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Doctoral Thesis

External Knowledge Sourcing and Firm Innovation: Essays on the Micro-Foundations of Firms' Search for Innovation

PhD Series, No. 44.2013

Provided in Cooperation with:

Copenhagen Business School (CBS)

Suggested Citation: Markus, Arjan (2013) : External Knowledge Sourcing and Firm Innovation: Essays on the Micro-Foundations of Firms' Search for Innovation, PhD Series, No. 44.2013, ISBN 9788793155015, Copenhagen Business School (CBS), Frederiksberg, <https://hdl.handle.net/10398/8854>

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<https://hdl.handle.net/10419/208878>

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COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN
SOLBJERG PLADS 3
DK-2000 FREDERIKSBERG
DANMARK

www.cbs.dk

ISSN 0906-6934

Print ISBN: 978-87-93155-00-8

Online ISBN: 978-87-93155-01-5

External Knowledge Sourcing and Firm Innovation

PhD Series 44, 2013



**Copenhagen
Business School**
HANDELSHØJSKOLEN

External Knowledge Sourcing and Firm Innovation

Essays on the Micro-Foundations
of Firms' Search for Innovation

Arjan Markus

The PhD School of Economics and Management

PhD Series 44, 2013

External Knowledge Sourcing and Firm Innovation

*Essays on the Micro-Foundations of Firms' Search for
Innovation*

Arjan Markus

PhD School in Economics and Management

Copenhagen Business School

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1st edition 2013
PhD Series 44.2013

© The Author

ISSN 0906-6934

Print ISBN: 978-87-93155-00-8

Online ISBN: 978-87-93155-01-5

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ENGLISH SUMMARY

Innovation is at the heart of firm competitiveness. Due to the limited potential for knowledge recombination within organizational boundaries, companies are increasingly forced to span boundaries and tap into external knowledge sources in order to innovate. The role that skilled individuals play in this process of harnessing external knowledge for firm innovation is an increasingly studied phenomenon. However, the conditions under which external knowledge sourcing impacts firm innovation remain underexplored. The research question that guides this dissertation is formulated as follows: *How does external knowledge sourcing affect firm-level innovative activity?* The purpose of this thesis is to examine how recruitment of skilled individuals, and to a lesser extent collaboration and licensing, affects firm-level innovation, and which individual- and firm-level characteristics moderate this relationship.

The dissertation consists of four empirical essays, an introduction, and a conclusion. The basis for three of these essays is The Integrated Database for Labor Market Research (IDA) provided by Statistics Denmark which is matched to patent data from the European Patent Office (EPO) and survey data on firm innovation from the Danish Centre for Studies in Research and Research Policy (CFA). One essay relies on a combination of the Deloitte Recap Database and patent data from the United States Patent and Trademark Office (USPTO). The combination of datasets used in each essay allows us to study the role of scientists and engineers and in particular their movement across organizational boundaries in great detail.

The first paper investigates how recruitment of so-called R&D workers impacts the degree to which firms produce innovations that explore technological areas other than present in its existing knowledge pool. The main finding of this study is that recruitment of cognitively

distant R&D workers is positively associated with firm-level exploration, yet this relationship attenuates as firms mature. The second essay examines how recruitment and R&D collaboration concurrently impact firm innovation when firms use these boundary-spanning mechanisms simultaneously in the academic and industrial knowledge domain. The results suggest that in some cases firms experience problems in combining these mechanisms effectively. The third paper studies the role of intrafirm inventor networks for the speed with which firms recombine external knowledge into their own invention. The findings reveal that dense and diverse collaboration networks among employees shorten the time to recombine distant external knowledge. The final and fourth paper asks whether recruitment of academic scientists may be seen as a driver of university-industry collaboration. The results show that recruitment of recent graduates and scientists formerly employed at university is positively associated with firm's likelihood to collaborate with university. Yet, the results suggest that science-dominated firms have less to gain from such recruitment.

In sum, this thesis explores how highly-skilled individuals affect the relationship between boundary-spanning and firm innovation. The main contribution of this thesis is shedding new light on the conditions under which external resources may foster organizational-level innovation. The findings of this thesis bring to light the role of scientists and engineers, as carrier of knowledge and skills when they cross organizational boundaries, and their role as firm-internal resource. This study thus contributes to the literature on organizational learning, the knowledge-based view of the firm and search for innovation by showing how external resources obtained through a variety of mechanisms may impact various dimensions of firm-level innovative activity.

DANSK SAMMENDRAG

Innovation er kernen i virksomhedens konkurrenceevne. På grund af det begrænsede potentiale for rekombination af viden indenfor organisationens egne grænser er virksomheder i stigende grad tvunget til at gå ud over disse grænser og trække på eksterne videnskilder for at kunne innovere. Den rolle som højtuddannede personer spiller i processen med at udnytte ekstern viden er blevet stadig grundigere studeret i litteraturen. Men de betingelser, hvorunder kilder til ekstern viden faktisk får en virkning på virksomheders innovation er fortsat kun lidt belyst. Forskningsspørgsmålet der guider denne afhandling er formuleret som følger: *Hvordan påvirker viden fra eksterne kilder virksomhedens innovative aktiviteter?* Formålet med afhandlingen er at undersøge, hvordan rekruttering af højtuddannede personer, og i mindre grad samarbejde og licensering, påvirker innovation på virksomhedsniveau, og hvilke faktorer på individ- og virksomhedsniveau, der moderer denne sammenhæng.

Afhandlingen består af fire empiriske essays, en introduktion og en konklusion. Grundlaget for tre af disse essays er den integrerede database for arbejdsmarkedsforskning (IDA) fra Danmarks Statistik, som er knyttet sammen med patentdata fra Den Europæiske Patentmyndighed (EPO) og surveydata om virksomheders innovation fra Dansk Center for Forskningsanalyse (CFA). Et essay er baseret på en kombination af Deloitte Recap Databasen og patentdata fra United States Patent and Trademark Office (USPTO). Kombinationen af datasæt, der anvendes i hvert essay giver os mulighed for i stor detalje at undersøge, hvilken rolle videnskabsfolk og ingeniører - og især deres bevægelser på tværs af organisatoriske grænser - spiller.

Det første papir undersøger, hvordan rekrutteringen af såkaldte forsknings- og udviklings (FoU) medarbejdere påvirker i hvilken grad virksomheder producerer innovationer, der udforsker

teknologiske områder som ligger ud over virksomhedens eksisterende vidensgrundlag. Hovedkonklusionen i undersøgelsen er, at rekrutteringen af kognitivt fjerne FoU-arbejdere er positivt forbundet med virksomhedens tilbøjelighed til at udforske nye områder fremfor at udnytte de eksisterende kilder til ekstern viden, som virksomheden allerede tidligere har anvendt. Graden af den positive sammenhæng aftager dog, efterhånden som virksomheden bliver ældre. Det andet essay undersøger, hvilken effekt rekruttering og FoU-samarbejde har på virksomhedens innovation når virksomheden bruger begge grænseafsøgende mekanismer i de akademiske og industrielle vidensdomæner. Resultaterne tyder på, at virksomheder i nogle tilfælde oplever problemer med at kombinere disse mekanismer effektivt. Det tredje papir undersøger den rolle som netværk mellem opfindere indenfor virksomheden spiller for den hastighed, hvormed virksomheder rekombinerer ekstern viden. Resultaterne viser, at tætte og mangfoldige samarbejdsnetværk blandt medarbejderne forkorter den tid det tager at rekombinere fjerne kilder til ekstern viden. Det fjerde og sidste papir spørger, om rekruttering af akademiske forskere kan ses som en drivkraft for industri-universitetssamarbejde. Resultaterne viser, at rekruttering af nyuddannede og af forskere der tidligere har været ansat på universiteter er positivt forbundet med firmaets sandsynlighed for at samarbejde med et universitet. Men resultaterne tyder også på, at videnskabsdominerede virksomheder har mindre at vinde ved en sådan rekruttering.

Samlet set udforsker denne afhandling, hvordan højtuddannede personer påvirker forholdet mellem grænseafsøgende aktiviteter og virksomheders innovation. Det vigtigste bidrag i afhandlingen er at kaste nyt lys over de betingelser, hvorunder eksterne ressourcer kan fremme innovation på organisationsniveau. Resultaterne af denne afhandling afdækker den rolle som forskere og ingeniører spiller som bærer af viden og færdigheder, når de krydser organisatoriske

grænser, og deres rolle som virksomhedsinterne ressourcer. Undersøgelsen bidrager dermed til litteraturen om organisatorisk læring, det vidensbaserede syn på virksomheden og dens søgning efter innovation ved at vise, hvordan eksterne ressourcer opnået gennem en række mekanismer påvirker forskellige dimensioner af innovativ aktivitet på virksomhedsniveau.

ACKNOWLEDGEMENTS

This PhD dissertation is the result of research on mobility, knowledge recombination, and learning. These terms likewise characterize my personal journey during my time as a doctoral student. The memory of the decision to move to Denmark to pursue my PhD and academic career is a very vivid one. I felt tremendously excited about this next step in my life, even though it meant leaving behind loved ones. Looking back, my time as a doctoral student at Copenhagen Business School has definitely been a great personal journey into academia and beyond. I feel truly fortunate that my adventure in research led to so many unexpected – but wonderful – benefits, above all being able to interact with many inspiring people and to visit intriguing places around the globe. My profound gratitude goes to those people whose support was crucial in this doctoral journey.

First and foremost, I am deeply indebted to the guidance of my supervisors Keld Laursen and Thomas Rønde. When I entered the doctoral program at the Department of Innovation and Organizational Economics (INO), I was secretly hoping that Keld and Thomas would be my supervisors, as my research interests matched theirs perfectly. Keld and Thomas have been crucial in my development as an academic scholar. They allowed me to pursue my own ideas and work independently on projects – exactly what I needed, and I am grateful for that. The sharp comments, focused guidance (“Arjan, you should learn to apply the concept of ‘embrace and extend’”) and lessons of academic rigor – mentorship in all its dimensions – were indispensable for finishing this dissertation, especially in the final phase of the PhD. Moreover, Keld has influenced my career by putting his trust in me and opening (academic) doors that I never thought would be possible. Also, the late evening conversations on academia and climbing

were very enjoyable. For me, during times that I needed it, Thomas showed genuine interest in my personal well-being, and I cherish those moments.

I was also fortunate to have Hans Christian Kongsted involved early-on in my PhD project. Our meetings at the University of Copenhagen were refreshing along many dimensions; Hans Christian's challenging questions regarding management fads and his ability to articulate and re-think problems was very helpful.

I am also indebted to Lori Rosenkopf who invited me to the Management Department at The Wharton School and served as my sponsor during my four-month visit. I feel very privileged to have had the chance to collaborate with Lori. I admire her enthusiasm and vast array of knowledge. Lori aptly drew my attention to relevant literature, while at the same time rightfully challenged the formulation of sentences I wrote. Her support and guidance have been crucial throughout this process, and were very dear to me. With regard to my visit in the US I kindly acknowledge the financial support from the Otto Mønsted Foundation.

This PhD dissertation benefitted greatly from the sharp and critical comments from Toke Reichstein and Valentina Tartari. All four papers in this dissertation improved significantly due to the effort and time they spent reading and commenting on the papers. In this respect, I would also like to emphatically thank my external PhD committee members, Paul Almeida and Karin Hoisl, for their indispensable suggestions for improving the empirical essays.

I also want to thank all of my PhD colleagues and professors at INO, as their intellects and personalities have been essential in providing a fruitful academic foundation. In particular I would like to thank the following people. Firstly, Gouya Harirchi, Maggie Mei, Maria Halbinger, Milan Miric, Solon Moreira and Virgilio Failla (or the "7"), thank you for the discussions, suggestions, critical comments, laughter, and dear moments during lunches, conferences and socials. Experiencing the heterogeneity in terms of nationalities and educational

backgrounds in our PhD cohort has been an absolute privilege. I would also like to thank Jens Frøslev Christensen for the many conversations about academia and beyond, in Dutch and Danish. Mark Lorenzen, thank you for your humor, especially during the Wednesday meetings. And thank you for your knowledge on the best restaurants and jazz bars in Copenhagen. I am also indebted to Christoph Hienerth, who has showed me awesome places in Copenhagen. I admire his positive attitude. Giancarlo Lauto, I tremendously enjoyed the gym visits and proximity discussions. Jing Chen, the kitchen conversations, especially during the weekend, were very nice. Peter Lotz, thank you for your support during the PhD and beyond. Thanks also to Christoph, Karin, Christine, Jan, Ulrich, Francesca, Jörg, Serden, Lee, Kristina, Marion and Jette. I would also like to take the opportunity to thank several of the visiting doctoral students, whose presence was a real asset to INO and the doctoral experience. Thank you, Jorge, Argyro, Thomas, Jaime and Marcelo.

I would also like to thank Bram Timmermans for letting me know about the PhD positions that were offered at INO. Also, he provided some tips regarding the Danish labor market database.

The friendship and kindness I experienced during my Philadelphia visit was impressive. The (visiting) PhDs and postdocs at the Management Department of Wharton, as well as the people I met during my stay at the International House Philadelphia were crucial for meeting my goals, and also for enjoyment during challenging academic times. Most notably, my sincere thanks to Linda, Daniel, Johannes, Thomas, Nicole, Lieke, Dieter, Andy, Andrew and Jennie, Justin, Rachel, Emanuel, Luis and Renata, Adam, Nick, Kinde, Shinjae, Patia, Shef, Andrea, Peter, Bastian, Dino, Mesfer, Adrian, Kevin, Valeriano, and Rodrigo. I also met Daniel Tzabbar during my Philadelphia visit, which resulted in engaging discussions and continued collaboration. I especially appreciated his honest comments regarding my papers.

I also found kindness and friendship in Copenhagen. Robert and Jonna, you two have been, without a doubt, crucial for my well-being. I cherish many special shared memories (for instance the visit to Møns Klint), and I admire the decisions you have made. Thank you for that. Salman, also you have been important for my well-being, and I learned a lot from your personality and life experience. I would also like to thank Johannes and Pelin, Helene, Gijs, Jon, Kerstin, Christine, Julio, Krista, Nina and the many people I have met during Danish class and my time in Copenhagen in general.

The support from The Netherlands has also been very important to me. Either during my time in Copenhagen or during the many short visits in The Netherlands, my friends kept me “sane” more than once. Thank you, Bart Hospes, Daan, Vincent, Bart van de Haak, Flip, Frans, Maarten and also Von Munchhausen, including Martijn, Pim, Erik en Ludo. Your visit in Copenhagen was great, and I hope you will enjoy my thesis defense which hopefully will partly make up for being gone the past three years or so. Also, Matté, you have been my buddy in both the academic and friendship realm. Your kind gesture to let me sit and work in your shared office at Utrecht University, our Skype talks, and our jointly attending the DRUID 2013 conference were great. Thanks for that. Also, I would like to thank Pierre-Alex for interesting discussions while I was in the office at Utrecht University.

I cannot express my gratitude for the unconditional support, love and attention from my parents, Rob en Annie, and my sisters, Marieke and Marjolein. During moments of success and despair you were there to support me and encourage me in my next steps. Your visits to Denmark and my visits to Gouda were crucial, warm moments of recuperation and setting new goals. I know you would like to have me close by, not in Denmark or the US, yet, at the same time I can also feel that you know that I need to do this, for my personal and professional

development. I would also like to thank for the warmth and support from René, Pauline, Ingeborg and Kim.

Finally, words cannot describe the unconditional love, warmth, and support from my love, Astrid. I am very grateful for the love and happiness I experience when I am with you. Astrid, you have been crucial in my perseverance. During moments of successes, but in particular during moments of despair, changing moods, and mere absence, you believed in me and my capacity to finish this thesis. Only you know how much I wanted this, and how much it also haunted me. Also, you have been on my side already during my undergraduate and graduate studies at Utrecht University, where I sometimes dedicated late nights to proximity and innovation, and not to you. Nevertheless, you remained on my side in the years that followed, and I am indescribably grateful for your unlimited support. At times you must have thought my dissertation was more important than you. Your ability to sacrifice some of your dreams so that I can achieve mine has been incredible; my next goal is to reciprocate in the future. As a start, I dedicate this thesis to you.

Arjan Markus

Philadelphia, December 2013.

CONTENTS

Chapter 1. <i>Introduction</i>	1
Chapter 2. <i>How Does R&D Worker Recruitment Affect Firm Exploration? A Longitudinal Study of the Role of Cognitive Distance</i>	21
Chapter 3. <i>Tapping into Industry and Academia: Inbound Mobility, R&D Collaboration, and Substitution Effects</i>	66
Chapter 4. <i>All for One and One for All: How Intrafirm Inventor Networks Affect the Speed of External Knowledge Recombination</i>	105
Chapter 5. <i>Bound to the Ivory Tower? Mobility of University Scientists as a Driver of University-Industry Collaboration</i>	157
Chapter 6. <i>Conclusion</i>	205

CHAPTER 1

INTRODUCTION

Innovation has been a long studied phenomenon in the economics and management literature. Early work by Schumpeter (1934) pointed to the recombination of existing knowledge components as a key driver of innovation. Yet, questions such as *who* engages in innovative activity, as well as *when* and *how*, still remain to attract scholarly attention. One insight that has not lost its importance in this respect is the role of the *individual* in “carrying out new combinations” (Schumpeter, 1934: 65–66). More than two centuries ago, in 1776, Adam Smith noted that “very intelligent artists” and “philosophers” or “men of speculation” are the chief cause of innovation (Rosenberg, 1965; Smith, 1976). Such individuals, which we refer to as *scientists* and *engineers* in contemporary terms, are key in understanding the economics and management of innovation. This PhD thesis aims to add to such understanding by focusing on the relationship between external knowledge sourcing and firm innovation. In particular, with this PhD dissertation I aim to improve our understanding of the role of individuals in the process of how firms search for, and subsequently develop, external knowledge to innovate. Thus, this thesis examines the impact of agents’ behavior at the *micro-level* (i.e. individual-level) on *meso-level* outcomes (i.e. firm-level).

Sources of innovation were long held to be inside firms, but in order to innovate firms are forced to cross organizational boundaries and tap into external knowledge sources (von Hippel, 1988; Rosenkopf & Nerkar, 2001). The phrase “not all the smart people work for us” (Chesbrough, Vanhaverbeke, & West, 2006: 38) illustrates this well. In line with this view, this

thesis mainly focuses on one particular *boundary-spanning* mechanism, namely labor mobility. Building on the idea that movement of labor involves transfer of knowledge and skills from one organization to the other (Arrow, 1962), I study the effect of mobility of highly-skilled workers on firm innovation outcomes. Thus, this thesis considers the role of *firm-external* resources for firms' innovative activity.

In this dissertation, I focus on the movement of scientists and engineers between organizations and how it impacts the *receiving* firm's innovative activity. As a secondary focus, this study also considers formal collaboration and licensing-in as boundary-spanning mechanisms. The aim of this thesis is to contribute to the current literature on external knowledge sourcing and innovation by providing a nuanced view of the internal and external conditions under which external knowledge sourcing leads to different innovation outcomes.

In the remainder of this first chapter I first discuss the main theories that form the backbone of the theoretical framework of this thesis. Next, I put forward the objectives and research question of this research, including its targeted contributions. The final section provides an overview of the PhD thesis.

THEORETICAL BACKGROUND

This thesis draws on three complementary literatures: organizational learning, the knowledge-based view (KBV) of the firm, and the literature on search for innovation. The following sections introduce these literatures and provide an introductory discussion on each.

