***	**Temporal Pattern of Innovative Output** ***(Appendix 2)***	**The Rate of Innovative Output** ***(Appendix 3)***
Relatedness of partner in terms of industry boundaries	Hypothesized industry relatedness to decrease novelty, but did not find significant effects.	Found a curvilinear effect over time: Intra-industry relationships exhibit greater knowledge creation especially in medium term.	Found a curvilinear effect: partnering with companies in related industries was associated with higher innovative output than relationships with intra-industry and unrelated companies. However, acquisitions show highest output for intra-industry relationships.
Technological similarity with partner company	Found technological relatedness with the partner to decrease the novelty of resulting inventions.	Not examined	Not examined*
Partner company is in a customer industry	Found that partnerships with companies in industries that resemble typical customers (downstream relatedness) exhibited lower level of novelty.	Not examined	Not examined
Relationship is joint venture (comparison to alliance)	Hypothesized inventions associated with joint ventures to exhibit less novelty than inventions from alliances. Although the effect was in hypothesized direction, the difference was statistically insignificant.	Hypothesized knowledge creation to be greater earlier. However, findings show that joint ventures have lower knowledge creation in early and late stages in comparison to alliances, while exhibiting greater knowledge production in mid-term.	Not examined
Relationship is acquisition (comparison to alliance)	Found acquisitions to result in inventions that were less novel than those resulting from alliances.	Hypothesized acquisitions to lead to greater innovativeness early in the relationship. Although effect was in in predicted direction, it is statistically insignificant.	Not examined
R&D Spending	Control variable with insignificant effect.	Found that greater R&D spending increases innovative output especially in the early stages of the relationship, but the effects diminish over time.	Control variable with insignificant effect**

* Prior research has found that technological relatedness has an inverted-u relationship with innovative output in acquisitions (Ahuja & Katila, 2001), and that relatedness increases inter-firm learning in alliances and joint ventures (Mowery et al., 1996).

** Studies controlling for the effects of R&D spending on learning from alliances and joint ventures have commonly found insignificant effects (Lane & Lubatkin, 1998; Mowery et al., 1996).

The studies reported here strongly suggest that companies can expand their operations in the technological space qualitatively (Appendices 1 and 5) and quantitatively (Appendices 2 and 3) by forming network ties that bridge the company to new competence areas. Social networks and initial technological proximity help companies to increase the efficiency and breadth of their technological search. The characteristics of external relationships also critically influence the search processes. In particular, ties with related companies lead to inventions that are closer to the existing capabilities (Appendix 1). Social networks provide access to pre-existing solutions and can lead to more incremental inventions (Appendix 4).

Table 1 depicts the key findings from the three first publications of the dissertation, explicating how different aspects of external relationships influence the quantity, temporal distribution, and novelty of new technological solutions developed by an organization.

4.2 Practical relevance

The studies reported in the dissertation provide several implications also for managerial practice, and specifically to the management of technology.

Appendices 1-4 provide concrete data on the influence of external relationships on the production of new inventions. Despite my belief in the validity and reliability of the findings, it is difficult to give normative advice. Companies cannot decide on relationship formation based simply on the factors identified in this dissertation or even in prior studies of strategic management. Alliances or acquisitions have a number of important outcomes that have not been attended to. Most importantly, the study of costs and risks associated with external relationships is beyond the scope of this dissertation. Costs and risks ofinterorganizational relationships have remained elusive to measurement also in strategic management literature more broadly, and it is thus quite difficult to provide any clear-cut recommendations regarding the overall benefits of external relations. Despite these limitations, the findings provide valuable knowledge regarding the influence external relationships have on technology development in organizations.

Appendices 1 and 4 suggest various factors managers should attend to. Overall, the external relationships have a significant effect on internal technology development, a benefit which should be factored in when evaluating the costs and benefits of external relationships, including acquisitions. For example, given that alliances provide greater early learning benefits than joint ventures on average, projects which exhibit high returns from early

entrance to new markets would be better served by alliance in comparison to joint ventures. In Appendix 4, I find that socially central teams working in peripheral technological areas tend to utilize more internal knowledge than less connected teams. Although there are many outcomes that are not attended to, a clear implication of the study is that socially central actors are more prone to reapplying pre-existing ideas to solve technological problems. This might lead to more efficient solutions, but also to a lesser generation of new knowledge. In this example, the endogenous nature of outcomes is emphasized: a manager might accomplish exploratory outcomes simply by instructing the team not to utilize pre-existing solutions – effectively intentionally changing the dynamics my research has found.