Organizational Learning

The organizational learning literature follows the perspective of organizations that learn and adapt over the course of their life (Argote & Miron-Spektor, 2011; Argote, 1999; Cohen &

Levinthal, 1990; Cyert & March, 1963; Huber, 1991; March, 1991). It is argued that the ability to learn and adapt is critical to the performance and long-term success of organizations (Argote, Mcevily, & Reagans, 2003). This literature is concerned with how firms create, retain and transfer knowledge (Argote, 1999). When new knowledge is generated within firms, this is referred to as knowledge creation. Knowledge retention occurs when firms store or embed knowledge in a repository. In this way, knowledge may persist in organizations. Social networks or member networks within organizations may function as such repositories (Argote, 1999). When knowledge is transferred, be it from one unit to the other (e.g. within a firm) or between organizations, this is called knowledge transfer (Argote, 1999). Other key concepts in organizational learning are routines and history-dependency. Routines refer to the forms, rules, conventions, beliefs and technologies through which firms operate (Levitt & March, 1988). Routines cannot be deduced to individuals and therefore may survive labor turnover (Carley, 1992). As a result, routines are history-dependent and organizations develop a collective memory over time.

The literature on organizational learning has identified several ways in which firms learn (Huber, 1991). Firms can learn through simple learning-by-doing and accumulate experience in-house (Levitt & March, 1988). Yet, as mentioned earlier, knowledge may also be transferred from one organization to the other (Lavie & Rosenkopf, 2011); this is often referred to as vicarious learning. This line of research within organizational learning has increased tremendously in recent years (Argote, 1999: 8–10/147–188). Classic examples of inter-organizational learning studies include Powell, Koput & Smith-Doerr (1996) and Song, Almeida & Wu (2003). Powell et al. (1996) showed how biotechnology firms are part of networks of learning through alliances, while Song et al. (2003) stressed the importance of recruitment of competitors' skilled workers to update firm's knowledge base. Note that the organizational

learning view stresses the importance of the individual: organizations learn through the learning of its employees or ingesting new ones (Simon, 1991).

The view that employees play an important role for organizational learning and the fact that knowledge is transferable, through various channels, from one firm to the other is a key building block of this dissertation.

Knowledge-Based View

The knowledge-based view (KBV) has grown out of resource-based theory and posits that knowledge is the primary resource underlying new value creation, firm heterogeneity and competitive advantage (Foss, 1996; Grant, 1996; Kogut & Zander, 1992). Rather than knowledge creation, the firm's role is knowledge application; companies function as a knowledge integrating institution (Grant, 1996). The focus of the KBV is therefore on the coordination and governance of its members, who create new knowledge (Grant, 1996). The outcome of knowledge integration is organizational capability, and that contributes to the performance heterogeneity of firms. In one approach within the KBV, the individual or member of the firm is the main source of value (Felin & Hesterly, 2007). In this view, individuals are the locus of knowledge. In another approach, the locus of knowledge is rather a more social or collective phenomenon (Brown & Duguid, 1991; Kogut & Zander, 1992; Nahapiet & Ghoshal, 1998). Individuals operate and are embedded in a social community; this higher-order organizing principle may refer to a team, organization or network (Kogut & Zander, 1992; Phelps, Heidl, & Wadhwa, 2012).

Similar to the organizational learning literature, the KBV literature stresses the importance of knowledge available outside the firm (Felin & Hesterly, 2007; Grant & Baden-Fuller, 2004; Nickerson & Zenger, 2004). External learning (Kogut & Zander, 1992) can be

fostered through mobility (Felin & Hesterly, 2007) or alliances (Grant & Baden-Fuller, 2004). A recent empirical example studies the mobility of individuals among firms and shows how movement of employees has important consequences for firms' knowledge bases through the transfer of human assets (Campbell, Ganco, & Franco, 2011). In another recent study, Mayer & Williamson (2012) develop a theory on specific types of human capital, which is the main locus for firms' capabilities. The different types of human capital can be sourced either inside or outside the firm.

Thus, by linking knowledge resources, either at the individual-level or firm-level, to firm-level outcomes, the KBV stresses the role of knowledge generation and coordination of this knowledge. In this dissertation, knowledge within the firm and movement of knowledge across organizations is a second key building block.

Search

A final important strand of literature for this thesis is the literature on search for innovation. Search refers to the process in which innovations emerge through the effort of individuals and organizations (Fleming & Sorenson, 2001, 2004; Fleming, 2001; Laursen, 2012). The search literature has its roots in the literature on complex systems and NK modeling (Levinthal, 1997; Siggelkow & Rivkin, 2006). Invention is viewed as a recombination of existing technologies or knowledge components, and may represent solutions to complex problems that individuals and firms encounter in their activities¹ (Fleming & Sorenson, 2001; Fleming, 2001; Schumpeter, 1934). To illustrate this, the automobile is a combination of the bicycle, the combustion engine and a horse carriage.

¹ Please note that invention refers to the development or creation of a new idea, while innovation involves commercialization of an invention (Schumpeter, 1934).

Knowledge and cognition are important for search as they guide firms' and individuals' (mental) processes in finding solution to problems (Gavetti & Levinthal, 2000). Two main types of search are emphasized in the literature, partly inspired by the organizational learning literature. First, local search (i.e. exploitation) refers to the inclination to search in (technological) areas which are familiar to a firm or individual as a result of bounded rationality and experience of prior accumulated knowledge. Firms thus search along established trajectories which are created by routines and experience (Helfat, 1994; Laursen, 2012; Stuart & Podolny, 1996). Non-local search (i.e. exploration) goes beyond the knowledge base of individuals or firms, and further involves an effort to experiment and discover uncharted (knowledge) paths (Katila & Ahuja, 2002; Rosenkopf & Mcgrath, 2011; Vincenti, 1990). Naturally, non-local search requires increased effort due to uncertainty and relatively high costs (Levinthal & March, 1993; March, 1991).

Again, similar to previous theories, the search literature emphasizes the role of firm-external knowledge as it may fuel non-local search processes due to limited in-house recombination capacity (See Laursen, 2012 for a recent overview). Through boundary-spanning, firms acquire a variety of knowledge inputs that may broaden the recombination space (Rosenkopf & Almeida, 2003). Recent empirical examples that stress the importance of external knowledge sources include Fabrizio (2009) and Phelps (2010). While Phelps (2010) focuses on inter-firm alliances among firms, Fabrizio (2009) illustrates how firms tap into universities and academic scientists to develop solutions to complex problems and subsequently innovate.

The literature on search for innovation is crucial to this PhD dissertation, as all chapters are concerned with innovative activity. The idea of firm- and individual-level recombinatory search and the importance of external partners in developing innovations is another building block of this thesis.

The organizational learning, KBV and search literatures share at least four commonalities. First, each literature is concerned with the role of knowledge, particularly in the context of sustaining competitive advantage or creating innovations. Second, all deal with the inherent tension between the individual versus the firm. Third, all stress the importance of firm-internal processes as well as the need for utilization of resources that are located outside a firm's boundary. And fourth, in addition to these more meta-level commonalities, each of the three theoretical perspectives emphasize the role of labor mobility as a mechanism through which knowledge and resources cross organizational boundaries. The complementarity among these specific strands of literature has been acknowledged by prior studies that have integrated them. See, for example, Nickerson & Zenger (2004) for their integration of the organizational learning and search literature, and Grant & Baden-Fuller (2004) for their combination of the KBV and organizational learning theory. In his influential study, March (1991) incorporates an organizational learning view on firms' search processes. It is the combination of these three literatures to which this dissertation will aim to contribute, which I will postulate in further detail in the next sections.

RESEARCH QUESTION AND AIM

As explained above, this study is concerned with the effect of individual-level processes on firm-level outcomes, and is positioned at the interface of innovation management and strategy. It analyzes the effect of specific boundary-spanning mechanisms on firm innovation. In particular, this study examines the internal and external conditions under which firms are able to innovate as a result of external knowledge sourcing. The main research question of this PhD thesis is formulated as follows:

How does external knowledge sourcing affect firm-level innovative activity?

The main research question is split into two sub-questions. They state the following:

- *How does recruitment of scientists and engineers, as well as collaboration and licensing, influence different dimensions of the recipient firm's innovative output?*
- *How do firm- and individual-level factors affect the relationship between these specific external knowledge sourcing mechanisms and firm innovative activity?*

The first sub-question focuses on the external-level determinants of innovation. It examines labor mobility, and, to a lesser extent, R&D collaboration and licensing as potential knowledge transfer mechanisms. With regard to innovation, this thesis examines several indicators of innovative activity, including search patterns and patenting output. The second sub-question relates to factors that affect the relationship between external knowledge sourcing and firm innovation. It takes the perspective that employee characteristics, such as educational background and work experience, and firm-level characteristics, such as age and the intrafirm collaboration network, affect how firms integrate and subsequently draw on external knowledge for innovation. The questions are addressed in a quantitative fashion using econometric techniques and large-scale databases.

In answering the research question, this thesis aims to contribute to the aforementioned literatures in the following three respects. First, this research aims to provide insight in the association between boundary-spanning and firm innovation. In this way, it contributes to the literature on why crossing boundaries is necessary for firms to innovate (Chesbrough et al., 2006). Rather than assuming that external knowledge is beneficial, this study attempts to

complement current learning- and knowledge-based arguments concerning why firms span boundaries.

Second, this study aims to formulate explanations for the heterogeneity in firm innovation performance. Previous research has shown that while some firms have similar knowledge inputs, they generate unequal innovative output. This research seeks to explain differences in innovation performance by distinguishing between internal and external conditions that may affect the relationship between external knowledge sourcing and firm innovation. Thus, this thesis intends to add to the resource- and knowledge-based views of the firm by highlighting differences in firms' in-house resources and heterogeneous utilization of external knowledge (Cohen & Levinthal, 1990; Grant & Baden-Fuller, 2004).

Third, another contribution pertains to the multiple levels that are studied in this research. While the level of analysis is the organization, it adopts individual-, system-, and firm-level reasoning to show how these different levels are interrelated. This research plans to contribute to an increasing understanding that individuals play an important part in organizations and their performance (Felin, Foss, Heimeriks, & Madsen, 2012; Felin & Hesterly, 2007).

DISSERTATION OVERVIEW

In order to answer the research question, this dissertation research contains four empirical essays. Each of the four chapters refers to separate essays, of which three chapters are co-authored and one chapter is single-authored. Chapter 2 is co-authored with Hans Christian Kongsted. The second empirical essay is co-authored with Lori Rosenkopf. Solon Moreira is co-author on Chapter 4. The final chapter is single-authored.

Each chapter focuses on the role of individual- and firm-level antecedents of firm-level innovation outcomes. Yet, each chapter uses different concepts and definitions to describe the

individuals involved, depending on the context. R&D workers (Chapter 2), scientists and engineers (Chapter 3 and 5) and inventors (Chapter 4) are distinct and sometimes overlapping groups of individuals, but share one characteristic in common: they are highly-skilled individuals involved in innovative activity. As mentioned before, labor mobility is the main boundary-spanning mechanism studied in this research. The main type of mobility is so-called “inbound mobility” which is also referred to as hiring and recruitment. To a lesser extent, the chapters in this thesis also study formal collaboration and licensing. The main database for this dissertation is Denmark’s Integrated Database for Labor Market Research (IDA being its Danish acronym) made available by Statistics Denmark, matched with patent data from the European Patent Office (EPO) and survey data on firms’ R&D and innovative activity conducted by the Danish Centre for Studies in Research and Research Policy (referred to by its Danish acronym CFA). Chapter 2, 3, and 5 present analyses based on this Danish dataset which allows for identification of mobility of all individuals active in the Danish labor market. Chapter 4 relies on licensing data from the Deloitte Recap Database on the global licensing industry, patent data from NBER and the Harvard Patent Network Dataverse, and firm-level data from WRDS Compustat. Below the four empirical chapters are briefly introduced.

Summaries of Chapters

Chapter 2: How Does R&D Worker Recruitment Affect Firm Exploration? A Longitudinal Study of the Role of Cognitive Distance

In this essay we build on the search and organizational learning literature to investigate how R&D worker recruitment affects firms’ non-local technological search. The paper specifically focuses on individuals’ cognitive ability and firm age as moderators of the relationship between hiring and firm exploration. Using Danish employer-employee register data matched with patent

data from the European Patent Office, we analyze how recruitment of scientists and engineers affect firms' degree of exploratory search using a patent citation measure. We complement the prior learning-by-hiring literature by showing that prior recruitment of distant R&D workers is positively associated with firm exploration (Rosenkopf & Almeida, 2003). Drawing on social psychology and the diversity literature (Jehn, Northcraft, & Neale, 1999), we hypothesize, yet do not find support for, the idea that educational diversity among the incumbent R&D workers decreases the effect of distant R&D workers on firm exploration. Also, we extend the current literature on the liability of aging (Sørensen & Stuart, 2000) revealing that the effect of recruited distant R&D workers on firms' non-local search attenuates as firms mature. This study points to specific individual- and firm-level conditions which influence the impact of new employees on the ability of firms to explore new knowledge areas.

Chapter 3: Tapping into Industry and Academia: Inbound Mobility, R&D collaboration and Substitution Effects

The second essay combines the knowledge-based view of the firm with the organizational learning and search literature to examine how simultaneous use of different boundary-spanning mechanisms affects firm innovation. We specifically investigate how inbound mobility and collaboration interact when firms use these mechanisms to tap into two distinct knowledge domains: industry and academia. Three independent data sources, including employer-employee register data, survey data, and patent data are analyzed and reveal that recruitment and collaboration do not lead to innovation synergies, but instead substitute for one another. This substitution effect is present in both within-domain and across-domain boundary-spanning. We extend the scarce literature on the costs related to the use of external knowledge (Laursen &

Salter, 2006). Firms may experience negative marginal returns with regard to innovation when they concurrently source similar and dissimilar knowledge domains with a different mechanism.

Chapter 4: All for One and One for All: How Intrafirm Inventor Networks Affect the Speed of External Knowledge Recombination

In Essay 3 we draw on the organizational learning, knowledge-based view and search literatures to examine the effect of intrafirm networks on the speed with which firms integrate external knowledge. In particular, this study focuses on the network density, average tie strength, and diversity of inventor networks within firms. The dataset includes 113 global pharmaceutical firms active in technology licensing from 1986 to 2003. Results from an event history study reveal that the time it takes for a firm to integrate external knowledge into its own innovation increases with technological distance. We extend the knowledge-based theory of the firm (Grant, 1996; Kogut & Zander, 1992) by showing that dense and diverse inventor networks shorten the time to recombine distant external knowledge. This suggests that networks and social communities within firms may shape communication and knowledge exchange, which is crucial in solving complex problems (Singh, Hansen, & Podolny, 2010). Moreover, this essay contributes to the absorptive capacity literature (Cohen & Levinthal, 1990) by exploring the largely neglected dimension of the speed with which firms absorb knowledge.

Chapter 5: Bound to the Ivory Tower? Mobility of University Scientists as a Driver of University-Industry Collaboration

The fourth and final essay of this thesis examines the influence of scientist mobility from academe into for-profit firms on a firm's propensity to engage in R&D collaboration with universities. Drawing on human and social capital theory, I study how scientists' academic

experience and firms' science base affect the relationship between scientist recruitment and firm-university collaboration. A unique dataset, which combines employer-employee register data with survey and patent data, reveals that firms are more likely to collaborate with university when they engaged in prior recruitment from academia. In contrast to the prediction that the impact of scientists' recruitment increases with individuals' academic experience, the findings suggest both novice and seasoned scientist recruitment are positively associated with firms' likelihood to collaborate with universities. This gives credence to prior work which has emphasized the role of skilled graduates as a driver of university-industry links (Gibbons & Johnston, 1974; Salter & Martin, 2001). Yet, science-dominated firms do not increase their likelihood of collaborating with academia following prior scientist recruitment. This highlights the role of available knowledge resources within the firm (Grant, 1996) and access to knowledge beyond the firm's boundaries through alternative mechanisms (Rosenkopf & Nerkar, 2001).

Figure 1 provides an overall conceptual model of the relationships which are tested in this dissertation. Chapters 2, 4 and 5 deal with the relationship between boundary-spanning and firm innovation, and explore several moderating factors. Note that the likelihood to collaborate with universities is interpreted as innovative activity, since innovation and university collaboration are highly correlated. Chapter 3 instead focuses on how two boundary-spanning mechanisms interact with regard to firm innovation. A quick overview of the specific empirical specifications of the four chapters is provided in Table 1. Chapter 2 explains the degree to which firms explore new knowledge areas using a fractional response model. A zero-inflated negative binomial model that explains the citation-weighted patents firms produce is provided in Chapter 3. Chapter 4 is a technology-level study which explains the time to external knowledge recombination with a hazard model. The fifth chapter estimates logit models on the likelihood to

collaborate on R&D with university. The final chapter, Chapter 6, will answer the main research question based on the four essays. It also includes a general reflection on how this dissertation fits into the broader theory, including organizational learning, KBV and search for innovation. Moreover, the final chapter will discuss the limitations of this study and formulate possible avenues for future research.

Insert Figure 1 around here

Insert Table 1 around here

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Figure 1. Conceptual Model

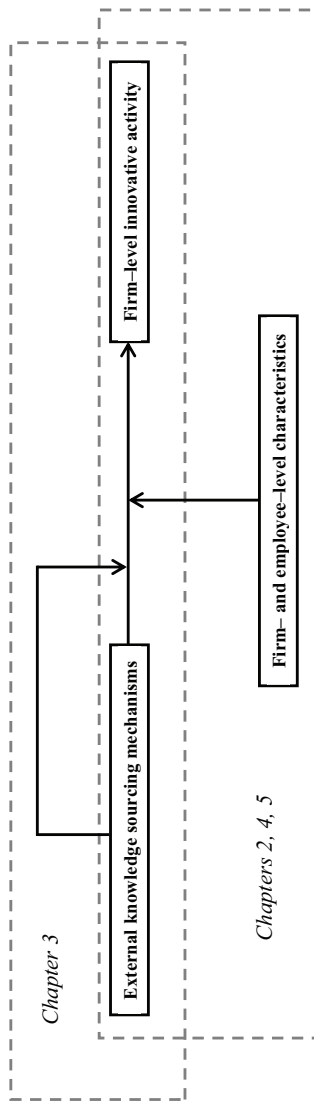


Table 1. Overview of the PhD Dissertation

Chapter	Data	Unit of Analysis	Dependent variable	Method
1. Introduction				
2. How Does R&D Worker Recruitment Affect Firm Exploration? A Longitudinal Study of the Role of Cognitive Distance	IDA data from Statistics Denmark and patent data from the EPO	Firm-level	Degree of exploratory innovation	Fractional response model
3. Tapping into Industry and Academia: Inbound Mobility, R&D Collaboration and Substitution Effects	IDA data from Statistics Denmark and patent data from the EPO and Danish surveys from CFA	Firm-level	Innovative performance	Zero-inflated negative binomial model
4. All for One and One for All: How Intrafirm Inventor Networks Affect the Speed of External Knowledge Recombination	Deloitte Recap Database, NBER patent project, Harvard Patent Network Database and WRDS Compustat	Technology-level	Time to external knowledge recombination	Log-logistic hazard model with gamma frailty
5. Bound to the Ivory Tower? Mobility of University Scientists as a Driver of University-Industry Collaboration	IDA data from Statistics Denmark and patent data from the EPO and Danish surveys from CFA	Firm-level	Likelihood of R&D collaboration with university	Logistic regression
6. Conclusion				

CHAPTER 2

HOW DOES R&D WORKER RECRUITMENT AFFECT FIRM EXPLORATION? A LONGITUDINAL STUDY OF THE ROLE OF COGNITIVE DISTANCE

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ABSTRACT. R&D worker hiring has been characterized as an important boundary-spanning mechanism through which firms search unexplored knowledge areas. In this paper, we examine the impact of the cognitive distance between recruited and incumbent R&D workers on the degree to which recipient firms explore new knowledge areas. In addition, we study the role of educational diversity among incumbent R&D workers and firm ageing in the association between hiring and firm-level exploratory search. Combining Danish employer–employee matched panel data with patent data from the European Patent Office for the period 1999–2004, we find that the cognitive distance between R&D recruits and incumbent R&D workers has a positive impact on the hiring firm’s subsequent degree of exploratory search. Whereas we do not find significant effects of educational diversity, we do reveal that the positive relationship between cognitive distance and the subsequent degree of firm exploration attenuates as firms mature. This study advances our understanding of how the mobility of problem-solvers affects the ability of firms to explore new knowledge areas and complements the literature on the liability of maturity.

KEYWORDS: learning-by-hiring, exploratory search, cognitive distance, labor mobility, liability of aging

INTRODUCTION

More than two decades ago, James March emphasized the introduction of “occasional newcomers” and “individuals with untypical skills” for organizational learning, arguing that firms may gain from their knowledge diversity (March, 1991: 79/83). Dissimilar external resources are key in balancing the natural tendency of firms toward the exploitation of familiar knowledge with the exploration of distant knowledge (March, 1991). Firms tend to search for local solutions to problems due to prior knowledge and experience accumulated in the research and development (R&D) department (Helfat, 1994; Levitt & March, 1988; Nelson & Winter, 1982). To overcome local search processes, firms may thus hire engineers and scientists (so-called *R&D workers*) to explore previously unknown knowledge areas (Rosenkopf & Almeida, 2003). Exploratory search (synonymous with non-local search and boundary-spanning) is fundamental to a firm’s long-term adaptability (Levinthal & March, 1993) and survival (March, 1991). Despite the general consensus that tapping into external knowledge sources with mechanisms such as recruitment or alliances enables firms to overcome local search behavior, the origins of exploratory search are far from established (cf. Lavie, Stettner, & Tushman, 2010; Phelps, 2010).

The *learning-by-hiring* literature points to firms hiring R&D workers to acquire new knowledge (Lacetera, Cockburn, & Henderson, 2004; Singh & Agrawal, 2011; Song, Almeida, & Wu, 2003). This literature has mainly focused on the effect of recruitment on the likelihood of knowledge transfer between source firm and hiring firm (and vice versa), as measured by patent citations (Corredoira & Rosenkopf, 2010; Rosenkopf & Almeida, 2003; Song et al., 2003). However, few attempts have been made to assess the impact of recruitment on firms’ balance between exploitation and exploration (see for an exception Tzabbar, 2009). More specifically, we address two limitations in the learning-by-hiring literature. First, we examine how the

individual characteristics of recruited R&D workers affect firm-level search processes, and second, we study how firm-internal characteristics moderate the recipient firm's ability to learn from distant recruits and subsequently explore new knowledge areas.

We build on the search and organizational learning literature to develop a set of hypotheses that predict how the recruitment of R&D workers affects the degree to which firms explore untamed knowledge areas. Complementing the current technological approach towards R&D workers (e.g. Tzabbar, 2009), we emphasize the as-yet-unexplored role of individuals' cognition in shaping their problem-solving and recombinative abilities. We predict that recruiting R&D workers with dissimilar cognitive characteristics to the incumbent R&D workers already employed by the recipient firm increases a firm's ability to engage in exploration. We define cognitive distance based on R&D workers' educational background, as the level and area of education shapes individuals' cognitive ability (Holland, 1973; Spence, 1973). Subsequently, we focus on two contingencies that potentially have an impact on the integration of new R&D recruits and, as a result, the level of novelty involved in firms' knowledge recombinations. First, we explore how heterogeneity in educational background among incumbent R&D workers (Dahlin, Weingart, & Hinds, 2005) affects the way in which firms absorb newly hired workers. Second, we consider the implicit claim in the liability of maturity literature that established firms face difficulties in implementing novel solutions proposed by R&D hires, as a result of their accumulated knowledge in a specific area (Sørensen & Stuart, 2000).

We test our hypotheses on fine-grained employer–employee register data from Statistics Denmark in combination with European Patent Office (EPO) patent application data for the period 1999–2004. Prior research has used information contained in patents to identify individual mobility, relying on the disambiguation of inventor names and, more importantly, on

inventors patenting both before and after their move from one organization to another. Instead, the data from Statistics Denmark allow us to identify annual mobility patterns for the whole population of Danish R&D workers. Our data include firms from 12 different industries, which improves the generalizability of our results. In addition, we take great care in addressing issues related to unobserved heterogeneity among firms, by using pre-sample patent information, and indicators of strategic change, by controlling for entering top management team members.

Our study makes several contributions to the literature. First, we contribute to the learning-by-hiring literature by showing that the cognitive distance between the recruited R&D workers and the incumbent R&D employees plays an important part in a recipient firm's ability to produce innovations that draw on new knowledge areas. This finding goes beyond the former focus on knowledge transfer in the technological realm (e.g. Song et al., 2003), and complements the findings from recent studies (Tzabbar, 2009). Second, the main focus of the search literature hitherto has been on alliances (Lavie & Rosenkopf, 2006; Phelps, 2010). We add to the limited evidence that considers labor mobility as one of the origins of firm-level exploratory search behavior. In particular, we emphasize individuals' cognition and mental models in the way in which they approach and solve problems. Our third contribution lies in our finding that certain firm characteristics limit the integration of distant workers, which complements the prior literature on firms' absorptive capacity (Volberda, Foss, & Lyles, 2010).

The structure of this paper is as follows. The next session introduces the relevant prior literature and is followed by the hypotheses development. Subsequently, the methods section introduces the data and variables used in this study. The next section presents our results, and is followed by robustness checks. The final section provides both theoretical implications and implications for managers.

THEORETICAL BACKGROUND AND HYPOTHESES

To understand how R&D worker hiring affects a hiring firm's exploratory search, we build on several streams of literature, including literature on the search for innovation, organizational learning, and cognitive distance.

Knowledge Recombination and Exploratory Search

An innovation is the outcome of an invention that is commercialized by a firm. Inventions are the result of a search process performed by inventors in firms and involve problem-solving (Nickerson & Zenger, 2004). Successful search processes eventually result in the recombination of existing knowledge components (Fleming, 2001; Fleming & Sorenson, 2001; Hargadon & Sutton, 1997; Schumpeter, 1934). Search is an uncertain process that is affected by bounded rationality and the experience of prior accumulated knowledge (Fleming, 2001; Fleming & Sorenson, 2004). The literature distinguishes between two archetypes of search: local and non-local search (March, 1991). Local search or exploitation is captured by terms like refinement, efficiency and selection (March, 1991: 71) and builds upon the knowledge, skills, and structures already present in the firm (Jansen, Van Den Bosch, & Volberda, 2006). This type of search creates knowledge that is close to the current knowledge base of the firm (Stuart & Podolny, 1996). As a result, exploitative search typically leads to incremental innovations and provides short-term benefits to the firm, due to its reliability and low search costs (Laursen, 2012; Lavie et al., 2010; Rosenkopf & Almeida, 2003). In contrast, exploratory or boundary-spanning search refers to processes such as variation, experimentation, and discovery (March, 1991: 71; Rosenkopf & Nerkar, 2001). This type of search involves a "conscious effort to move away from current organizational routines and knowledge bases" (Katila & Ahuja, 2002: 1184). Consequently, exploratory search creates inventions in knowledge areas new to the firm, and

this process involves uncertainty and relatively high costs, which naturally limit the firm's willingness to engage in exploratory activities (Levinthal & March, 1993; March, 1991). However, engaging in non-local search is important as it shapes a firm's adaptability in the long run and ultimately its survival (Levinthal & March, 1993; Phelps, 2010). In short, while an exploitative innovation builds upon the skills and knowledge already present in the firm, an exploratory innovation refers to "the creation of technological knowledge that is novel relative to a firm's extant knowledge stock" (Phelps, 2010: 892).

Learning-by-Hiring and Cognitive Distance

Since the internal environment of a firm has limited opportunities for non-local search, knowledge outside the firm boundaries is likely to be a relevant source for novel recombinations. Accordingly, firms utilize a variety of external knowledge sources to broaden their search scope (e.g. Rosenkopf & Almeida, 2003). The tacit and complex nature of knowledge, however, inhibits the smooth transfer of knowledge across firm boundaries (Kogut & Zander, 1992; Polanyi, 1966). In this respect, mobile individuals prove to be carriers of complex knowledge between firms (Arrow, 1962) and enable firms to adopt new processes and introduce products and services based on the inflow of new knowledge (Ettlie, 1985). This is in line with Simon (1991), who argues that "an organization learns in only two ways: (a) by the learning of its members, or (b) by ingesting new members who have knowledge the organization didn't previously have" (Simon, 1991: 125). However, hiring new employees does not equal organizational learning due to the organizational routines and knowledge embedded in the social fabric of the firm (Kogut & Zander, 1992; Marengo, 1996). Consequently, scholars have become increasingly interested in how and when labor mobility affects organizational learning (Argote, 1999; Palomeras & Melero, 2010).

In particular, the learning-by-hiring literature has scrutinized highly skilled workers like engineers and scientists. They bring complex technical or scientific knowledge that may enhance or expand the current technological capabilities of hiring firms (Groysberg & Lee, 2009). In its original definition, learning-by-hiring is defined as “the acquisition of knowledge from other firms through the hiring of experts” (Song et al., 2003: 352) and follows early works claiming that organizations learn through recruitment (Arrow, 1962; Levin et al., 1987). Mostly this stream of research has paid attention to inter-firm knowledge transfer. Various studies indeed have shown that hiring firms draw upon the knowledge of the previous employers of new recruits (Rosenkopf & Almeida, 2003; Singh & Agrawal, 2011; Song et al., 2003) and conversely those firms that lose employees may also benefit from reverse knowledge transfer through social ties (Agrawal, Cockburn, & McHale, 2006; Corredoira & Rosenkopf, 2010; Somaya, Williamson, & Lorinkova, 2008). This literature makes a recurrent claim that firms can overcome their predominant focus on local search through the recruitment of R&D workers, which thus serves as a measure to balance exploitation and exploration (Rosenkopf & Almeida, 2003; Tzabbar, 2009).

The degree to which a firm is able to explore new knowledge areas hinges upon the relative novelty of knowledge and skills that individual R&D workers bring. To understand the extent to which hired R&D workers bring new knowledge and skills to the hiring firm, we draw on the concept of cognitive distance (Nooteboom, 2000; Wuyts, Colombo, Dutta, & Nooteboom, 2005). The concept of cognitive distance refers to the distance in the ways in which actors perceive, interpret, understand, and evaluate the world according to mental frames (Gavetti & Levinthal, 2000; Gilsing, Nooteboom, Vanhaverbeke, Duysters, & Vandenoord, 2008; Wuyts et al., 2005). Cognitive distance is thus a relational concept that denotes the separation between two entities, in this case R&D workers from inside and outside the firm’s

boundaries. The literature on cognitive distance claims that with increasing distance between agents, opportunities for novel combinations arise because the interactions between agents with divergent mental frames foster new links and connections between knowledge components (Nooteboom, 2000). Note that cognitive distance is a broader concept than the commonly used technological distance concept, which refers to differences in agents' technical abilities. Distance (between firms) from a technological viewpoint has for instance been used in the prior literature on the mobility of engineers in the semiconductor industry (e.g. Song et al., 2003). Going beyond the mere technological realm, the aim of this paper is to understand how firm-level search is affected by the cognitive differences among R&D workers, that is, the differences in mental activity including perception, sense-making, inference, and value judgments (Nooteboom, Vanhaverbeke, Duysters, Gilsing, & Van Den Oord, 2007). This broader definition of distance corresponds to our focus on highly educated workers who come from a variety of backgrounds and differ in how they solve problems (Helfat, 1994). Consequently, we define cognitive distance in terms of the separation between individuals rather than between firms, as R&D workers are the agents of knowledge recombination within a firm's boundaries.

Recruitment and cognitive distance. Hiring experts from other firms and universities provides the recipient firm with novel knowledge and skills (Song et al., 2003). Skilled individuals thus act as boundary-spanners when they move from one organization to another and they may provide the receiving firm with heterogeneous knowledge inputs. We argue that the impact of R&D worker recruitment on firms' ability to engage in exploratory search varies with individuals' cognition. The dissimilarity of hired R&D workers' cognitive ability depends on the cognitive minds that a hiring firm already has at its disposal. Thus, the available incumbent R&D workers define the distance of new R&D recruits.

We propose that the recruitment of cognitively dissimilar R&D workers contributes positively to the hiring firm's likelihood of exploring new knowledge areas. Three mechanisms underlie this claim. First, distant R&D workers increase the opportunity space for knowledge recombination (Almeida & Kogut, 1999). Hiring firms and their incumbent R&D workers may use previously unknown knowledge components and skills from distant recruits recombined with internally available knowledge. The likelihood that a recruiting firm will engage in non-local search therefore increases with the availability of new knowledge and skill sets from distant workers. Second, cognitively distant R&D workers may also provide a fresh and alien perspective on a firm's current way of solving problems. The cognitive maps that R&D workers bring with them to the hiring firm may guide them differently through the search process (Fleming & Sorenson, 2004), which could result in different products and processes. Third, the impact of dissimilar R&D workers may also penetrate the firm's search process by providing access to a broader community of practice to which individuals relate (Brown & Duguid, 1991; Gittelman, 2007). Consequently, the recruitment of cognitively distant R&D workers may foster the development of new perspectives on problem-solving and the implementation of novel recombinations.² Following these arguments, our baseline hypothesis states:

Hypothesis 1: The cognitive distance between new R&D hires and incumbent R&D workers at the hiring firm has a positive relationship with the hiring firm's subsequent degree of exploratory search.

² Prior research has also pointed out the costs related to increasing cognitive distance, for instance as a result of a lack of mutual understanding. This could give rise to the idea that cognitive distance has an inverse u-shaped relationship with exploration. We address this important issue in the discussion section, in which we provide arguments for why our context is not likely to be affected by such costs.

Educational diversity among incumbent R&D workers. Although hiring cognitively distant R&D workers provides the hiring firm with access to novel knowledge, we argue that the positive effect is contingent upon the level of educational heterogeneity among the hiring firm's incumbent R&D workforce. Educational diversity refers to the different skill sets and knowledge that R&D workers within the hiring firm possess as a function of their educational background. Educational diversity is a concept similar to functional background diversity, except that education does not involve social categorization, as is the case with functional diversity (Bunderson & Sutcliffe, 2002; Dahlin et al., 2005). Two opposite views exist on the role of diversity with regard to the use of external knowledge and innovation. Following the literature on absorptive capacity, diversity of backgrounds or expertise available within the firm increases a firm's ability to exploit external knowledge (Cohen & Levinthal, 1990). Diversity among employees increases the likelihood that the incoming information will match what is already known, and therefore facilitates subsequent innovative capacity. However, we follow an alternative view, as educational diversity is likely to hamper the use of distant R&D workers in the process of exploration. This is the case in particular because we aim to explain the degree of exploratory search performed at the hiring firm, rather than general innovative capacity.

The diversity literature provides three main reasons why a diverse group of incumbent R&D workers at the hiring firm may have a negative impact on the relationship between cognitive distance and subsequent exploratory search. First, the impact of distant R&D hires declines with increasing educational diversity, because knowledge duplication is more likely to occur (Haunschild & Beckman, 1998; Tzabbar, 2009). The marginal effect of distant hires decreases with increasing educational diversity at the hiring firm, because the knowledge from distant hires is likely to overlap with that of the incumbent R&D workers and thus does not contribute to a higher exploratory output. Second, the integration of distant R&D workers

requires interaction and communication among incumbent R&D workers. The development of collective and shared knowledge among diverse incumbent R&D workers is problematic, because common conceptual ground is absent (Dahlin et al., 2005). As a result, educational diversity may incur high communication costs and coordination problems due to a lack of mutual understanding between the incumbent R&D workers in the hiring firm (Hambrick, Cho, & Chen, 1996; Jehn, Northcraft, & Neale, 1999). Third, educational diversity also negatively affects the impact of distant R&D workers on the firm-level exploratory search, because incumbent R&D workers may experience an overload of information. An R&D worker employed at a hiring firm that displays a high variety of educational backgrounds may experience misunderstanding and confusion when distant R&D workers join the firm (Laursen, 2012). This, in turn, may lead to a suboptimal search and the termination of search processes and exploratory projects at the hiring firm. The second hypothesis therefore states:

Hypothesis 2: The positive effect of cognitive distance between new R&D hires and incumbent R&D workers on the hiring firm's subsequent degree of exploratory search is negatively moderated by the educational diversity among the hiring firm's incumbent R&D workers.

Firm ageing and accumulated knowledge. The impact of the recruitment of distant R&D workers on the hiring firm's degree of exploration is likely to be affected by the experience the firm has accumulated over time. The search literature has provided evidence of the idea that routines and expertise in knowledge areas that are built up over the years may lead to a higher rate of firm innovation (Sørensen & Stuart, 2000). In contrast to this, mature firms tend to exhibit minimal exploratory search behavior (Sørensen & Stuart, 2000). The main reason for

this relates to the fact that over time firms accumulate knowledge in specific knowledge areas and showcase path-dependent behavior (Levinthal & March, 1993; Nelson & Winter, 1982). As a result, experienced firms are likely to exploit those inventive areas in which they have been successfully active over the years.

We extend this intuition by our claim that firms suffer from a liability of maturity in terms of exploration when they engage in the recruitment of R&D workers. We posit that mature firms experience difficulties in implementing fresh views from distant hires. Two mechanisms are at the core of our argument. First, the search routines or repositories of organizational knowledge within a firm become rigid over time and tend to favor the dominant type of solutions to problems (Ahuja & Lampert, 2001). Even the labor turnover is not likely to change the collective memory of a firm (Carlile, 2002). Built-up routines thus limit firms' flexibility by restricting their range of potential adaptation activities. When distant R&D workers enter a mature firm, they are therefore less likely to change the status quo, that is, the current way of search for new inventions. Second, firm ageing also impedes the integration of distant R&D workers, because older firms are likely to have built up expertise in a few related knowledge areas. Cognitively distant R&D workers bring knowledge and skill sets in which the firm lacks a deep understanding of the know-how and know-what. The lack of familiarity (Cohen & Levinthal, 1990) inhibits firms from successfully developing exploratory inventions with the input from distant hires. In line with these arguments, the third hypothesis states:

Hypothesis 3: The positive effect of cognitive distance between new R&D hires and incumbent R&D workers on the hiring firm's subsequent degree of exploratory search is negatively moderated by the hiring firm's age.

DATA AND METHODS

Register and patent application data. We test the aforementioned hypotheses using a comprehensive data set of Danish employer–employee register data in combination with European Patent Office (EPO) application data. The Danish Integrated Database for Labor Market Research (IDA being its Danish acronym) is a detailed employer–employee register database, which has been updated annually in November from 1980 onwards (Kaiser, Kongsted, & Rønde, 2011; Timmermans, 2010). The main advantage of this data set is that we are able to measure individual mobility directly, compared with previous studies that rely on patent data to identify mobility (Almeida & Kogut, 1999; Song et al., 2003; Tzabbar, 2009). We utilize patent application data from the EPO to identify the technological activities of Danish firms. Although not all innovations are patented (Wu, 2011), patent data have been widely used to measure inventive output (Griliches, 1990). Our focus on a single country, Denmark, maintains reliability, consistency, and comparability across firms (Griliches, 1990; Yang, Phelps, & Steensma, 2010). We merged the IDA data with firm-level balance sheet data (FIDA) and European Patent Office (EPO) patent application data. Due to a structural break of unique firm identifiers in 1999 and lags in reporting at the European Patent Office (EPO), our final data set consists of all Danish patenting firms, their patent applications, and their hiring for the period 1999–2004.