The concept of local search is also useful in underlining the potential myopias in decision making (Levinthal & March, 1993). Appendix 5 suggests that by expanding their scope in alternative search contexts, companies may gradually expand the set of the alternative strategic choices they possess enough information of, and familiarity with, to carry out. By expanding alliances portfolio or diversifying technological operations, the firm also makes an indirect investment into its future ability to create and pursue new opportunities.

Overall, this dissertation suggests that network can, if carefully managed, provide companies with a variety of novel opportunities and help overcome local search tendency and create exploratory change. Ranging from boundary-spanning acquisitions to exploratory learning, networks can help companies step outside the "beaten path". However, as Appendix 4 shows, tight social networks can also easily start reinforcing pre-existing strategies and behavior. In contrast to earlier research, I find that collaboration with more related partners is not necessary optimal. Although a medium level of relatedness appears to provide the highest rate of invention (Appendix 3), relatedness can also hamper exploration (Appendix 1).

4.3 Recombinatory and Optimizing Search Processes

The model of technological evolution utilized is based on the idea of "recombinant search" (Fleming & Sorenson, 2001). Such a model may form a useful basis for a broader examination of organizational evolution. Recombinant search refers to the creation of novel solutions through creative recombination of pre-existing knowledge and artifacts. In contrasts to the optimizing search processes of evolutionary economists (Gavetti, 2005; Levinthal, 1997), and interpretative processes related to environmental search (Barr, Stimpert, & Huff, 1992; Daft & Weick, 1984), recombinant search provides a model that can accommodate a

large degree of both indeterminacy and descriptive power. The sources of new capabilities are traced to pre-existing practices, but new capabilities are not determined by the old.

Evolutionary economists have recently produced a range of analytical studies based on simulation models of search processes in rugged landscapes (Gavetti, 2005; Gavetti & Levinthal, 2000; Levinthal, 1997; Levinthal & Warglien, 1999; Siggelkow, 2002; Siggelkow & Levinthal, 2003). Since the optimizing search model has become increasingly popular explanation for organizational evolution, it is useful to contrast it with a recombinatory model of search. Ironically, the comparison between the two models is bound to remain theoretical: optimizing search processes are almost impossible to test empirically and are thus addressed through analytical simulations, whereas recombinant search processes appear ill suited for simulations but subject to empirical examination. The main difference between the two models lies in the definition of dimensions for search, the magnitude of choices, and the determinacy of outcomes.

Perhaps most importantly, the dimensions through which companies search in the theoretical models of optimizing and recombinant search are conceptualized differently. In optimizing search, each dimension represents a range of choices available to the decision maker (Gavetti, 2005). In contrast, the dimensions in recombinant search are not choices, but rather references to alternative existing configurations. Positioning of recombinant search outcomes refers to similarity with given prior outcomes.

The models of optimizing search typically presume a landscape with a limited number of dimensions that are either binary or continuous. Typically, decision makers are assumed to experiment with changes in one dimension at a time (Levinthal, 1997). The dimensions through which a company can change are predetermined, and known to the actors. These dimensions are also assumed to be tangential: deliberate changes in one dimension do not influence the firm's position along other dimensions. This is in drastic contrast to recombinant search, which assumes a very high number of dimensions. Because there are abundant pre-existing solutions, the actors can only be aware of very small fraction of them. Unlike in optimizing models, in which actors can experiment with changes in random dimensions (Gavetti, 2005; Gavetti & Levinthal, 2000), recombinant search is importantly influenced by limited attention to a small sub-set of all potential solution domains.

Finally, the two models differ in the exactness of search outcomes. Optimizing search models assume that any given position in fitness landscape determines a specific outcome;

each position is associated with a definite value of organizational fit that is directly comparable to those of other positions. Recombinatory search in contrast involves a creative problem-solving process, which results in a new solution. Any given position in a technological space may spawn multiple solutions, with wildly different utility. Even ex post the value of recombinations is difficult to estimate, and inventions of initially apparently low value may turn out to be highly valuable (Cattani, 2006). Almost none of the combinations can exhaustively be experimented with: even great care and time to explore a distinct spot in technological space does not guarantee that the actor would not miss key solutions that are later invented by others.

Although one cannot simply combine these models, which are based on very different assumptions, it seems instructive to compare these two models of organizational evolution. Both "ideal type" search processes represents sources of variation in organizational practices. Optimizing search provides more efficient combinations of available choices whereas recombinatory search results in new capabilities that form entirely novel choice alternatives. There appear to be important interactions with other organizational search processes. Recombinant search could be conceptualized to provide new dimensions to optimizing search processes. Although prior research has suggested that hierarchical distribution of decision making can influence organizational evolution (Gavetti, 2005; Siggelkow & Levinthal, 2003) based on patterns of optimizing search, such effects may also rise due to the effects optimizing search processes have on allocating attention in recombinatory search (Ocasio, 1997). The details of such connections are intriguing, and need to be attended by future research.

The model of technological spaces suggests that innovators are to some extent aware of the available solutions, and "operate" within certain domains of the space (Fleming & Sorenson, 2001). The findings of this dissertation vindicate the proposition that networks could be seen as bridges to new domains in this space that expand the solutions inventors draw on (Almeida, Dokko, & Rosenkopf, 2003; Singh, 2005). Recombinant search provides a model of networks influence on the evolution of organizations. By bridging to new domains of knowledge, the networks feed creative recombination (Burt, 2004). The existing research does not specify the cognitive models utilized by technologists, but implicitly assumes that the technological space measurable ex post by the researchers is representative of the engineers' knowledge structures. Future research could investigate the actual cognitive structures underlying recombinant search. As a result, the interactions between various

organizational search processes could be traced empirically and the cognitive dynamics of organizational evolution could be better specified.

The individual studies of the dissertation illustrate and open up the recombinant search processes operating in the organizations. The first three studies find support for the proposition that the characteristics of network partners greatly influence not only the number of novel technological recombinations, but the characteristics and timing of these inventions. The findings build on a process model of learning, in which two firms first form a relationship, then absorb and assimilate knowledge from one other, and finally exploit the knowledge by transforming it into new solutions (Zahra & George, 2002). Appendix 4 examines technological search within organizations. Based on the findings, I argue that the context of problem-solving task influences the use of novel knowledge to in recombinatory search. When solving problems in the technological core, well-connected teams bring in new external knowledge to create more radical new inventions. However, when working in the technological periphery, network ties are instead utilize to leverage the familiar proprietary knowledge in non-core areas. One might argue that less connected teams actually tend to focus on optimizing solutions based on available knowledge, whereas the operations of more connected teams have on average a larger extent of recombinatory search. Finally, Appendix 5 investigates the recombinatory search on the broadest scale: how companies identify and choose other firms to combine their operations with.

Whereas optimizing search processes attempt to take the available parameters and find the optimal solution, the recombinatory search examines new parameters that could be brought into the equation – metaphorically, it changes the equation to be optimized. Both processes feed on information and knowledge available through network ties (Fleming & Sorenson, 2004; Gavetti & Levinthal, 2000; Siggelkow & Levinthal, 2003). My research indicates that recombinatory search processes are influenced by the form of the network relationship and the characteristics of the network partners.

4.4 Explication of Contribution

In accordance to university guidelines, I have to explicate my contribution within the publications.

As the first author in the study reported in Appendix 1, I designed the research setting, including the research question and statistical testing. Although much of the data had been

collected within the project I worked in already, I composed novel data sets. I also wrote the initial hypotheses and composed initial draft of introduction, theory, and methodology sections. I also participated in rewriting and improving the final text during a number of iterations with my co-authors.

In Appendix 2, my role was relatively similar. I came up with the research question, hypotheses and the statistical test. I wrote brief outline of the research paper, and participated in improving the text during a number of iterations.

In Appendix 3 my role was somewhat smaller. The research question had been specified when I joined the project, and my task was to do the initial design measures and statistical setting as well as compose the required data set. I subsequently also participated in rewriting the text of the paper during a number of iterations.

As the first author in the study reported in Appendix 5, I have designed the research setting and written the initial versions of the paper. Although the theoretical framing was made collaboratively with the co-author, the theory and hypotheses are my own writing,. The final text, though, has undergone multiple rounds of editing by my co-author, various copy editors, and finally by the editor of *Strategic Organization*, Joel Baum.

5 LIMITATIONS

This section covers the limitations of studies and the dissertation broadly. I will cover the limitations in Appendices 2 and 3 in more detail, as the publications of other studies covered their respective limitations in detail. The generic limitations of the study relate to patent data as well as endogeneity and reverse causality. Finally, I examine limitations related to network analysis.