R&D workers. To determine whether a worker is potentially involved in R&D, we used information on individuals' highest attained level of education and their occupation. The worker must hold at least a bachelor degree in engineering or natural sciences, including veterinary, agricultural, and health sciences. In terms of occupation, we include workers who are employed in job functions that require a high level of skills (equivalent to professionals and managers). This definition follows the Danish version of the International Standard Classification of

Occupations (ISCO) from the International Labour Organization. The main tasks of the professionals we study in this paper “consist of increasing the existing stock of knowledge, applying scientific and artistic concepts and theories to the solution of problems, and teaching about the foregoing in a systematic manner” (ILO, 2004). In addition to this, the person must be between 20 and 75 years old and not yet retired. We follow Kaiser et al.’s (2011) definition of R&D workers. It relies on the finding of prior studies that most inventors have a tertiary education (Giuri et al., 2007; Kaiser, 2006) and perform a job function that involves problem-solving. We believe that individuals with these characteristics are likely to be involved in search and inventive activity.

Hiring. The IDA database provided us with a complete career history of R&D workers. R&D workers were recorded as mobile when they change employer. Due to the richness of the data, we are able to distinguish hiring from splits, spin-offs, mergers, and acquisitions among firms. Moreover, we extend the idea of learning-by-hiring through the inclusion of recruits from both firms and universities, because university researchers are likely to affect firm-level search processes (Ejsing, Kaiser, Kongsted, & Laursen, 2012; Gibbons & Johnston, 1974; Gruber, Harhoff, & Hoisl, 2013).

Firms. Danish patent applications were matched to firm identifiers based on assignee name. Based on the firm identifier we were able to match the patent applications with the IDA and FIDA at the firm level. In the sample, we included firms that have at least one R&D worker and have engaged in prior patenting (due to the nature of the dependent variable). The firms are from 10 different industries (see Table 1) and have on average 751 employees (median 293 employees). We excluded governmental organizations from the analysis. Compared with previous studies on mobility and search, which have focused on firms within a single industry (e.g. Rosenkopf & Almeida, 2003), our analysis relies on a cross-industry setting. Our final

sample consists of 197 across-industry firms and 436 firm-year observations for the period 1999–2004.

Insert Table 1 around here

The Dependent Variable

Exploratory innovation. We follow the prior research by characterizing exploratory innovation as a manifestation of the exploratory search processes of the firm³ (Benner & Tushman, 2002; Phelps, 2010; Rosenkopf & Nerkar, 2001). The dependent variable represents the utilization of knowledge that is novel relative to the firm’s existing knowledge stock. We measure the level of exploratory search at the firm level utilizing patent citations from patent applications, in line with previous studies (Benner & Tushman, 2002; Benner & Waldfoegel, 2008; Katila & Ahuja, 2002; Phelps, 2010; Wu, 2012). We prefer to use patent citations over methods using patent classes connected to firms’ focal patents (e.g. Gilsing et al., 2008), because the citations to prior art reflect the recombinative nature of search (Katila & Ahuja, 2002). One concern that may arise with our use of patent citations is related to the patent application process. Particularly in the case of Europe, patent examiners at the patent office add citations to prior art (Criscuolo & Verspagen, 2008). From a knowledge transfer viewpoint, one may therefore question the usefulness of backward citations. Nevertheless, for the purpose of providing a complete picture of the knowledge base of a firm, examiner-added citations are crucial, as firms (and their inventors and patent attorneys) are not necessarily fully aware of the prior art that relates to their work.

³ We acknowledge the fact that technological search is a process (March, 1991). Our measure relies on patents, which essentially are the result of successful search processes. However, we believe that the exploratory content of produced patents provides a consistent proxy for exploratory firm behavior.

The use of patent applications is preferred to the use of patent grants, because the application date is closest to the actual search process. Applications also provide a better insight into the variety of technological activities of firms, and hence are a good indicator of exploratory technological activities (Belderbos, Faems, Leten, & Looy, 2010). For each firm i in year t we retrieved the backward citations from the patent applications. We determined for each citation whether it has been referred to as prior art in patent applications by the firm prior to year t . In line with the previous research, we use a seven-year window to assess exploratory behavior (e.g. Katila & Ahuja, 2002), because the value of knowledge depreciates over time (Argote, 1999). We compute the variable as the number of new citations (minus the self-citations) divided by the total citations for the patents of a firm in a given year. Thus, our measure is as follows:

$$\text{Exploratory innovation} = \frac{\text{no. of new citations}}{\text{total citations}}$$

Our measure represents the share of new citations and not a count of exploratory inventions, as used for instance by Gilsing et al. (2008) and Nooteboom et al. (2007). Our measure rather captures the propensity to generate exploratory innovations, independently of the firm scale (Phelps, 2010: 898). Moreover, our measure is consistent with the theory that views exploration and exploitation as two ends of a continuum (Lavie et al., 2010).

Explanatory Variables

Cognitive distance. To measure the cognitive distance between recruited and incumbent R&D workers, we follow a method that is commonly used to determine the technological position of

firms (Jaffe, 1986). It measures the distribution of patents over patent classes to position a firm in technological space (e.g. Benner & Waldfoegel, 2008; Kaiser, 2002; Sampson, 2007; Tzabbar, 2009). Following this approach, we instead use the distribution of educational backgrounds of R&D workers to determine the position of recruited workers or incumbents in cognitive space. We use the educational background to measure cognitive positions, because prior research has identified education as an important factor that shapes an individual's cognitive ability (Gruber et al., 2013; Holland, 1973; Pelled, 1996). Two main mechanisms are at the core of this claim. First, the *level* of education determines the extent to which an individual is able to utilize abstract knowledge to provide solutions to problems. This is also referred to as a second-order form of knowledge or the “knowledge of knowledge” (Gibbons & Johnston, 1974). Second, individuals develop knowledge in a specific area during their studies. Individuals with different subjects or areas of education draw from different knowledge bases and possess different skill sets. Thus, the *area* of education affects the specific maps that individuals use in their search for relevant knowledge in the problem-solving process (Fleming & Sorenson, 2004). The hired R&D workers and incumbent R&D workers are represented by a vector that counts the percentage of R&D workers in a specific educational class. Thus, by using the distribution of workers across educational classes, we aim to capture the differences in the cognitive scope between the recruited R&D workers and the incumbent R&D workers. The educational classes are based on the workers' highest completed degree and denote both area and level of tertiary education (i.e. vocational, bachelor, master, and PhD). Our sample contains 223 distinct education classes at the most detailed (8-digit) level of classification used by Statistics Denmark. Examples of educational classes include a Professional Bachelor in product development (class 40598555), a Master of Science degree in mathematics (class 65351005), a Bachelor in astronomy (60354510), and a PhD degree in veterinary sciences (class 70800030).

We measure the cognitive distance between hired workers (vector F_H) and incumbent workers (vector F_I) as an angular distance. The entries of vector $F_H = (F^1, \dots, F^S)'$ represent the shares of hired R&D workers in educational class s , $s=1, \dots, S$. This vector is updated for each year in the period 1999–2004. The formula of cognitive distance is as follows:

$$\text{Cognitive distance} = \cos^{-1} \frac{F_H' F_I}{\sqrt{(F_H' F_H)(F_I' F_I)}}$$

Our angular measure varies from 0 to $\frac{\pi}{2}$, where a value of 0 is a full overlap (i.e. identical cognitive scope) and the maximum value is no overlap (i.e. distant). This measure of separation is not sensitive to the population in a specific class (Sampson, 2007). Note that this measure does not take into account the relatedness between specific educational classes, but rather measures the overlap in the distribution of R&D workers across educational classes.

Educational diversity. The diversity of each firm's workforce is defined by the heterogeneity or variety among the incumbent R&D workers based on their educational background. We utilize the Herfindahl index, with which we determine how equally populated educational classes are with incumbent R&D workers. Let the firm have N incumbent R&D workers in total and N_s R&D workers with educational background s (based on the 8-digit educational class system). Educational diversity is then defined as follows:

$$\text{Educational diversity} = 1 - \sum_{s=1}^S \left[\frac{N_s}{N} \right]^2$$

which ranges between 0 (only one educational class being populated) and $1 - \frac{1}{s}$ (workers equally distributed across all educational classes).

Firm age. We measure age as the logarithm of the number of years since the date of founding.

Control Variables

Outbound mobility. R&D workers who *leave* our hiring firm may affect the degree of exploratory search performed at our focal firm as they retain social ties with their former colleagues, which may lead to a reverse knowledge flow (Agarwal, Ganco, & Ziedonis, 2009; Corredoira & Rosenkopf, 2010; Kaiser, Kongsted, & Rønde, 2013). We control for this social capital effect using a dummy variable with a value equal to 1 if R&D workers left the hiring firm.

Mean experience R&D worker. The cognitive and problem-solving ability of R&D workers can also be determined by their industry experience. The relative importance of education may depreciate over time as a result of on-the-job training and skill acquisition throughout the professional career of an individual (Bidwell & Briscoe, 2010). We calculate professional experience based on the labor market pension contributions of Danish individuals. To proxy for working experience, we include the mean experience of the newly hired and incumbent R&D workers for each firm-year observation.

Technological breadth. Firms characterized by broad search practices are likely to retain such practices in the future (Laursen, Leone, & Torrisi, 2010; Tzabbar, 2009). We account for

search breadth by utilizing the degree of dispersion of the focal firm's patents across Schmoch's 30 technological areas (OECD, 1994) for the five years prior to t . The Herfindahl measure varies between 0 and $1 - \frac{1}{30}$.

Co-patenting. We aim to account for alternative forms of formal or informal external sources other than R&D worker recruitment. A dummy is included that is equal to 1 if the firm co-patented in prior years.

Size. As the firm size increases, firms tend to show less exploratory behavior (Almeida, Dokko, & Rosenkopf, 2003). We include the logarithm of the number of employees.

R&D intensity. To account for the firms' investments in the creation of knowledge and absorptive capacity, we control for R&D intensity (Griliches, 1990). We construct the measure of R&D intensity by dividing the number of incumbent R&D workers by the firm's total number of employees.

Firm patent stock. We account for the patenting experience of firms by measuring their patent stock, including pre-sample patents (1978–1999). This measure captures the depth of a firm's technological resources and absorptive capacity (Cohen & Levinthal, 1990). We take the natural logarithm of the total number of patents accumulated until $t-1$.

Industry. We account for industry-specific effects by industry dummies at the level of classification listed in Table 1.

Region. We add four regional dummies to control for region-specific heterogeneity in technological opportunities and knowledge spillovers.

Year. We also add year dummies to account for year-specific effects.

Model Specification and Estimation

We express exploratory innovation as a function of cognitive distance, educational diversity, firm age, and a number of covariates. To reduce concerns of reverse causality and to avoid simultaneity, we lag the independent variables by one year. Such an approach only holds in the absence of serial correlation of the errors. We test for serial correlation using the `xtserial` command implemented in Stata (i.e. the Wooldridge test). The results suggest that the errors are not significantly serially correlated ($p = 0.08$). Our measure of exploratory search is a proportion between 0 and 1. Consistent with our dependent variable, we apply a so-called fractional response model (see, for recent applications, Phelps, 2010; Wu, 2012), which is part of the generalized estimating equations (GEEs). Fractional response models account for the fact that proportions are naturally bounded and have values at the boundaries, which raise issues in terms of inference and functional form (Papke & Wooldridge, 1996; Papke & Wooldridge, 2008; Wooldridge, 2002: 748–755). In addition to this, GEE models account for within-subject correlation, which reduces the variance of the parameters and leads to the overestimation of significance. Fitting a GEE model requires the specification of a link function, the distribution of the dependent variable, and the correlation structure of the dependent variable (Liang & Zeger, 1986; Zeger & Liang, 1986; Zeger, Liang, & Albert, 1988). First, to model the expected value of the marginal response, one needs to specify the link transformation function (Ballinger, 2004). The logit and probit response functions are appropriate in our case as we have a binary dependent variable (Papke & Wooldridge, 2008). We choose to use the probit link function (a cumulative probability function), even though the logit function leads to very similar results. Second, the next step is to specify the distribution of the outcome variable, which allows us to calculate the variance as a function of the mean response as identified in the link function (Ballinger, 2004). As the responses are binary in nature, we specify a binomial distribution. The

final step involves specifying how the responses within subjects are correlated and a suitable specification will increase the efficiency of the estimation. We choose an exchangeable correlation structure as our panel data are characterized by unbalanced observations with unequal spacing. Other correlation structures that are suitable for such characteristics, such as the independent correlation structure, provide very similar results. To sum up, according to the characteristics of the dependent variable, we estimate GEE models with a probit link function, binomial distribution, exchangeable correlation structure, and semi-robust standard errors (Ballinger, 2004; Papke & Wooldridge, 2008).

In our specification, we also aim to control for unobserved firm-specific heterogeneity. Some firms may be more prone to exploration than others for unobserved reasons. Because our model is non-linear, there is no straightforward way, such as fixed-effect estimation, to address this important issue. Instead, we aim to proxy unobserved heterogeneity in firm-level search using firm-specific historical averages of exploratory innovation. Obtaining a proxy for the unobserved permanent component by averaging the values of exploratory innovation to even out year-to-year variations follows the logic of the “pre-sample” mean estimator approach (Blundell, Griffith, & Reenen, 1995). Similar to Blundell et al. (1995), we use the availability of information during a “pre-sample” period (in our case, the years prior to 1999) on the dependent variable, exploratory innovation, although not on the explanatory variables. We decide not to rely exclusively on the pre-1999 values because that would lead to the loss of 25% of the observations. Instead, we measure a firm’s average exploratory rate by taking the average of exploratory searches performed by firms up to the most recent observation available, or year $t-1$.

RESULTS

Table 2 presents descriptive statistics and correlations for all the variables except the industry, regional, and year dummies. A visual inspection leads us to believe that no correlation is critically high. This is confirmed by the individual variance inflation factor (VIF) values, since none of them are above the value of 6 and thus they are well below the level of 10 that is usually regarded as critical (Belsley, Kuh, & Welsch, 1980). The mean variance inflation factor (VIF) is 2.28. We nevertheless re-estimate the models including variables in a stepwise manner and check for any instability in the coefficients or standard errors. This is not the case.

Insert Table 2 around here

Table 3 contains the results of the GEE panel regression models explaining exploratory innovation. Model I includes all the control variables. In model II, we add cognitive distance, firm age, and educational diversity. The subsequent models III and IV include the interaction effects between cognitive distance and educational diversity and age, respectively. The final model V reports the results of the full model.

Insert Table 3 around here

The first hypothesis predicted that *the cognitive distance between new R&D hires and the incumbent R&D workers at the hiring firm has a positive relationship with the hiring firm's subsequent degree of exploratory search*. As shown in models II to V, we find a significant and positive main effect of cognitive distance ($p < 0.01$, two-sided, model V). This result lends

support to the idea that with increasing cognitive distance between recruited and incumbent R&D workers, the hiring firm is more likely to showcase a higher degree of exploration. The second hypothesis conjectured that *the positive effect of cognitive distance between new R&D hires and incumbent R&D workers on the hiring firm's subsequent degree of exploratory search is negatively moderated by the educational diversity among the hiring firm's incumbent R&D workers*. We do not find significant support for this hypothesis in models III and V. The interaction effect between educational diversity and cognitive distance is negative although insignificant (two-sided). Our third and final hypothesis stated that *the positive effect of cognitive distance between new R&D hires and incumbent R&D workers on the hiring firm's subsequent degree of exploratory search is negatively moderated by the hiring firm's age*. In models IV and V, we include the interaction effect between firm age and cognitive distance and find support for this hypothesis. A negative and significant effect ($p < 0.05$, two-sided, model V) exists when we include the interaction between cognitive distance and firm age. We interpret this result as evidence that established firms do not benefit as much from hiring cognitively distant workers as young firms in terms of exploration.

Three results pertaining to the control variables warrant further discussion. First, we include a firm's average exploratory rate prior to the present period. This variable is positive and significant in all the estimations ($p < 0.01$, two-sided, model V). It shows a high degree of persistence in firms' exploratory behavior and also suggests that we capture some of the unobserved heterogeneity of firms related to their ability and likelihood of exploring new knowledge areas. Second, the results of models II to V suggest that with increasing mean working experience of incumbent R&D workers, firms are less likely to explore ($p < 0.05$, two-sided, model V). This may suggest that with increasing working experience R&D workers are more susceptible to the not-invented-here (NIH) syndrome and become myopic in their behavior

(Katz & Allen, 1982; Levinthal & March, 1993). Third, in contrast to what one would expect, we find a direct positive and significant effect of firm age on subsequent exploratory search in models II to V. However, this positive effect of firm age is present when controlling for the impact of patenting experience. The coefficient of the patent stock is negative and significant in all the models ($p < 0.05$, two-sided, model V), which suggests that firms' experience in patenting decreases their likelihood of engaging in exploratory behavior. The positive effect of age may be related to the likelihood of patenting or the diversity of firms' patent portfolios.

ALTERNATIVE EXPLANATIONS AND ROBUSTNESS CHECKS

In this section, we discuss the robustness of our results and address alternative explanations. As a robustness check, we estimate several models and compare the results with the GEE models in Table 4. First, we re-estimate the full model without the mean exploratory rate variable and find similar results in terms of significance. The interaction between cognitive distance and firm age is only weakly significant ($p < 0.10$, two-sided, model V-1) in this model. We also re-estimate the models with regard to key firm characteristics. To avoid concerns that our cognitive distance measure may be sensitive to firm size (although our measure is independent of size), we estimate our models excluding small firms (model V-2) and large firms (model V-3). Overall, we find identical and consistent effects in terms of direction and significance. In models V-4 and V-5, we respectively present an ordinary least squares and tobit model. With these estimated models, we find similar results when we compare them with the GEE estimations in Table 3.

As mentioned above, to reduce the concerns about the presence of unobserved heterogeneity, we include a proxy for fixed effects: the average exploratory rate of a firm since its first patent. However, one of the major concerns remaining is that the results of our analysis may be unduly affected by the presence of endogeneity. Endogeneity occurs when a regressor is

correlated with the error term (Bascle, 2008; Hamilton & Nickerson, 2003). We specifically need to deal with endogeneity of the firm's decision to hire a distant R&D worker. The decision to hire an R&D worker might be correlated with unobservable factors that also influence the exploratory behavior of R&D firms. Strategic decisions made by managers are among the possible unobserved factors that may affect the recruitment of R&D workers as well as the exploratory behavior of firms. In other words, firms that have adopted a new strategy may simultaneously decide to recruit distant R&D workers. Consequently, firms that choose to change strategy are more likely to select into the hiring of cognitively distant R&D workers (Lacetera et al., 2004; Rao & Drazin, 2002; Singh & Agrawal, 2011; Tzabbar, 2009). To reduce concerns of (innovation) strategy change, we control for top management team (TMT) change. The top management team (TMT) and CEO take strategic decisions (Tushman & Rosenkopf, 1996; Wiersema & Bantel, 1992), including decisions related to the general innovation strategy, and thus the likelihood of performing an exploratory search (Sørensen & Stuart, 2000). Thus, we aim to proxy for such innovation strategy change by including a dummy variable with the value 1 when a firm in our sample hired a new TMT member. Our results remain similar in sign and magnitude with the inclusion of this variable (Model V-6).

Insert Table 4 around here

DISCUSSION AND CONCLUSION

This study was motivated by the fact that most studies in the learning-by-hiring literature have focused on the likelihood of knowledge transfer, while only a few have examined the actual effect of hiring on the recipient firm's degree of exploratory search. At the same time, the search

literature has neglected R&D worker hiring as one of the prominent sources of firms' exploratory behavior. Finally, the learning-by-hiring literature has relied on incomplete measures of recruitment, which raises questions about the real effect of hiring highly skilled workers.