5.1 Patent data

Although patents have been considered as an excellent measure for knowledge flows (Jaffe, Trajtenberg, & Henderson, 1993; Nerkar & Paruchuri, 2005), several problems with patent-based measures are widely acknowledged. A large variance exists in the scope and value of patents. The likelihood that an invention is patented depends on the national, industry-specific, company-specific factors. Patents thus represent only a portion of a company's inventions, and absolute patent counts are not directly comparable companies, let alone across industries. The number of patents a company has filed is thus not a robust indicator of the value or the quantity of their innovative output (Desrochers, 1998). Patent citation-based measures also suffer from noise, since citations might be included simply to protect a firm from litigation (Rosenkopf & Almeida, 2003), and part of citations are added ex post by the official patent examiners.

Despite these weaknesses, patent citations are very frequently used measure for knowledge flows in interorganizational learning literature. The greatest problems associated with patents can be overcome when variance in patenting is compared within firms over time (using fixed effects, rather than between effects models). Earlier research provides a plenty of support for the use of patent citation-based measures for knowledge flows. Patent citations have been used to measure technological similarity and knowledge flows between companies and geographical areas (Almeida et al., 2003; Mowery et al., 1996; Mowery, Oxley, & Silverman, 1998; Stuart & Podolny, 1996). Providing support for the method, a recent survey of inventors found direct patent citations to be a relatively good indicator of knowledge flows (Jaffe, Trajtenberg, & Fogarty, 2000).

A major strength of patents is that they are systematically compiled and thus provide detailed information across long time periods (Rosenkopf & Almeida, 2003). Firms have incentives to patent inventions as quickly as possible, since the first firm to apply for a patent generally acquires monopoly rights to the invention (given that the invention is otherwise

deemed patentable). In conclusion, patents are probably the only feasible way to approximate knowledge flows between a large number of focal companies and thousands of their partners in a longitudinal research setting. To the extent that patents suffer from noise, this should result only in less significant models, and not in systematic bias in hypothesis testing.

The sole focus on patents does provide a somewhat limited picture of all the knowledge exchange among partners in inter-organizational relationships. To investigate the generalizability of findings in this dissertation, it would be necessary to investigate how the variables of interest relate to other types of learning outcomes that could be captured, for example, using surveys. Furthermore, patent-based measures cannot really distinguish informal and formal contacts across companies, nor does they indicate whether tacit or explicit knowledge was transferred. Patents merely represent accomplished outcomes that result indirectly from knowledge exchange.

5.2 Endogeneity and reverse causality

Studies in strategic management are often plagued by problems of endogenous choice and the threat of reverse causality (Hamilton & Nickerson, 2003). This effect is demonstrated clearly by a simple example: Does the choice to increase R&D spending increase innovativeness, or do more innovative firms rationally choose to spend more in R&D? A researcher who ignores the latter possibility and naively takes a relationship between R&D spending and innovativeness to vindicate the first proposition has a high risk of drawing a false conclusion.

I have attempted to discuss this issue in each of the publications when space limitations have allowed it. Although effort was taken to reduce the potential problems associated with endogeneity e.g. by testing GMM models in the study reported in Appendix 3, these issues can seldom be fully solved. Furthermore even when endogenous choice can be modeled e.g. using Heckmann selection models, available variables seldom provide an externally valid explanation for the selection process.

In the case of the studies reported here, the effects should be interpreted conservatively as associations, not necessarily as causalities. For example, in the case of explorative and exploitative learning, the findings relate different forms of external relationships to probabilities of alternative learning outcomes. In the specific study I admit that this association can result from the endogenous choice to use certain form of relationship when

certain outcomes are desired or even expected. Although the form is likely to genuinely make some learning outcomes more likely than others, the tests cannot verify that the associations are not endogenously caused by strategic intent.

5.3 Network Relationships

Although network relationships have become highly popular research topic, there are several systematic limitations in data collection common to most of network studies.

Inter-organizational networks have three common limitations. First, since the network relationships are virtually always identified through public data sources, it is likely that a significant share of actual collaborative relationships across companies are never identified. Moreover, some of the announced relationships may turn out to actually create very little concrete collaboration across firms (Barley, Freeman, & Hybels, 1992). Second, in practice the strength or intensity of network relationships varies, but it is very difficult to measure (Koka & Prescott, 2002). In this dissertation, I was not able to meaningfully measure the strength of relationships, reducing the range of research questions that could be addressed. Third, while the initiation of inter-organizational networks is commonly announced, the decisions to discontinue collaborations are seldom announced publicly (Ahuja, 2000). Thus, I was unable to track the ending of collaborative relationships, and had to assume they continued for a number of years, as in prior research (e.g. Gulati, 1995).