This study addressed these limitations by examining the effect of R&D worker hiring on the subsequent degree of exploratory search. We achieve this by utilizing unique firm-level data that combine patent applications with employer–employee register data. We complement the existing learning-by-hiring literature by our focus on a variety of individual-level and firm-level characteristics. Driven by the idea that formal education influences the cognitive frames of R&D workers and therefore their problem-solving ability, we predicted a positive effect on the subsequent exploratory search of the cognitive distance between R&D hires and incumbent R&D workers. At the firm level, we hypothesized a negative moderation effect of educational diversity on the relationship between cognitive distance and exploratory search. In addition, this study drew on research on the role of firm age in search processes to predict a negative moderation effect of firm age.

The results from the empirical analysis showed a positive effect of cognitive distance on the subsequent exploratory behavior of hiring firms. We interpret this finding as evidence of education as an important determinant of the problem-solving ability of individuals. However, the hiring firm's ability to explore is contingent upon firm age. These findings suggest that firm-level characteristics limit the extent to which firms can leverage learning-by-hiring as an exploration mechanism.

These results complement our understanding of learning-by-hiring and search processes in the following directions. First, consistent with the prior research, we corroborate that R&D worker hiring induces novelty in firms' search for inventions. Indeed, our findings suggest that

firms utilize hiring as a boundary-spanning mechanism, enabling them to explore new knowledge areas. Nevertheless, we need to take the individual characteristics of hired workers into account, because these determine the novelty they may bring to the hiring firm (Tzabbar, 2009). This is in line with several studies that find that the likelihood of knowledge transfer increases when the hired R&D worker possesses technical knowledge that is new to the firm (Rosenkopf & Almeida, 2003; Singh & Agrawal, 2011; Song et al., 2003). Instead of technical knowledge, our interest lies in the general cognitive abilities of R&D workers. Accordingly, we focus on the educational background of R&D workers, because education shapes cognitive abilities (Holland, 1973; Laursen, 2012). We believe that the role of education in shaping one's cognitive skills and problem-solving ability is a promising area of research within the learning-by-hiring literature and beyond (e.g. Bidwell, 2011; Bidwell & Briscoe, 2010).

This research also adds to the increasing literature on the cognitive distance between agents (Nooteboom, 2000). Cognitive distance has been mainly studied on the firm-dyad level drawing on alliance portfolios (Nooteboom et al., 2007; Wuyts et al., 2005). As a result, we know relatively little about how the cognitive distance between individuals affects firm-level outcomes. This study extends this literature by proposing that the cognition of individuals, and in particular the extent to which recruited individuals and incumbent employees are dissimilar in cognitive terms, has an impact on firm-level search outcomes.

One of the main claims in the cognitive distance literature is the inherent trade-off between the opportunities and the disadvantages of distance (Nooteboom, 2000; Nooteboom et al., 2007). With increasing cognitive distance, opportunities for novel recombinations arise, but at the same time, mutual understanding decreases. This suggests that there is an optimal cognitive distance (Nooteboom et al., 2007). In preliminary empirical analyses, we tested the idea of a curvilinear relationship between cognitive distance and the subsequent degree of

exploratory search, but did not find such an effect. There may be four explanations for this. First, our analysis only included those individuals who are likely to be part of the R&D department based on occupational and educational characteristics. Specifically, we included individuals with a specific educational background as they are most likely to contribute to firm-level search processes. This selection set-up may avoid excessively distant workers, for instance, those with a social science background. Second, firms may also simply avoid hiring R&D workers who are too distant (see Phelps, 2010, for a similar explanation from an alliance perspective). The process of hiring involves a comprehensive screening and interview process, in which those individuals who are too distant may not be hired. Third, another explanation could be that firms make the necessary investments to recombine dissimilar cognitive frames effectively with the internal knowledge available. In other words, firms and their R&D managers may have invested in their ability to absorb distant knowledge (Phelps, 2010). Fourth, another explanation for our linear finding may be related to our dependent variable. It measures the degree of exploration, based on the citations present in the patent applications. Too much cognitive distance may not necessarily affect the degree of exploration, but rather the rate of innovation.

This study did not provide evidence of negative effects of diversity. The literature on diversity is indecisive in this respect, since it deals with a key tension. On the one hand, firms may benefit from diversity, because it allows the recombination of knowledge components and supposedly increases the absorptive capacity of firms (Cohen & Levinthal, 1990; Laursen, 2012; Østergaard, Timmermans, & Kristinsson, 2011). On the other hand, firms and their managers may experience problems with regard to the coordination of cognitively different persons in the search and inventive process. Our findings are not decisive in this respect, and we believe that the concept of educational diversity, in its many dimensions, warrants future research.

A final contribution of this study is that we further extend the scarce empirical literature on the effect of aging on innovation processes (Sørensen & Stuart, 2000). The effect of age on inventive processes is twofold. First, increasing experience causes firms to rely on their competences and routines and become more efficient. This generates an increase in the number of patents (Sørensen & Stuart, 2000). However, the knowledge components underlying such innovations may be uniform in nature. That is, the same competences and routines that allow firms to innovate may lead them to exploit solely the knowledge areas that made them successful. Following organizational ecology, evolutionary thinking, and recombinatory search we therefore interpret the negative moderation effect of firm age as an example of myopic behavior. With increasing age, firms are less likely to implement suggestions from distant R&D workers beyond what they already know.

The results and contributions should nevertheless be considered in the light of the limitations of this study. First, empirically we are not able to identify interaction patterns between hired and incumbent R&D workers. In other words, we are not able to study the micro-social process of integration of the cognitive frames and knowledge of the R&D workers active in the firms' invention process. Only recently have studies investigated how knowledge from hired R&D workers diffuses within the hiring firm (Singh & Agrawal, 2011). Second, the use of patent citation data to measure exploratory search processes has limited suitability. We can only proxy for exploratory search processes by measuring the novelty of new patent applications compared with previous applications and their citations (Laursen, 2012). In particular, the use of citations is subject to criticism, because citations are also added by inventors, patent attorneys, and examiners (Alcácer & Gittelman, 2006; Criscuolo & Verspagen, 2008). In addition, firms may not patent all their inventions. Finally, despite our robustness checks, we are not able to rule out endogeneity concerns completely. We therefore hesitate to make any strong claims

about causality and want to emphasize the conditions under which hiring is associated with firm exploration.

This study also provides practical implications for managers. The findings corroborate the existing evidence that R&D managers may hire highly skilled workers who bring novel abilities to the firm when a situation demands exploration. More importantly, the findings indicate that R&D managers should direct their attention to the degree to which the new hires' abilities match those of the incumbent scientists and engineers. Our study finally suggests that R&D managers of experienced firms should devote their effort to escaping from myopic processes and making the necessary investments in the integration of R&D hires, as they may prove useful in long-term adaptation.

Overall, our study sheds light on how firms may overcome the local search bias by hiring cognitively distant R&D workers. In particular, educational background proved to be an important determinant of firm-level search processes. Still, internal and external conditions affect the extent to which firms succeed in exploration. Future research on the intersection of individual cognition, recombinatory search and firm-level change would advance our understanding of the process of learning-by-hiring.

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APPENDIX

Table 1. Descriptive Statistics on Firm-Year Observations by Industry

Industry	Obs.	Firm size		Patent stock	
		Mean	Median	Mean	Median
Farming and food	25	1880	505	39	14
Textile and paper	5	466	377	8	5
Chemicals	52	1552	738	210	32
Plastics and glass	27	847	360	49	20
Metals	14	577	379	9	10
Machinery	83	1071	427	37	12
Electrics	39	759	521	16	13
Medical	45	398	310	20	15
Gross and retail trade	20	195	144	20	11
Technical services	100	188	43	34	11
Business and other services	6	125	68	65	32
Rest	20	341	254	9	7
Total	436	751	293	51	13

Table 2. Descriptive Statistics and Correlations

Variables	Mean	S.D.	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
<i>Dependent variable</i>																	
(1) Exploratory innovation	0.844	0.214	0.000	1.000	1.00												
<i>Independent variables</i>																	
(2) Cognitive distance	0.924	0.416	0.000	1.571	0.08	1.00											
(3) Educational diversity	0.698	0.228	0.000	0.939	-0.09	-0.24	1.00										
(4) Firm age	2.951	0.961	0.000	4.644	0.11	-0.27	0.27	1.00									
<i>Control variables</i>																	
(5) Outbound mobility	0.860	0.347	0.000	1.000	-0.09	-0.27	0.47	0.19	1.00								
(6) Mean experience R&D hires	11.603	5.377	0.250	38.002	0.06	0.05	0.02	0.10	-0.05	1.00							
(7) Mean experience R&D incumbents	14.313	4.110	3.490	27.336	0.06	-0.06	0.07	0.38	-0.05	0.14	1.00						
(8) Technological breadth	0.475	0.272	0.000	0.864	-0.12	-0.08	0.30	0.01	0.18	0.00	-0.07	1.00					
(9) Co-patenting	0.044	0.204	0.000	1.000	-0.04	-0.03	0.09	0.04	0.02	-0.02	0.02	0.10	1.00				
(10) Firm size	5.540	1.645	0.693	9.152	0.05	-0.47	0.45	0.57	0.36	0.03	0.23	0.26	0.06	1.00			
(11) R&D intensity	0.150	0.128	0.003	0.667	-0.18	0.09	0.21	-0.27	0.04	-0.01	-0.13	0.10	0.02	-0.47	1.00		
(12) Firm patent stock	2.503	1.473	0.000	7.202	-0.24	-0.33	0.44	0.41	0.27	0.00	0.12	0.46	0.16	0.59	0.04	1.00	
(13) Average exploratory rate	0.898	0.112	0.482	1.000	0.41	0.06	-0.21	-0.06	-0.14	0.02	0.16	-0.24	-0.07	-0.09	-0.20	-0.55	1.00

Correlations above 0.13 are significant at the 1% level.

Table 3. Results of GEE Panel Regressions Predicting the Degree of Exploratory Innovation

VARIABLES	Model I	Model II	Model III	Model IV	Model V
Cognitive distance		0.375** (0.141)	0.633** (0.214)	0.492*** (0.146)	0.647** (0.209)
Educational diversity		-0.331 (0.334)	-0.171 (0.365)	-0.294 (0.316)	-0.195 (0.358)
Firm age		0.182** (0.069)	0.187** (0.068)	0.185** (0.067)	0.188** (0.067)
Cognitive distance × educational diversity			-0.680 (0.426)		-0.448 (0.441)
Cognitive distance × firm age				-0.252* (0.104)	-0.217* (0.109)
Outbound mobility	-0.217 (0.163)	-0.135 (0.176)	-0.127 (0.174)	-0.131 (0.174)	-0.126 (0.174)
Mean experience R&D hires	0.009 (0.007)	0.005 (0.008)	0.007 (0.008)	0.006 (0.008)	0.006 (0.008)
Mean experience R&D incumbents	-0.015 (0.013)	-0.028* (0.013)	-0.030* (0.013)	-0.028* (0.013)	-0.029* (0.013)
Technological breadth	0.075 (0.209)	0.138 (0.198)	0.121 (0.201)	0.118 (0.195)	0.110 (0.198)
Co-patenting	0.091 (0.122)	0.111 (0.127)	0.108 (0.123)	0.129 (0.129)	0.124 (0.127)
Firm size	0.140* (0.062)	0.163* (0.080)	0.148+ (0.081)	0.180* (0.080)	0.168* (0.084)
R&D intensity	0.330 (0.698)	0.778 (0.780)	0.695 (0.769)	0.864 (0.771)	0.799 (0.776)
Firm patent stock	-0.146* (0.065)	-0.159* (0.071)	-0.169* (0.068)	-0.178* (0.072)	-0.181* (0.070)
Average exploratory rate	1.519** (0.500)	1.693*** (0.512)	1.596** (0.509)	1.655** (0.523)	1.595** (0.518)
Industry dummies	Yes	Yes	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Constant	-0.655 (0.551)	-1.427* (0.599)	-0.581 (0.602)	-0.758 (0.601)	-0.673 (0.609)
Observations	436	436	436	436	436
Wald Chi ²	108.976***	142.788***	147.575***	158.001***	163.556***

Robust standard errors in parentheses; *** p < 0.001, ** p < 0.01, * p < 0.05, + p < 0.10 (two-sided)

Table 4. Additional Regressions Predicting the Degree of Exploratory Innovation

VARIABLES	Model V-1	Model V-2	Model V-3	Model V-4	Model V-5	Model V-6
	W/o expl. rate	W/o small firms	W/o large firms	OLS	tobit	TMT control
Cognitive distance	0.673** (0.206)	0.613** (0.204)	0.645** (0.214)	0.125* (0.049)	0.207* (0.082)	0.644** (0.210)
Educational diversity	-0.172 (0.365)	-0.171 (0.365)	-0.210 (0.359)	-0.022 (0.078)	-0.092 (0.130)	-0.200 (0.357)
Firm age	0.187** (0.070)	0.186** (0.068)	0.181** (0.067)	0.045*** (0.013)	0.076*** (0.023)	0.187** (0.067)
Cognitive distance \times educational diversity	-0.588 (0.449)	-0.381 (0.437)	-0.425 (0.449)	-0.086 (0.108)	-0.124 (0.179)	-0.437 (0.440)
Cognitive distance \times firm age	-0.213+ (0.110)	-0.212+ (0.110)	-0.210+ (0.112)	-0.049* (0.024)	-0.076+ (0.042)	-0.219* (0.109)
Outbound mobility	-0.159 (0.178)	-0.116 (0.171)	-0.128 (0.176)	-0.026 (0.031)	-0.011 (0.057)	-0.127 (0.173)
Mean experience R&D hires	0.007 (0.008)	0.007 (0.008)	0.006 (0.008)	0.002 (0.002)	0.001 (0.003)	0.006 (0.008)
Mean experience R&D incumbents	-0.023+ (0.013)	-0.029* (0.014)	-0.029* (0.013)	-0.006+ (0.003)	-0.008 (0.005)	-0.029* (0.013)
Technological breadth	0.148 (0.202)	0.122 (0.199)	0.093 (0.196)	0.022 (0.041)	0.016 (0.077)	0.107 (0.197)
Co-patenting	0.130 (0.134)	0.123 (0.127)	0.115 (0.137)	0.014 (0.032)	0.058 (0.049)	0.124 (0.126)
Firm size	0.215** (0.082)	0.167* (0.083)	0.175* (0.087)	0.029+ (0.015)	0.052+ (0.028)	0.169* (0.084)

R&D intensity	0.872 (0.766)	0.757 (0.783)	0.782 (0.779)	0.143 (0.161)	0.292 (0.264)	0.817 (0.772)
Firm patent stock	-0.284*** (0.061)	-0.180* (0.070)	-0.177* (0.075)	-0.031* (0.013)	-0.086*** (0.024)	-0.182* (0.071)
Average exploratory rate		1.616** (0.518)	1.600** (0.529)	0.555*** (0.153)	0.640** (0.213)	1.586** (0.518)
TMT hires					0.052 (0.168)	
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.553 (0.485)	-0.722 (0.616)	-0.616 (0.629)	0.285+ (0.164)	0.343 (0.226)	-0.676 (0.612)
Observations	436	431	412	436	436	436

Robust standard errors in parentheses; *** p < 0.001, ** p < 0.01, * p < 0.05, + p < 0.10 (two-sided)

CHAPTER 3

TAPPING INTO INDUSTRY AND ACADEMIA: INBOUND MOBILITY, R&D COLLABORATION, AND SUBSTITUTION EFFECTS

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ABSTRACT. This paper considers how two boundary-spanning mechanisms concurrently impact firm innovation. We specifically examine how *learning-by-collaborating* and *learning-by-hiring* interact when firms use these mechanisms to tap into two distinct knowledge domains: *industry* versus *academia*. We argue that companies experience substitution effects when they use both mechanisms to source knowledge in the same domain (i.e. *within-domain*). In contrast, we expect that simultaneous inbound mobility and collaboration in different domains leads to innovation synergies (i.e. *across-domain*). To examine the impact of simultaneously sourcing academia and industry through recruitment and collaboration, we utilize a unique Danish dataset which draws on three independent data sources: employer-employee register data from Statistics Denmark, R&D survey data, and patent application data from the European Patent Office. We find that firms either experience substitution effects or no effect at all, and this is evident in both within- and across-domain learning. We interpret these results as evidence of knowledge redundancies and attention-allocation problems. We contrast prior research on the benefits of involving external partners in a firm's R&D process by underscoring negative marginal returns from simultaneously sourcing organizations in similar or different knowledge domains with two distinct mechanisms.

KEYWORDS: hiring, collaboration, innovation, substitution, university-industry

INTRODUCTION

Organizations increasingly require knowledge inputs that reside outside their organizational boundaries for their research and development (R&D) activities. External knowledge facilitates learning and may bolster firms' innovative capacity in similar or different domains (Lavie & Rosenkopf, 2006; Levin et al., 1987; Mowery, Oxley, & Silverman, 1996). As a result, scholars have underscored the value of different mechanisms in acquiring external knowledge, such as R&D alliances and recruitment of skilled individuals (Gulati, 1999; Rosenkopf & Almeida, 2003; Tzabbar, 2009). At the same time, a growing body of literature has alluded to innovation synergies between internal resources and resources that reside outside firms (Cassiman & Veugelers, 2006; Dyer & Singh, 1998; Hess & Rothaermel, 2011; Lavie & Drori, 2012; Rothaermel & Alexandre, 2008). Yet, little attention has been paid to the interplay between *specific* boundary-spanning mechanisms that firms utilize to learn from external organizations, with few exceptions (e.g. Stettner & Lavie, 2013). That is, interdependencies among the different boundary-spanning mechanisms may exist, and they may either strengthen or weaken the combined effect of such mechanisms. In this study, we seek to shed light on the interaction between two mechanisms identified by prior research through which firms acquire external knowledge: (1) inbound mobility (or hiring) of scientists and engineers and (2) R&D collaboration. Specifically, we direct attention to the fact that firms use multiple mechanisms to learn from other organizations (Levin et al., 1987; Rosenkopf & Almeida, 2003) and explore how one external sourcing mechanism complements or substitutes for another in terms of innovation output.

We address this underexplored issue by investigating the possible tradeoffs and synergies between *learning-by-hiring* and *learning-by-collaborating* for firm innovation. We posit that the learning enabled by these boundary-spanning mechanisms is transferred from two

domains, namely industry and academia. While prior research has addressed how these mechanisms affect innovation outcomes in a single domain (e.g. Bercovitz & Feldman, 2007; Lacetera, Cockburn, & Henderson, 2004), research addressing the effects of simultaneous collaboration and recruitment in both domains is quite scarce (cf. Hess & Rothaermel, 2011).

Drawing a distinction between the industrial and academic knowledge domain is an important one. Notwithstanding the emergence of hybrid organizations, we argue that the knowledge provided by the industrial versus the academic domain is fundamentally different. Tapping into industry tends to provide firms with knowledge of an applied or downstream nature. In this case, collaboration or hiring attempts are primarily focused on generating and exploiting current advances in the industrial realm (Hess & Rothaermel, 2011; Lavie & Rosenkopf, 2006). Instead, upstream collaboration or hiring from universities is inherently connected to knowledge of basic nature (Cockburn & Henderson, 1996). Firms that attempt to hire from and collaborate with universities engage in a rather exploratory, yet uncertain, endeavor (Rothaermel & Deeds, 2004). Consequently, we examine whether simultaneous R&D collaboration and hiring within or across each domain act as complements or substitutes with regard to firm innovation.

Using the industry-university domain lens, we build a theory that describes when concurrent recruitment and collaboration is a complementary strategy and when we expect a substitutive relationship. We posit that simultaneous tapping into the same knowledge domain by means of collaboration and inbound mobility incurs negative performance effects due to knowledge redundancy. In contrast, we expect innovation synergies to occur when firms incorporate knowledge of disparate nature by targeting the industrial and academic with a different mechanism.