There are two major limitations related to studies on intra-organizations networks. First common limitation shared by the great majority of studies is that they only examine social networks within a single organization (Kilduff & Tsai, 2003). Publication reprinted in Appendix 4 shares this limitation. Although extremely common, this limitation begs to question the generalizability of results. For example, I was not able to replicate some of the findings from prior research (Nerkar & Paruchuri, 2005) with my data. The second limitation relates to different types of network ties. Although prior research has often investigated two, or even three types of network ties (Ibarra, 1993), informal networks cannot readily be observed over long periods of time. Thus, prior studies have often focused on the most visible and formal networks that can be tracked over time through archival data (Nerkar & Paruchuri, 2005; Singh, 2005). Although Appendix 4 provides richer and more detailed data than these two prior studies by tapping into internal archives, I am still unable to capture most of the relationships that leave no tangible traces.

While these problems are substantial, it is unlikely that they create systemic biases in the results. Rather, the problems in data collection reduce the generalizability of results to other forms of network relationships, and they most likely introduce random variance in the data sets and thereby reduce the significance of the results.

5.4 Additional Information on Appendix 2

Due to the limited space in conference proceedings format, several analyses related to the study in Appendix 2 could not be included in the publication. I report the methodology and the results of analyses in greater detail here to provide a more complete perspective on the study.

In this study, we investigated the flow of knowledge between companies over time. We utilize fixed and random effects negative binomial models with robustness tests using zero inflated negative binomial models in *Stata*. Unfortunately, we could not get longitudinal zinb models, which are only available in *LISTREL* software, to converge. Table 2 below depicts the results of our analyses. We did several robustness tests, e.g. by varying the number of months analyzed following the initiation of the external relationships. We found that periods over 48 months provided similar results, but the variance for learning outcomes increased dramatically after the fourth year, making predictions of cross-citation rates far less accurate.

Table 2 clearly shows that there is a significant inverted-U relationship between rate of cross-citations and the months passed since the beginning of the relationships. The most significant and statistically robust finding relates to the influence of R&D spending on cross-citation rates. We ran further analyses to show that this relationship cannot be simply explained through the size of the company. Several problems, of course, remain. As the termination of relationships is impossible to capture accurately, we had to assume that the abandonment of relationships does not correlate strongly with our independent measures. Moreover, we can only capture the dates when inventions are filed (i.e. when information becomes exploited by the focal firm), not the dates when knowledge was “absorbed and assimilated” (Zahra & George, 2002).

Table 2: Regression analysis results of the study reported in Appendix 2.

	(1)	(2)	(4)	(5)	(6)
Hypothesis 1					
Months	1.33% +	.60%	10.11% *	1.19% +	11.76% **
	(.81%)	(.98%)	(4.82%)	(.92%)	(5.24%)
Months^2	-.04% *	-.02%	-.18% *	-.03% +	-.19% *
	(.02%)	(.02%)	(.09%)	(.02%)	(.09%)
Hypothesis 2					
Intra-industry	48.23% ***	29.96% +	48.05% ***	47.58% ***	23.53%
	(8.64%)	(23.97%)	(8.59%)	(8.65%)	(23.21%)
Intra-industry * Months		2.19%			2.61% +
		(1.75%)			(1.78%)
Intra-industry * Months^2		-.05% +			-.06% *
		(.03%)			(.03%)
Hypothesis 3					
Firm R&D spending (ln)	19.47% ***	19.37% ***	36.12% ***	19.55% ***	42.32% ***
	(3.77%)	(3.77%)	(9.83%)	(3.79%)	(10.70%)
R&D spending * Months			-1.17% *		-1.49% **
			(.60%)		(.62%)
R&D spending * Months^2			.02% *		.03% *
			(.01%)		(.01%)
Hypothesis 4					
Joint venture	-16.32% *	-16.17%	-15.98% *	-46.41% *	-46.35% *
	(6.70%)	(6.72%)	(6.71%)	(14.57%)	(14.58%)
JV*Months				5.42% *	5.53% *
				(2.64%)	(2.63%)
JV*Months2				-.11% *	-.11% *
				(.05%)	(.05%)
Acquisition	29.97% *	28.84%	31.62% *	134.64% *	186.72% ***
	(15.40%)	(15.38%)	(15.54%)	(63.79%)	(78.98%)
Acquisition * Months				-1.81%	-3.81%
				(3.28%)	(3.23%)
Acquisition * Months^2				-.06%	-.02%
				(.08%)	(.08%)
CVC	-6.22%	-5.34%	-5.51%	-69.99%	-67.75%
	(27.34%)	(27.66%)	(27.43%)	(35.47%)	(37.97%)
CVC*Months				14.00%	13.54%
				(12.06%)	(11.98%)
CVC*Months^2				-.28% +	-.27%
				(.22%)	(.22%)
Control Variables					
Prior cross-citations	125.14% ***	124.48% ***	125.80% ***	122.16% ***	122.83% ***
	(10.80%)	(10.81%)	(10.85%)	(10.77%)	(10.84%)
Focal patent rate (/1000)	2.60% ***	2.60% ***	2.60% ***	2.60% ***	2.60% ***
	(.00%)	(.00%)	(.00%)	(.00%)	(.00%)
Partner patent rate	1.60% ***	1.60% ***	1.60% ***	1.57% ***	1.58% ***
	(.08%)	(.08%)	(.08%)	(.08%)	(.08%)
Relationship renewed	142.57% ***	151.41% ***	142.55% ***	157.33% ***	167.71% ***
	(.07)	(.07)	(.07)	(45.37%)	(47.40%)
< Industry and year dummies are included, but not shown >					