Our study draws on a unique database from Denmark for the period 2001–2004. The dataset combines three independent data sources: (1) Danish register employer-employee data, (2) survey data concerning firms' R&D and innovation activities (similar to the European Community Innovation or CIS Survey), and (3) patent application data from the European Patent Office (EPO). The main advantage of our dataset is the opportunity to identify mobility of all scientists and engineers and distinguish between scientists and engineers who previously worked in industry and those who have academic working experience prior to joining the recipient firm. In addition, the yearly surveys provide us with self-reported answers about the type of firms' R&D collaboration partners. Our zero-inflated negative binomial regression analysis relies on a total of 12608 general inbound mobility events, 691 general collaborations, and 13472 firm-year observations across multiple Danish industries in the period 2001–2004.

Using citation-weighted EPO patent applications to capture innovation performance, we primarily find evidence of negative marginal returns when firms simultaneously engage in recruiting skilled workers from, and collaboration with, external organizations. More importantly, our study reveals that firms experience substitution effects for both within- and across-domain learning. We interpret these results as an indication that firms acquire redundant knowledge in case of within-domain learning, yet experience problems related to diseconomies of scope and attention-allocation when they concurrently hire from, and engage in, collaboration with the industrial and academic knowledge domain.

Our study provides a nuanced account of tapping into knowledge sources outside the firm with different mechanisms. Our contribution to the literature on external knowledge sourcing to harness innovation is threefold. First, this study increases our understanding of the contingency effects of different external sourcing mechanisms on firm innovation. Prior research has either considered independent effects of different mechanisms (e.g. Rosenkopf &

Almeida, 2003) or examined complementary or substitution effects between external and internal resources (e.g. Hess & Rothaermel, 2011). However, the *combined effect* of simultaneously using different external or boundary-spanning mechanisms on firm-level innovation has not been studied so far. Second, we complement the growing literature on alliances and mobility with a study that distinguishes between industry and academia. Prior work on mobility has investigated recruitment from industry or universities separately (e.g. Lacetera et al., 2004), with few exceptions (e.g. Ejsing, Kaiser, Kongsted, & Laursen, 2012). Likewise, the alliance literature has examined different types of alliances but has focused less on the type of organization that firms ally with. We provide evidence that collaborating with, and hiring from, either knowledge domain has differential direct and moderating effects on firm innovation across industries. Third, we complement prior research on open innovation in which claims are made that firms may suffer from too much openness (Laursen & Salter, 2006; Lavie & Drori, 2012). We demonstrate that open strategies may incur costs and this raises questions on how firms may simultaneously source external knowledge through different mechanisms in an efficient way.

The paper is structured as follows. First, we introduce our theoretical framework and develop the hypotheses. The second section discusses the different datasets and variables used in this study. The subsequent section presents our results, following which we consider the results in light of previous work on external knowledge sourcing mechanisms in the discussion section. We conclude in the final section.

THEORY AND HYPOTHESES

Our aim is to understand how inbound mobility of scientists and engineers and collaboration with external organizations concurrently affect firm innovation. Before we develop the

hypotheses on within- and across-domain learning by means of recruitment and cooperation, we first discuss firms' search for innovation and introduce the definitions of the specific boundary-spanning mechanisms and concepts of complementarity and substitution.

A firm's innovation process involves search and problem-solving and is ultimately the result of recombination of existing knowledge components (Fleming, 2001; Hargadon & Sutton, 1997; Schumpeter, 1934). Internal personnel and resources often fail to provide all the relevant knowledge firms need to innovate. In particular, firms in high-tech industries therefore access knowledge outside the firm boundary to broaden the available search space, which may subsequently increase a firm's innovative performance (Ahuja, 2000; Powell, Koput, & Smith-Doerr, 1996; Rosenkopf & Almeida, 2003). External knowledge acquisition enables firms to combine internal with external resources and this has been shown to result in innovation synergies (Cassiman & Veugelers, 2006).

Several mechanisms have been studied through which firms cross their boundaries and access sources of external knowledge, including alliances (Arora & Gambardella, 1990; Lavie & Rosenkopf, 2006; Rothaermel, 2001), licensing (Arora & Gambardella, 2010), firm acquisition (Ahuja & Katila, 2001), and hiring of personnel (Ettlie, 1985; Song, Almeida, & Wu, 2003). Two means of external knowledge sourcing have our specific interest in this paper: R&D collaboration and inbound mobility of skilled workers. R&D collaboration is defined as cooperation or active participation in joint projects between a firm and another organization with the intention to conduct joint R&D. Joint cooperation on R&D facilitates organizational learning and enables firms to share knowledge, take advantage of scale economies in research, acquire knowledge from indirect partners, and leverage complementary assets (Grant & Baden-Fuller, 2004; Gulati & Gargiulo, 1999; Powell, White, Koput, & Owen-Smith, 2005). Inbound mobility is defined as the recruitment of highly-skilled individuals (i.e. engineers and scientists) by firms

to acquire new knowledge and skills to foster internal R&D. Recruitment allows firms to tap into an individuals' human capital accumulated through education (Fleming & Sorenson, 2004; Gibbons & Johnston, 1974) and on-the-job training (Bidwell, 2011), and firms may tap into the expertise of the prior employer (Song et al., 2003). In addition, hired engineers and scientists maintain informal contact with their previous colleagues and a wider network of professional contacts and such social ties may provide access to potentially innovation-relevant knowledge (Dokko & Rosenkopf, 2009; Somaya, Williamson, & Lorinkova, 2008). Early work on external knowledge sourcing has shown firms simultaneously utilize different mechanisms (Levin et al., 1987).

Inbound Mobility vs. R&D Collaboration

Our choice of recruitment and collaboration as main mechanisms of external learning follow prior work on boundary-spanning and innovation (Almeida, Dokko, & Rosenkopf, 2003; Rosenkopf & Almeida, 2003). Learning-by-hiring (Song et al., 2003) is different from learning-by-collaborating (Powell et al., 1996) in at least four aspects. First of all, recruitment and collaboration differ in terms of type of mechanism. Interorganizational mobility of skilled individuals is an informal mechanism of knowledge transfer, while collaboration is a formal mechanism (Ahuja, 2000; Almeida & Kogut, 1999). Second, the degree of tacitness involved in external learning is likely to be higher in case of recruitment. Individuals embody experience accumulated over the course of their career, which facilitates the replication of individual know-how and capabilities from the prior workplace. Instead, collaboration will more likely involve a combination of codified and tacit knowledge, because even though face-to-face interaction is part of the collaborative process, firms engaged in collaboration act at a distance and thus acquire codified knowledge (Grant & Baden-Fuller, 2004). Each mechanism also differs in

terms of learning. A recruited individual contributes to firm innovation with his or her limited area of expertise and is in most cases a matter of implementation (Singh & Agrawal, 2011), while collaboration involves learning of the incumbent scientists and engineers from an external organization's knowledge base. As a consequence, the effective time related to learning-by-collaborating is also different from learning-by-hiring. Learning from formal R&D cooperation takes time to ferment and is an ongoing process (Grant & Baden-Fuller, 2004). In comparison, the recruitment of an individual is a relatively fast process of learning.

Notwithstanding differences between hiring and collaboration, we argue that these mechanisms both embody "rich modes" of knowledge flows (Rosenkopf & Almeida, 2003). This means that hiring and collaboration are both mechanisms that involve knowledge transfer from one organization to another and are expected to have positive impacts on subsequent innovative performance. Knowledge acquisition through both mechanisms may either occur in the industrial or academic knowledge domain or a combination of both.

Industrial vs. Academic Knowledge Domain

External learning from industry is distinct from academia. From a value chain perspective, sourcing other firms can be characterized as downstream activity (Teece, 1992). Knowledge from the industrial domain is mainly of an applied nature and likely to be linked to commercialization of novel recombinations. Even though crossing firm boundaries can pose a challenge to some firms, tapping into other firms poses relatively few problems as it does not involve crossing knowledge boundaries. Thus, external learning from other firms is a rather exploitative activity (Rothaermel & Deeds, 2004). Instead, tapping into academic organizations such as universities can be characterized as an upstream activity (Bercovitz & Feldman, 2007; Rothaermel & Deeds, 2004). Rather than applied knowledge, universities provide firms with

state-of-the-art basic research (Gittelman & Kogut, 2003). In addition to spanning organizational boundaries, recruiting from or collaborating with universities also spans knowledge boundaries. Although risky, such exploratory behavior (Lavie & Rosenkopf, 2006) is likely to result in superior innovative performance if firms do not initially fail to incorporate basic knowledge. We propose that the distinction between the industrial versus the academic knowledge domain affects the potential for recruitment and collaboration to be complementary versus substitutive.

Combined Effects: Complementary vs. Substitution Effects

Simultaneous collaboration and hiring may be complementary to each other or may act as substitutes. Complementarity refers to the idea that the marginal return to one activity (e.g. inbound mobility) increases as the intensity of the other (e.g. collaboration) increases (Cassiman & Veugelers, 2006; Milgrom & Roberts, 1990, 1995; Parmigiani & Mitchell, 2009). Alternatively, resources or activities are substitutes if doing more of one activity reduces the marginal benefit of another (Arora & Ceccagnoli, 2006; Hess & Rothaermel, 2011).

We posit that concurrent recruitment and collaboration may lead to either innovation synergies or innovation underperformance. Given the fact that the mechanisms are intrinsically different, for example, in the extent to which they carry tacit knowledge, they may complement each other. Yet, maintaining interaction with an external organization through different activities also increases the complexity and costs of managing multiple boundary-spanning mechanisms. In addition, firms may experience diseconomies of scope and attention-allocation problems (Laursen & Salter, 2006; Ocasio, 1997), which can decrease firm innovation. Given this tension, central to our argument is the proposition that inbound mobility and collaboration are complementary or substitutive learning mechanisms dependent on whether they occur in the same or different knowledge domain. We discuss these two possibilities in turn.

Within-Domain External Learning with Both Mechanisms. We expect that simultaneous recruitment and collaboration in the same knowledge domain decrease the marginal returns to innovation. When firms engage with both mechanisms in the same domain, either the industrial or the academic domain, a similar type of knowledge is acquired. That is, learning takes place in the same domain and focuses on the same stage of the value chain. Consequently, inbound mobility and R&D collaboration become redundant in terms of innovation benefits. In such cases, the interplay between inbound mobility and collaboration shifts towards experiencing problems related to attention-allocation (Ocasio, 1997) and diseconomies of scope as time and resources are devoted to managing redundant mechanisms of learning. In line with this argument, we offer the following two hypotheses:

Hypothesis 1A: *Inbound industry mobility and R&D collaboration with industry are substitutes in such a way that the interaction between inbound industry mobility and industry collaboration negatively impacts a firm's innovative performance*

Hypothesis 1B: *Inbound university mobility and R&D collaboration with university are substitutes in such a way that the interaction between inbound university mobility and university collaboration negatively impacts a firm's innovative performance*

Across-Domain External Learning with Both Mechanisms. Concurrent R&D collaboration and inbound mobility in different domains lead to innovation synergies. In this case, firms match complementary assets as each knowledge domain provides inherently different knowledge to the

firm in question. Even though firms may struggle in combining and leveraging both mechanisms, each mechanism enhances the knowledge obtained by the other as they target different activities in the value chain. Also, even though considerable heterogeneity exists within-domain, we argue that tapping into a combination of industrial and academic knowledge domain is linked to ambidextrous behavior (Lavie & Rosenkopf, 2006; Raisch, Birkinshaw, Probst, & Tushman, 2009). In fact, firms combine utilization of relative novel and basic knowledge with an efficient process of integrating readily applicable knowledge.

Hypothesis 2A: Inbound industry mobility and R&D collaboration with university are complements in such a way that the interaction between inbound industry mobility and university collaboration positively impacts a firm's innovative performance

Hypothesis 2B: Inbound university mobility and R&D collaboration with industry are complements in such a way that the interaction between inbound university mobility and industry collaboration positively impacts a firm's innovative performance

In summary, our framework considers four sourcing types through which firms tap external knowledge and we examine four specific contingent effects on firm innovation. Figure 1 visualizes and summarizes the four boundary-spanning mechanisms we examine in this study. Figure 2 shows the conceptual model with the hypothesized relationships.

Insert Figure 1 around here

Insert Figure 2 around here

DATA AND METHODOLOGY

Data. Our research setting comprises Danish firms from a variety of industries that responded to Danish R&D and innovation surveys in the period 2001–2004. In order to test our hypotheses concerning the interplay between hiring of skilled workers and research collaboration, we rely on a unique longitudinal Danish dataset. The dataset combines three major datasets available in Denmark. First, we use the Danish Integrated Database for Labor Market Research (IDA being its Danish acronym), which is the Danish employer-employee register database (e.g. Nanda & Sørensen, 2010; Timmermans, 2010). All persons, establishments, and firms are followed annually, from 1980 onwards. The information in the database allows us to follow directly the career of all scientists and engineers in Denmark. Second, we utilize Danish R&D and innovation surveys in the period 2000–2003. These surveys are annually conducted by the Danish Centre for studies in Research and Research Policy (CFA being its Danish acronym) and around 3000 cross-industry firms responded each year. The survey is similar to the European CIS. From the survey, we extract information regarding a firm’s collaboration partners. Third, patent application data from the EPO provides us with innovation indicators. We merged the three databases on the firm-level and focused on the representative sample of Danish firms that responded to the R&D survey.

Scientists and engineers. In this paper, we specifically focus on employees that conduct R&D and add value to a firm’s innovativeness. To distinguish employees who are potentially

involved in a firm's R&D, we utilize individual information available in the employer-employee register data. The definition of a skilled worker is based on three main requirements: education, occupation, and age. First, scientists and engineers are employees with at least a bachelor degree in engineering, natural, veterinary, agricultural or health sciences. Second, they should be employed in a job function which requires a high level of skills following the International Standard Classification of Occupations (ISCO). Such a job position consists "of increasing the existing stock of knowledge, applying scientific and artistic concepts and theories to the solution of problems, and teaching about the foregoing in a systematic manner" (ILO, 2004). Also, we exclude employed individuals younger than 20 years, older than 75 years, and retired individuals.

Hiring. We recorded hiring when an individual moved to a firm from either another firm or a university. The data allowed us to distinguish recruitment from firm splits, mergers, and spin-offs. Firms in our sample annually hire on average 0.04 university researchers and 0.90 scientists and engineers from other firms (i.e. 0.94 general skilled workers). A total of 12068 inbound industry mobility events and 540 inbound university mobility events are identified.

Collaboration. In the Danish R&D survey firms self-report the use of collaboration partners for their innovation process. More specifically, firms' respondents answered the following question: "Has your company collaborated with university (or industry) in year 'X' in connection with the company's R&D? Collaboration with regard to a firm's innovation process includes active cooperation in projects regarding R&D, and other innovative activities. Licensing or other ties with external partners that involve no active collaboration with external partners is not part of R&D collaboration. In the four-year period, a total of 273 unique firms collaborate at least once only with industry, 328 firms collaborate at least once only with

academia, and 219 firms collaborate with both industry and university in the same year. Overall, 691 firms collaborate with external organizations, regardless of the organization type.

Firms. The sample of Danish firms that responded to the R&D survey was matched with the employer-employee register data through the national identification number. Patent applications applied for by Danish firms at the EPO were matched to firm identifiers based on assignee name. We excluded governmental organizations from the analysis. The final dataset includes 8966 across-industry firms and 13472 firm-year observations in the period 2001–2004 (see Figure 3 for the number of observations with each type of inbound mobility and collaboration per year).

Insert Figure 3 around here

The panel data is unbalanced, since the waves of R&D surveys target a representative sample of firms, but not necessarily the same firms. As a result, firms occur on average 1.5 times in the four-year period.

Measures

Dependent variable: Citation-weighted patents. Firm innovative performance is measured using a count of the number of patents a firm applied for at the EPO, weighted by the number of forward citations in a three-year moving window. We used patent application data as the application date is the point in time which is closest to the firm's innovation process. Citation-weighted patents are widely used to measure innovative performance (Sampson, 2007) as it indicates the number of innovations and quality of innovations that firms produce (Trajtenberg, 1990). Firms in our sample apply on average for 0.26 citation-weighted patents per year.

Focal independent variables. We measure hiring or inbound mobility as the log number of recruited scientists and engineers. Two variables are constructed to examine the impact of hiring on firm innovativeness. We distinguish between individuals hired from firms (*Inbound industry mobility*) and universities (*Inbound university mobility*). The main difference between the two types of employees is that university workers have been employed at a university. Typically, university scientists hold a master or PhD degree and have worked for several years at the university as doctoral student or post-doc. We are aware of the fact that both groups of recruits are far from homogeneous. For example, there is considerable variation among industrial and academic recruits in terms of length and area of education. In line with our theoretical framework, we are generally interested in differences in knowledge domains, and thus assume that university hires are more likely to carry knowledge with a higher degree of abstraction compared with industrial recruits.

We obtain information on collaboration partners from the Danish R&D survey. In the period 2000–2003, firms were asked with which types of external partners they had collaborated in the past year. In this paper, we focus on collaboration with Danish firms and universities. A dummy variable indicated whether firms' respondents answered positively to the question whether they maintain formal collaboration with respectively university and industry (i.e. value 1). The dummy variable took the value 0 when respondents answered negatively or in cases of a missing value. Again, two variables regarding collaboration are constructed. We distinguish between collaboration with industry (*Industry collaboration*) and academia (*University collaboration*). Note that we assume knowledge to be fairly homogeneous with each knowledge domain. Even though this is a strong assumption, the public university system in Denmark is not characterized by pronounced differences among universities, for instance, in terms of quality.

We are unable to extract more detailed data from the Danish R&D and innovation surveys in terms of type of collaboration partners.

To capture the combined effect of hiring and collaboration, we center and interact the inbound mobility and collaboration variables (Aiken & West, 1991). In line with our theoretical framework, we constructed four interaction variables: hiring from firms with firm collaboration (*Inbound industry mobility x industry collaboration*), university hiring and collaboration with academia (*Inbound university mobility x university collaboration*), recruiting from firms with university collaboration (*Inbound industry mobility x industry collaboration*), and university hiring with industry collaboration (*Inbound university mobility x industry collaboration*). Interactions in the analysis correspond to complements and substitutes, because their combined effects are different from the sum of their separate parts (cf. Hess & Rothaermel, 2011). Even though there are a varieties of ways to test for complementarity and substitution effects (see e.g. Cassiman & Veugelers, 2006), we utilize an interaction effect approach where a positive interaction indicates innovation synergies and substitution is represented by a negative interaction effect (Cohen, Cohen, West, & Aiken, 2003).

Control Variables. We added the log number of employees to control for firm size (*Firm size*) and the log number of years since the firm was established (*Firm age*), considering that old and large firms are more likely to patent. To control for executive hiring and strategy change (Boeker, 1997), we added a variable which measures the number of recruited top management team (TMT) members (*Inbound TMT mobility*). Skilled workers that leave the hiring or recipient firm are accounted for by a dummy variable (*Outbound mobility*) indicating whether a firm lost a scientist or engineer due to retirement or job change. Employees who leave a firm may indirectly affect firm-level search processes (Corredoira & Rosenkopf, 2010). We control for a firm's R&D spending to account for its investment in creation of knowledge and absorptive

capacity (*R&D intensity*). We measured R&D spending by dividing the number of scientists and engineers by the total number of employees. In addition to these control variables, we add industry, regional, and year dummies to capture sectoral, regional, and time differences in innovative output.