We report coefficients as incident rate ratios (percentage changes to cross-citation counts are based on 1-unit non-standardized change in independent variables). Standard errors (proportional to IRR) are reported below coefficients in parentheses. N=39083. This is a population-averaged panel model of 1253 external relationships. We model up to 48 months following the initial formation of a relationship. The model is estimated with an autoregressive correlation structure (AR 1). All models are significant at p<.001. One-tailed tests of significance were used for independent variables and two-tailed tests for control variables.

+p < .10, *p < .05, **p < .01, ***p < .001

6 CONCLUSIONS AND FUTURE RESEARCH

The dissertation research utilized quantitative methods to evaluate the conditions for path-dependent and path-breaking change. As such, the work has provided new insights into the behavior of firms. I find that network connections provide both exploratory and exploitative outcomes, which depend systematically on the relatedness of the partners and the form of external relationship. Networks help companies overcome local search and create novel inventions by bridging the firm to new domains in technological space. Relations with similar others, "short bridges" across technological space, tend to lead to solutions with lesser novelty in comparison to "long bridges" with dissimilar others (Appendices 1, 3, and 5). I also find that the effects of social networks are influenced by technological specialization. In core technological areas, networks help create novel inventions, while in more peripheral areas network centrality is associated with more exploitative inventions (Appendix 4).

The introductory chapter develops an analytical model of organizational evolution based on intertwined search processes. Even though technology and strategy may evolve through path-dependent local search (Nelson & Winter, 1982), these evolutionary paths have non-trivial interdependencies that can together create non-incremental change. Technological recombinations are influenced by managerial decisions, while they themselves provide organizations with new decision alternatives (Itami & Numagami, 1992).

There are many avenues for further research on technological evolution. Given the dominance of firm-level evolutionary studies, future research on technological evolution could expand to the individual- and group-level dynamics (Gavetti, 2005). Appendix 4 represents an endeavor in this direction. Unfortunately, the data available did not allow me to examine how inter-firm relationships influence group-level innovative activities, a logical continuum from the studies included here. Earlier research has suggested that organizational structure and initial conditions of inter-firm relationships influence group-level processes (Doz, 1996), but these dynamics have not been linked to technological evolution of firms. For a more comprehensive picture of group-level dynamics, we might need to pay more attention to the social processes and power structures beyond relatively simplistic account of information flows. Several social processes have been found to underlie the reproduction of social order, and thus the local search behavior (see e.g. Bourdieu, 1977). Mixing and synthesizing disparate research traditions is never a popular endeavor, but here I would be optimistic that pre-existing micro-sociological theories could be leveraged to elaborate regularities in organizational evolution.

Finally, recombinant search appears to complement prior models of organizational evolution based on optimizing search (Gavetti & Levinthal, 2000; Levinthal, 1997). Although both the processes of recombinant and optimizing search are analytical simplifications of extremely complex and potentially heterogeneous processes, these two models may provide a powerful framework for understanding how companies change. By further investigating empirically how recombinant and optimizing search processes interact on the level of cognitive representations and through the direction of attention, a more detailed model of organizational change may be developed. Thus, this dissertation as a whole contributes to the application of local search framework to explicate how network relationships influence the evolutionary paths of firms.

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