Model Specification and Estimation

We estimate firms' innovative performance as a function of scientist and engineer recruitment, collaboration, and the control variables. To investigate the relationships between innovative performance and hiring and collaboration, we perform a firm-level study in which we explain the number of citation-weighted patent applications. The dependent variable is a count with an excess of zeroes (97% of the observations have zero patent applications) and we therefore considered zero-inflated models. The likelihood-ratio test indicates the presence of over-dispersion and the significant Vuong statistic ($z=7.76$, $p<0.000$) indicates that we should choose a zero-inflated negative binomial model. The zero-inflated model handles over-dispersion by estimating the likelihood of observing a zero (i.e. *no patent*) using the logit specification and estimating the count of citation-weighted patent applications (i.e. *forward citations*) by a negative binomial model. The observed distribution of the dependent variable and the zero-inflated negative binomial model thus enables us to estimate two distinct processes. First, we are able to examine the predictors of the likelihood that firms patent at all with the logit model. At the same time, this model allows us to infer patenting value, because the count model estimates the number of patent applications weighted by the forward citations received in a subsequent three-year period. We cluster the standard-errors by firm to allow for within-group correlation, because observations for the same firm are likely to be correlated. The estimations are robust

using the Huber-White-sandwich standard errors to correct for heteroskedasticity. All independent variables are lagged one year.

In our specification, we aim to control for firm-specific permanent heterogeneity in firm innovativeness. To address the fact that some firms are more likely to patent for reasons that we do not observe, we follow a so-called pre-sample approach (Blundell, Griffith, & Reenen, 1995, 1999; Blundell, Griffith, & Windmeijer, 2002). We utilize the advantage of having a longer history of information for the dependent variable than the independent variables. Patenting is persistent over time and the pre-sample mean estimator based on patent stock thus acts as a “fixed-effect” estimator (Blundell et al., 1999, 2002). To do so, we included the pre-sample mean share of patent applications per firm (divided by the total number of patents) with a correction for the upward patenting trend among firms in the Danish economy (*Pre-sample mean estimator*). Firms that do not patent are given an arbitrarily small constant. Since we take the natural logarithm of this share, the variable has negative values. A dummy variable captures whether a firm patented in t-1 (*Patent dummy*) to control for state dependence.

RESULTS

Table 1 provides the descriptive statistics and correlations. Each of the individual VIF values are below the maximum value 10 (Belsley, Kuh, & Welsch, 1980), and the mean variance inflation factor (VIF) is 1.96. No correlations are high (>0.6), except the correlation between the pre-sample mean estimator and the patent dummy. The results do not alter when we remove the patent dummy. Thus, we do not find reasons that our results are unduly affected by multicollinearity. We follow a hierarchical or stepwise estimation procedure.

Insert Table 1 around here

Table 2 reports the results of the zero-inflated negative binomial model with clustered robust standard errors explaining innovative performance. As mentioned before, the zero-inflated negative binomial model estimates two models. The count model estimates the number of patent applications weighted with the number of forward citations and the zero-inflated model estimates the likelihood that a firm does not patent at all, or has the value 0. Model I to IV report the estimators for the control variables and include each of the four types of external learning mechanisms. The control variables plus all four main independent variables are added in model V. Subsequently, we added the interactions between within- and across-domain inbound mobility and collaboration in model VI to IX. The final model reports the coefficients of all variables. Note that complementarity corresponds to a positive interaction in the citation-weighted model, while a substitutive relationship is represented by a negative interaction (Cohen, Cohen, West, & Aiken, 2003). However, in the zero-inflated model, we estimate the likelihood of no patenting and therefore complementarity and substitution correspond to the opposite effects of interactions.

Insert Table 2 around here

We may now comment on the final model with regard to hypothesis testing. Hypothesis 1A predicted that inbound industry mobility and R&D collaboration with industry act as substitutes. Model X presents the first within-domain interaction between industrial recruitment

and collaboration. We find no support for hypothesis 1A. The interaction shows a positive and insignificant effect in both the citation-weighted and zero-inflated model.

Hypothesis 1B stated that inbound university mobility and R&D collaboration with university are substitutes and thus we expect a negative and significant interaction in the count model and a positive and significant interaction in the zero-inflated model. Consistent with our predication, we find that the interaction between inbound university mobility and R&D collaboration with university is negative and significant in the count model ($p < 0.05$, two-tailed). Yet, we do not find support for this hypothesis with regard to not observing a patent at all. Thus, simultaneous hiring from, and collaborating with, academia has a negative impact on innovation quality.

We stated that inbound industry mobility and R&D collaboration with university are complements in hypothesis 2A as they occur in complementary knowledge domains. We find no effect in the count model, yet in model X we unexpectedly find the opposite effect with regard to the likelihood of observing no firm patenting. The interaction effect between inbound industry mobility and university collaboration is positive and significant ($p < 0.05$, two-tailed) in the zero-inflated model. This finding suggests that firms that simultaneously hire from other firms and maintain cooperation with universities increase the likelihood of producing no patents at all.

In the final hypothesis of this paper, we stated that inbound university mobility and industry collaboration are also complements, due to targeting different knowledge domains. In model X we do not find any significant effect in either the zero-inflated or the count model. Thus, we do not find any support for hypothesis 2B.

Regarding the main effects of the four types of boundary-spanning mechanisms, we find differential effects. The final model reports on all variables and shows that inbound mobility

from university has a positive and significant effect ($p < 0.001$, two-tailed) on the number of citation-weighted patent applications. Indeed, this suggests hiring university researchers increases a firm's capacity to produce valuable patents. Furthermore, inbound industry mobility and collaboration with academia both have a negative and significant effect on the likelihood to apply for zero patents (respectively $p < 0.001$ and $p < 0.01$, two-tailed). The results suggest that these boundary-spanning mechanisms increase a firm's likelihood to apply for a patent.

With regard to the control variables, we find in the zero-inflated negative binomial models that the pre-sample mean estimator negatively and significantly predicts zero patent applications in all models (at least $p < 0.05$). In addition, the pre-sample mean estimator has a positive and statistically significant effect on the number of forward citations in all models. This suggests its importance as a control for unobserved heterogeneity at the firm-level. Also, firm size is positive and significant in most count models, which indicates that large firms are more likely to produce valuable patents. In some models, we also find evidence that firm size increases the likelihood that firms apply for a patent at the EPO. Yet, this finding disappears when we include all boundary-spanning mechanisms. This may indicate that large firms engage more in boundary-spanning, which finds support in the correlation table. It may also be the case that this finding hints at the idea that large firms are better able to incorporate several boundary-spanning mechanisms at the same time. Firm age, inbound TMT mobility, general outbound mobility, and R&D intensity do not affect either forward citations or the likelihood to apply for patents in the estimated models.

DISCUSSION

The present study was motivated by two gaps in the literature on external knowledge sourcing. First, studies have overlooked the common practice that firms simultaneously utilize different

boundary-spanning mechanisms to source external knowledge, raising the question whether different boundary-spanning activities complement or rather substitute for one another. Second, few studies have addressed the fact that firms engage in learning-by-hiring and learning-by-collaborating in two specific knowledge domains: industry and academia. We posit that each knowledge domain may have differential effects on firm innovation. In this study, we addressed these shortcomings and explored the joint and contingent effects of scientist and engineer recruitment and R&D collaboration on subsequent firm-level innovation. We specifically examined the interplay between hiring and collaboration within and across the industrial and academic knowledge domain.

Drawing on a unique multi-industry dataset, which combines employer-employee register data, R&D and innovation survey data, and EPO patent application data, we demonstrated that pursuing boundary-spanning mechanisms simultaneously can result in a marginal decrease in innovative performance as measured by citation-weighted patent applications. As hypothesized, we found partial support for the hypothesis that concurrent inbound mobility from, and collaboration, within the same knowledge domain leads to decreased innovation. We suggested that this may be due to managerial challenges and acquisition of redundant knowledge when firms tap into the same knowledge domain with different mechanisms. However, in contrast to what we hypothesized, simultaneous boundary-spanning through recruitment and collaboration across domains in some cases also associated with a marginal decrease in firm-level innovation performance. This suggests that the benefits of acquiring complementary knowledge types (i.e. basic and applied knowledge) that fit different stages of the value chain do not outweigh the costs related to maintaining multiple boundary-spanning activities.

Our findings have implications for different bodies of literature. First, our study provides insight into the costs related to the use of external knowledge and the development of open innovation practices (Chesbrough, Vanhaverbeke, & West, 2006; Owen-Smith & Powell, 2004). Paradoxically, the erosion of internal R&D as a result of, for example, the increase in mobility of skilled workers has directed firms to both make and buy R&D (Parmigiani & Mitchell, 2009). Yet, too much emphasis on external partners may paralyze firms' innovative performance. In our paper, we uncover boundaries in the extent to which firms should engage in scientist and engineer recruitment and joint research participation as part of their R&D strategy. Delicate decision-making on which boundary-spanning mechanism is beneficial for firm innovation could perhaps counteract negative effects of concurrent sourcing. Also, we did not consider firm-internal characteristics which may either strengthen or attenuate external learning (Cassiman & Veugelers, 2006; Hess & Rothaermel, 2011).

Second, to our knowledge, this is the first study in the collaboration and learning-by-hiring literature, which demonstrates the contingent effects between two alternative external knowledge sourcing mechanisms: inbound mobility and R&D collaboration. Simply controlling for alternative sourcing mechanisms or comparison of boundary-spanning channels (e.g. Al-Laham, Tzabbar, & Amburgey, 2011; Rosenkopf & Almeida, 2003; Tzabbar, Aharonson, & Amburgey, 2013) is not sufficient; our findings strengthen the idea that the contingent relationships between a variety of boundary-spanning mechanisms need to be examined.

We also extend the literature on university-industry interaction (Agrawal & Henderson, 2002; Audretsch & Feldman, 2003; Rosenberg, 1990; Stuart & Ding, 2006) by our attempt to uncover complementarities or substitution effects between hiring of academics and joint research cooperation with university. Previous research has suggested star scientists may act as translators of science and function as linchpin between basic research and, for instance,

application in drug-development (Lacetera et al., 2004; Zucker & Darby, 1996). This would suggest firms can benefit from possible complementarities between having in-house scientists and maintaining joint research projects with universities. Going beyond an external-internal framework, we find that a firm experiences decreased marginal returns to innovation when engaging in two different types of university-industry interaction.

In an attempt to uncover contingent relationships between inbound mobility and research collaboration, we acknowledge that our study is limited in the following ways. Recruitment and joint R&D collaboration between organizations are two of many alternative boundary-spanning mechanisms. Firms engage in a myriad of external sourcing mechanisms and our study is an initial attempt to reveal contingent effects between two channels. In addition, our data contain limited self-reported information on collaboration practices. Future research can shed more light on contingencies by looking into the size and specific content of research collaboration and other mechanisms. Moreover, another possible extension may be to distinguish between different types of industrial and academic partners. Also, our research setting raises questions about the generalization of our results. Even though we identify the mobility of all skilled workers active in a multi-industry setting in the period 2000–2004, our findings may be specific to the Danish context. Being a small country, characterized by high mobility rates, Denmark and its firms may be unique. Nevertheless, the analysis which draws on three independent data sources strengthens our confidence in the results.

CONCLUSION

In conclusion, our study reveals the contingent nature of simultaneous engagement in different external sourcing mechanisms. Extending current literature on complementarities between internal and external R&D, our study reinforces the need to consider substitution effects

between hiring scientists or engineers and alternative mechanisms of external learning, such as joint R&D collaboration. In this way, research in the field of innovation management can improve our understanding of how firms can optimize the process of harnessing external knowledge to fuel future innovative activity.

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APPENDIX

Figure 1. Types of Boundary-Spanning (N=13472)

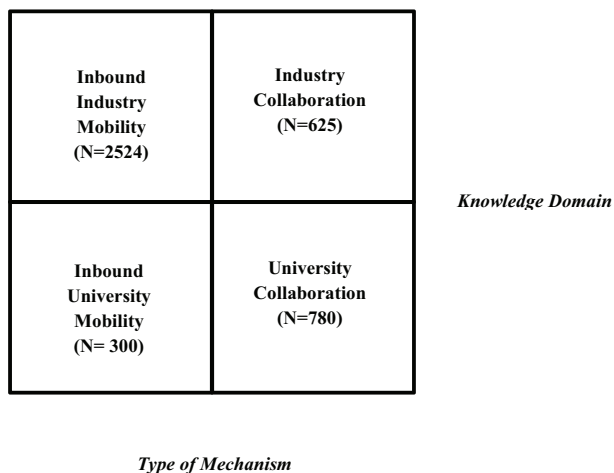


Figure 2. Conceptual Model

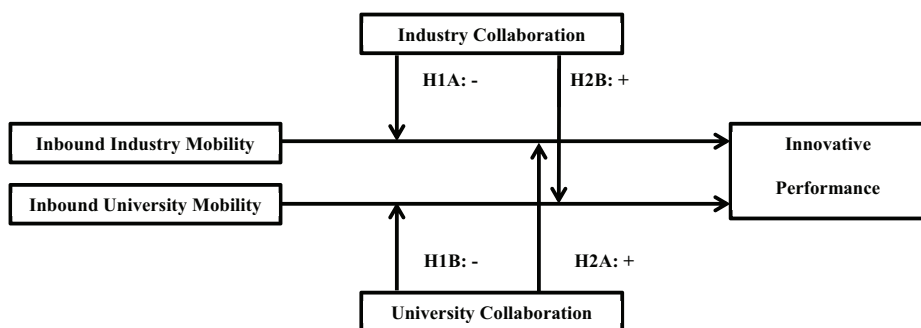


Figure 3. Frequency Counts of Observations with Inbound Mobility and Collaboration in the Period 2001–2004 (N=13472)

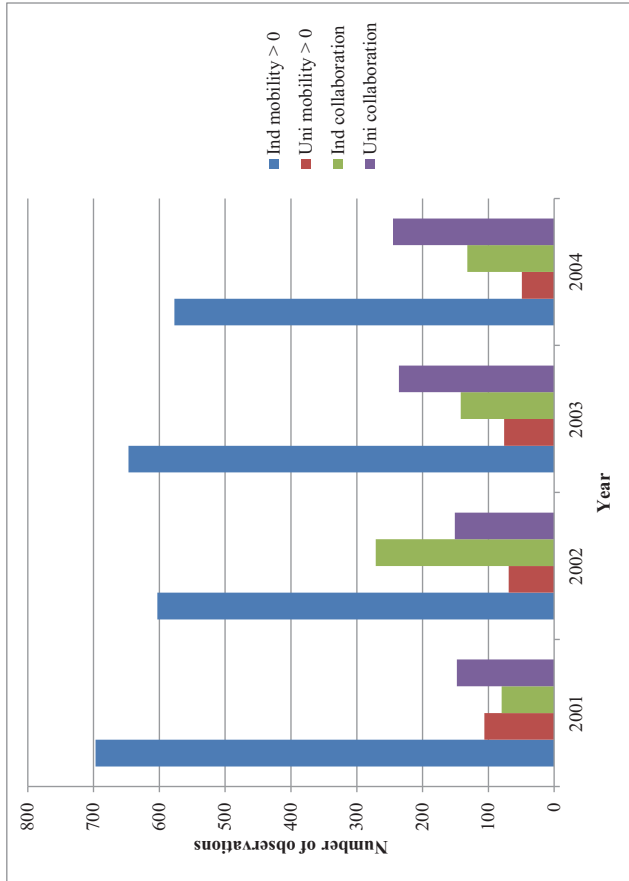


Table 1. Descriptive Statistics and Correlations

Variable	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
<i>Dependent variable</i>																
(1) Citation-weighted patent appl.	0.257	4.537	0.000	325.000	1.00											
<i>Independent variables</i>																
(2) Inbound industry mobility	0.235	0.592	0.000	6.392	0.27	1.00										
(3) Inbound university mobility	0.020	0.147	0.000	3.258	0.44	0.53	1.00									
(4) Industry collaboration	0.046	0.210	0.000	1.000	0.15	0.23	0.19	1.00								
(5) University collaboration	0.058	0.234	0.000	1.000	0.16	0.32	0.25	0.42	1.00							
<i>Control variables</i>																
(6) Firm age	2.759	0.768	0.693	5.489	0.05	0.08	0.04	0.03	0.05	1.00						
(7) Firm size	3.730	1.503	0.000	10.228	0.13	0.45	0.23	0.16	0.23	0.27	1.00					
(8) Inbound TMT mobility	0.039	0.203	0.000	7.000	-0.00	0.05	0.02	0.02	0.00	0.02	0.08	1.00				
(9) Outbound mobility	0.234	0.423	0.000	1.000	0.09	0.55	0.23	0.17	0.25	0.07	0.39	0.04	1.00			
(10) R&D intensity	0.048	0.119	0.000	1.000	0.05	0.37	0.19	0.14	0.19	-0.06	-0.04	-0.00	0.40	1.00		
(11) Pre-sample mean estimator	-11.173	1.152	-11.513	-2.249	0.27	0.38	0.28	0.23	0.35	0.15	0.30	0.04	0.30	0.13	1.00	
(12) Patent dummy	0.089	0.285	0.000	1.000	0.15	0.31	0.19	0.19	0.30	0.15	0.29	0.04	0.28	0.10	0.94	1.00

Correlations above 0.02 are significant on the 1% level

Table 2. Zero-Inflated Negative Binomial Models Explaining Citation-Weighted Patent Applications

VARIABLES	Model I		Model II		Model II		Model IV		Model V	
	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>
<i>Within-domain</i>										
Inbound ind mobility x ind coll										
Inbound uni mobility x uni coll										
<i>Across-domain</i>										
Inbound ind mobility x uni coll										
Inbound uni mobility x ind coll										
<i>Main-effects</i>										
Inbound industry mobility	0.331*	-0.320							0.085	-0.446
	(0.168)	(0.238)							(0.164)	(0.279)
Inbound university mobility			1.082***	-0.051					0.939***	0.419
			(0.222)	(0.484)					(0.220)	(0.556)
Industry collaboration					0.373+	-0.900			0.354	-0.450
					(0.219)	(0.605)			(0.216)	(0.397)
University collaboration							-0.071	-1.433*	-0.033	-0.846
							(0.200)	(0.585)	(0.195)	(0.524)
<i>Controls</i>										
Firm age	-0.144	-0.033	-0.192	-0.057	-0.236	-0.082	-0.201	-0.068	-0.192	-0.074
	(0.174)	(0.223)	(0.140)	(0.190)	(0.164)	(0.211)	(0.157)	(0.214)	(0.150)	(0.208)
Firm size	0.422*	-0.211	0.463***	-0.322**	0.551***	-0.304	0.517**	-0.318	0.397*	-0.167

Inbound TMT mobility	(0.183)	(0.169)	(0.121)	(0.122)	(0.160)	(0.186)	(0.175)	(0.210)	(0.156)	(0.148)
	-0.404	-0.772	-0.265	-0.591	-0.358	-0.716	-0.330	-0.821+	-0.263	-0.626
Outbound mobility	(0.369)	(0.525)	(0.308)	(0.484)	(0.365)	(0.564)	(0.343)	(0.478)	(0.302)	(0.518)
	-0.553	-0.736	-0.460	-0.782+	-0.324	-0.699	-0.149	-0.503	-0.441	-0.606
R&D intensity	(0.425)	(0.502)	(0.374)	(0.457)	(0.646)	(0.630)	(0.523)	(0.635)	(0.457)	(0.547)
	1.107	-0.572	1.977	-0.579	1.190	-1.255	1.003	-1.450	1.206	-0.042
Pre-sample mean estimator	(2.558)	(2.255)	(2.344)	(1.780)	(2.951)	(2.711)	(2.435)	(2.433)	(2.150)	(1.927)
	0.344*	-0.778*	0.272*	-0.813***	0.390*	-0.849*	0.469**	-0.782*	0.267+	-0.778**
Patent dummy	(0.139)	(0.322)	(0.106)	(0.226)	(0.168)	(0.420)	(0.149)	(0.313)	(0.154)	(0.297)
	-1.141	0.237	-0.789	0.546	-1.515	0.284	-1.773*	-0.111	-0.765	0.446
Industry dummies	(0.786)	(1.120)	(0.608)	(0.901)	(1.183)	(1.210)	(0.864)	(1.276)	(0.853)	(1.000)
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.776	-2.050	0.243	-1.874	1.246	-2.427	1.666	-1.914	0.401	-2.135
	(2.685)	(3.963)	(2.100)	(2.979)	(2.506)	(5.015)	(2.493)	(3.933)	(2.413)	(3.535)
Number of observations	13,472	13,472	13,472	13,472	13,472	13,472	13,472	13,472	13,472	13,472
Number of zeros	13,093	13,094	13,095	13,096	13,097	13,098	13,099	13,100	13,101	13,102
Log pseudolikelihood	-1786.650	-1786.650	-1782.212	-1782.212	-1788.146	-1788.146	-1786.154	-1786.154	-1763.096	-1763.096
Wald Chi2	485.328	485.328	441.313	441.313	449.348	449.348	401.115	401.115	426.290	426.290

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 2. Zero-Inflated Negative Binomial Models Explaining Citation-Weighted Patent Applications (Continued)

VARIABLES	Model VI		Model VIII		Model VII		Model IX		Model X	
	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>	<i>Fwd cites</i>	<i>No patent</i>
<i>Within-domain</i>										
Inbound ind mobility x ind coll	0.060 (0.130)	0.583* (0.281)							0.026 (0.247)	0.273 (0.371)
Inbound uni mobility x uni coll			-0.562+ (0.301)	0.914 (0.779)					-1.057* (0.518)	-0.430 (0.690)
<i>Across-domain</i>										
Inbound ind mobility x uni coll					0.042 (0.129)	0.773** (0.257)			0.314 (0.253)	0.835* (0.330)
Inbound uni mobility x ind coll							-0.109 (0.232)	0.809 (0.735)	0.103 (0.418)	-0.095 (0.822)
<i>Main effects</i>										
Inbound industry mobility	0.071 (0.167)	-0.563* (0.239)	0.128 (0.172)	-0.396 (0.271)	0.076 (0.175)	-0.700** (0.222)	0.094 (0.167)	-0.437+ (0.261)	-0.027 (0.184)	-0.776*** (0.230)
Inbound university mobility	0.944*** (0.209)	0.378 (0.482)	1.268*** (0.203)	0.041 (0.513)	0.964*** (0.199)	0.370 (0.407)	0.994*** (0.215)	0.230 (0.495)	1.481*** (0.251)	0.588 (0.481)
Industry collaboration	0.213 (0.358)	-1.151* (0.518)	0.416+ (0.223)	-0.369 (0.374)	0.331 (0.216)	-0.490 (0.351)	0.369 (0.244)	-0.594 (0.398)	0.237 (0.381)	-0.843 (0.553)
University collaboration	-0.023 (0.188)	-0.819+ (0.428)	0.090 (0.232)	-0.962+ (0.533)	-0.147 (0.300)	-1.725*** (0.524)	-0.015 (0.192)	-0.797+ (0.448)	-0.256 (0.349)	-1.699*** (0.571)
<i>Controls</i>										
Firm age	-0.194 (0.148)	-0.092 (0.199)	-0.162 (0.150)	-0.061 (0.205)	-0.186 (0.147)	-0.087 (0.193)	-0.185 (0.149)	-0.074 (0.202)	-0.136 (0.157)	-0.051 (0.201)

Firm size	0.392** (0.149)	-0.176 (0.141)	0.341* (0.166)	-0.197 (0.157)	0.406** (0.154)	-0.148 (0.148)	0.397* (0.153)	-0.173 (0.146)	0.342* (0.159)	-0.191 (0.155)
Inbound TMT mobility	-0.285 (0.281)	-0.672 (0.447)	-0.213 (0.305)	-0.609 (0.481)	-0.253 (0.304)	-0.600 (0.502)	-0.259 (0.295)	-0.638 (0.470)	-0.143 (0.387)	-0.494 (0.692)
Outbound mobility	-0.409 (0.373)	-0.524 (0.471)	-0.513 (0.440)	-0.678 (0.542)	-0.435 (0.339)	-0.543 (0.456)	-0.461 (0.412)	-0.608 (0.507)	-0.483 (0.350)	-0.589 (0.473)
R&D intensity	1.105 (1.924)	-0.118 (1.733)	1.119 (2.029)	-0.017 (1.799)	1.665 (1.895)	0.512 (1.604)	1.231 (1.979)	-0.005 (1.742)	1.353 (1.959)	0.354 (1.660)
Pre-sample mean estimator	0.262* (0.112)	-0.752** (0.252)	0.310* (0.130)	-0.735** (0.283)	0.258* (0.105)	-0.746*** (0.206)	0.269* (0.122)	-0.760*** (0.267)	0.308** (0.106)	-0.677*** (0.200)
Patent dummy	-0.775 (0.618)	0.359 (0.931)	-0.902 (0.691)	0.305 (0.993)	-0.753 (0.561)	0.317 (0.861)	-0.769 (0.681)	0.407 (0.958)	-0.892 (0.551)	0.102 (0.857)
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.452 (2.026)	-1.575 (3.050)	1.221 (2.315)	-1.401 (3.580)	0.300 (1.993)	-1.559 (2.678)	0.509 (2.172)	-1.832 (3.302)	1.436 (1.927)	-0.344 (2.642)
Number of observations	13,472	13,472	13,472	13,472	13,472	13,472	13,472	13,472	13,472	13,472
Number of zeros	13,103	13,104	13,105	13,106	13,107	13,108	13,109	13,110	13,111	13,112
Log pseudolikelihood	-1759.917	-1759.917	-1759.228	-1759.228	-1755.925	-1755.925	-1762.031	-1762.031	-1752.048	-1752.048
Wald Chi2	399.159	399.159	537.190	537.190	389.921	389.921	444.645	444.645	472.636	472.636

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

CHAPTER 4

ALL FOR ONE AND ONE FOR ALL: HOW INTRAFIRM INVENTOR NETWORKS AFFECT THE SPEED OF EXTERNAL KNOWLEDGE RECOMBINATION

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ABSTRACT. Drawing on absorptive capacity and social network theory, we examine the effect of intrafirm network density, tie strength, and diversity on firms' *recombination speed* of technologically distant external knowledge. Results from an event history study of 113 pharmaceutical firms that engaged in technology licensing in the period 1986-2003 reveal that the time it takes for firms to recombine external knowledge into their own inventions increases with technological distance. However, intrafirm co-invention network density and diversity shorten the time to recombine distant external knowledge. These results underline the importance of inventors' knowledge networks as antecedents of the speed with which firms can absorb external knowledge.

KEYWORDS: recombination speed, absorptive capacity, intrafirm inventor networks, innovation, licensing

INTRODUCTION

Firms increasingly rely on recombination of internal and external knowledge to create inventions that can be subsequently commercialized into innovations (Hargadon & Sutton, 1997; Laursen & Salter, 2006). Particularly in high-tech and fast-paced industries, external partners play a critical part in a firm's R&D process as firms gain access to complementary assets (Dyer & Singh, 1998; Sampson, 2007). Acquisition of external knowledge is an attractive alternative to in-house R&D, because firms spread the risk and cost inherent to R&D and may shorten the development of inventions (Ahuja, 2000; Kessler & Chakrabathi, 1996). Yet, firms significantly differ in the ability to draw on and benefit from acquiring external knowledge (Cohen & Levinthal, 1990). Despite our growing understanding of firms' ability to harness external knowledge for own invention, the absorptive capacity literature has overlooked the intraorganizational antecedents of knowledge integration (cf. Volberda, Foss, & Lyles, 2010). As a consequence, little is known about the role of individuals and groups in the process through which firms integrate external knowledge.

In an attempt to address this gap some scholars have alluded to intrafirm informal networks among employees as determinant of firms' absorptive capacity (Mors, 2010; Paruchuri, 2009; Volberda et al., 2010). This claim resonates well with Cohen & Levinthal's (1990) idea that the interactions and links across individuals alter the way external knowledge is absorbed into the firm as interaction facilitates knowledge-sharing within the firm (Allen & Cohen, 1969; Tushman, 1977). In this respect, the literature on knowledge recombination has recently underlined the role of intrafirm networks among inventors as the locus of firms' recombinant capacity (Carnabuci & Operti, 2013; Guler & Nerkar, 2012; Nerkar & Paruchuri, 2005).

In this paper, we build on the prior literature on absorptive capacity to examine how intrafirm networks configurations among inventors influence a firms' ability to integrate external knowledge. We specifically focus on a dimension of absorptive capacity that has received relatively little attention; the speed of external knowledge integration. Yet, prior research has pointed to the fact that firms that are able to innovate in a fast pace achieve first-mover advantages and capture new market opportunities (Markman, Gianiodis, Phan, & Balkin, 2005). More in general, examining how quick firms can internalize external knowledge is important as it is a source of competitive advantage, especially in industries where time-based competition is paramount (Kessler & Chakrabathi, 1996; Leone & Reichstein, 2012; Tzabbar, Aharonson, & Amburgey, 2013; Zahra & George, 2002). Two recent studies are worth mentioning in this respect. First, a recent study by Leone & Reichstein (2012) shows that licensing-in accelerates firms' invention speed, yet this effect reduces when firms license-in unfamiliar technologies. In similar vein, a recent paper by Tzabbar et al. (2012) shows that the rate of knowledge integration depends on the type of external knowledge sourcing mechanism (i.e. scientist recruitment vs. R&D alliance) and the degree of familiarity with the knowledge that is transferred. We depart from these two specific studies and examine how the structure and composition of intrafirm inventor networks may accelerate or slow down the integration of distant or unfamiliar external knowledge. Our choice to focus on inventors is motivated by the fact that inventors carry out inventive search using their skills and knowledge, and subsequently propose and implement solutions to problems faced during the process of external knowledge integration (Fleming, 2001). In addition, we take a social network perspective, because inventors are unlikely to operate in isolation (Singh & Fleming, 2009), but instead rely on a web of colleague-inventors through which they search for advice, obtain referrals and acquire useful knowledge for problem-solving (Singh, Hansen, & Podolny, 2010; Tsai & Ghoshal, 1998). In

sum, we develop a theoretical framework that explains how specific configurations of intrafirm networks may speed-up the recombination of external knowledge into firms' own inventions.

Building on the literature on recombinant search, absorptive capacity literature and social network theory we develop a set of hypotheses that predict how intra-firm network characteristics influence recombination of external knowledge into firms' own invention. Based on the intuition that inventors encounter difficulties in integrating external knowledge components with which they have no prior experience, we predict that firms' recombination speed decreases with the degree of unfamiliarity. Yet, we subsequently posit that certain intrafirm network configurations attenuate problems related to time-costly recombination of distant external knowledge. We follow prior social network research on search-transfer issues by focusing on intrafirm network density, diversity and average tie strength (Hansen, 1999; Phelps, 2010; Reagans & McEvily, 2003). Considering the social network literature, those three measures have been recurrently pointed out as the main group-level compositional and structural characteristics that shape knowledge flow patterns among individuals. On the structural side, network density and tie strength are particular relevant characteristics as they determine the amount and the quality of the knowledge that will flow within the network (Granovetter, 1973; Reagans & McEvily, 2003). On the compositional side, network diversity refers to the qualitative aspects (e.g., heterogeneity of the resources) of the knowledge that the network members can access when relying on their peers (Phelps, 2010). We specifically address the fact that structural and compositional characteristics have distinct benefits to inventors who are part of the network and therefore disentangle them both theoretically and empirically.

We examine our predictions in the context of 113 US pharmaceutical firms in the period 1986-2003. The pharmaceutical industry is a suitable setting as firms in this industry regularly innovate and engage in external knowledge sourcing (Arora & Gambardella, 1990; Powell,

Koput, & Smith-Doerr, 1996). The analysis draws on a unique and detailed dataset which combines data on licensing agreements, inventors and patents. A total of 708 licensed technologies serve as instances of external knowledge acquisition. We follow prior studies with the idea that co-invention or collaboration between inventors represents non-directional communication and information exchange channels (Allen, 1977; Guler & Nerkar, 2012; Singh, 2005). The observed co-invention ties between inventors then serve as inputs to construct our intrafirm knowledge networks, where inventors are represented by nodes and ties indicate co-inventions with colleagues. In the analysis we utilize event history analysis to test our hypotheses and employ a difference-in-differences method to strengthen our choice of licensing as a knowledge acquisition mechanism.

Our findings provide overall support for all hypotheses, except our prediction regarding average tie strength. Even though acquisition of a distant technology requires a firm and its inventors to devote more time to recombine this technology with internal knowledge, we find support for our predictions that intrafirm network density and diversity both shorten the time of distant external knowledge recombination. We interpret these findings as evidence of how dense networks facilitate *access* to colleagues and willingness among inventors to *support* each other. Also, the presence of a set of heterogeneous contacts in an inventor's intra-organizational network facilitates the access to a *diverse set of heuristics* increasing the collective problem-solving ability of inventors within the firm.

The main contribution of this research lies in postulating the role of intra-organizational employees' informal networks in the process of external knowledge integration. Unlike prior empirical work on absorptive capacity, we disentangle internal informal networks, to advance our understanding about the effect of group-level antecedents on firm-level absorptive capacity (cf. Volberda et al., 2010). In addition, we examine a rather unexplored dimension of absorptive

capacity, the speed with which firms are able to integrate external knowledge components. Time-to-recombination is crucial in consolidating firms competitive position and first-to-market successes (Kessler & Chakrabathi, 1996). We also add a complementary perspective to prior work on social networks as the locus of recombination (Carnabuci & Operti, 2013; Guler & Nerkar, 2012; Nerkar & Paruchuri, 2005; Phelps, Heidl, & Wadhwa, 2012) which has mostly examined internal knowledge recombination. Our study highlights the function that intrafirm networks serve in recombining external knowledge. Finally, we add to research on the role of intraorganizational social networks for overall firm innovation outcomes (Kleinbaum & Tushman, 2007).

THEORY AND HYPOTHESES

An invention is the outcome of a search process that involves problem-solving by inventors and eventually, recombination of existing knowledge components in a novel manner (Fleming, 2001; Hargadon & Sutton, 1997; Schumpeter, 1934). The invention process has shifted from taking place solely within the firm to a more open model in which firms acquire knowledge from a variety of sources (Chesbrough, Vanhaverbeke, & West, 2006; Laursen & Salter, 2006). Acquisition of external knowledge facilitates firm invention due to the complementarity between externally and internally generated knowledge components (Cassiman & Veugelers, 2006). Firms do not have all relevant knowledge in-house and therefore engage in alliances, licensing, and hiring to update their R&D process (Arora & Gambardella, 1990; Levin et al., 1987). The process of knowledge recombination thus increasingly relies on the recombination of both internal and external knowledge components. In this respect, Cohen & Levinthal (1990) argue that firms vary in the ability to draw on external knowledge. The absorptive capacity of

firms refers to the ability to recognize, assimilate, and exploit external knowledge and “is largely a function of the level of prior related knowledge” (Cohen & Levinthal, 1990: 128).

According to the knowledge-based theory of the firm, knowledge is collectively stored among employees and firms can be seen as social communities (Kogut & Zander, 1996; Matusik & Heeley, 2005). Social communities are the origin of knowledge creation and knowledge transfer within the firm (Tsai, 2000, 2001). In a similar manner, the literature on organizational learning asserts that learning involves knowledge transfer among individuals and business units within the firm (Argote, Mcevily, & Reagans, 2003; Huber, 1991). Organizations can thus be understood as network arrangements (Brass, Galaskiewicz, Greve, & Tsai, 2004; Reinholt, Pedersen, & Foss, 2011; Tsai, 2001). Networks among employees, and especially those individuals that are active in a firm’s R&D process, inventors, influence the extent to which knowledge is diffused and generated within a firm (Guler & Nerkar, 2012; Nerkar & Paruchuri, 2005).

Intrafirm social networks can be seen as an antecedent of a firm’s absorptive capacity (Volberda et al., 2010) because intrafirm networks shape knowledge flows among individuals and determine the efficiency of communication between them. Relevant knowledge for problem-solving is distributed among individuals within the firm (Lenox & King, 2004) and can be detected and shared through networks (Brass et al., 2004; Turner & Makhija, 2012). To illustrate this, Nerkar & Paruchuri (2005:773) argue that “bounded rational inventors search across the internal knowledge network on the basis of incomplete information about which knowledge should be recombined”. Networks among inventors also constitute communication patterns. The efficiency of communication (Cohen & Levinthal, 1990) refers to inward-looking absorptive capacity and determines the effectiveness of internal sharing of external knowledge (Volberda et al., 2010). In this sense, intrafirm inventor networks influence firm innovation

through sharing, development, and recombination of external knowledge. As a consequence, interpersonal networks can be seen as an antecedent of a firm's capacity to deal with external knowledge, constituting the micro-foundations of a firm's inventive capabilities (Allen & Cohen, 1969; Brown & Duguid, 2001; Tushman & Scanlan, 1981).

The use of external knowledge in a firm's R&D process may shorten the time of the invention process (Kessler & Chakrabathi, 1996; Leone & Reichstein, 2012). Speeding up the invention process is crucial to consolidate the competitive position of firms. Yet, the effect of external knowledge acquisition on subsequent invention speed depends on the channel through which external knowledge is acquired (Lee & Allen, 1982; Tzabbar et al., 2013; Vasudeva & Anand, 2011) and a firm's absorptive capacity (Cohen & Levinthal, 1989, 1990). In this paper we examine the influence of specific intrafirm network configurations of inventors on the speed with which a firm integrates and recombines externally acquired knowledge. We define *external knowledge recombination speed* as the time it takes a firm to recombine externally acquired knowledge into the firm's own invention. In the next paragraphs we develop hypotheses on how structural and compositional features of intrafirm networks among inventors affect the recombination speed of external knowledge.

Technological distance and recombination speed. Firms acquire external knowledge to complement their own technological knowledge base. In fact, in order to fill in the gaps related to the lack of specific knowledge components, firms tend to reach out for technologically distant knowledge (Rosenkopf & Almeida, 2003). Yet, we argue here that even though firms are prone to engage in distant knowledge sourcing, this comes at a cost with regard to recombination speed. The ease with which firms recombine external knowledge hinges upon having related prior experience with the acquired knowledge (Cohen & Levinthal, 1990; Zahra & George,

2002). Prior experience becomes the natural starting point for subsequent searches for new knowledge, and a firm's knowledge stock, which is accumulated over the years, is used as a lens through which the firm makes sense of knowledge from the environment (Rosenkopf & Almeida, 2003). The technological development of a firm over time thus affects the technological distance between a firm's knowledge base and external knowledge. Assimilation of external knowledge requires a common base of understanding, or overlap in the knowledge base, in order to achieve successful application of this piece of knowledge (Cohen & Levinthal, 1990). As a result, when the technological distance between the firm's knowledge base and acquired external knowledge increases, the absorptive capacity of a firm declines (Gilsing, Nootboom, Vanhaverbeke, Duysters, & Vandenoord, 2008; Lane & Lubatkin, 1998). This means that the cost and effort to recombine external knowledge increases with distance (Leone & Reichstein, 2012; Weitzman, 1998). To illustrate this, integration of distant external knowledge will require more effort and time as inventors in the firm are likely to encounter problems when they deal with unfamiliar knowledge. The solution generation process will subsequently prolong the time it takes for the firm to recombine distant external knowledge into an invention. Consequently, a firm requires more time to understand distant knowledge and may need more time to invest in its absorption, and this will slow down the process of external knowledge recombination. Our baseline hypothesis therefore states:

Hypothesis 1. The larger the distance between the externally acquired knowledge and the firm's knowledge base, the longer it takes the firm to recombine external knowledge

Intrafirm network density and the recombination speed of distant external knowledge. Dense networks (also called cohesive or closed networks) are networks in which the members are well-connected with each other. From an innovation perspective, previous studies have indicated that network density may either be beneficial or harmful for firm innovation (Burt, 1992; Coleman, 1988). On the one hand, network density leads to knowledge-sharing among members of the network and fosters information flow through the network (Gargiulo, Ertug, & Galunic, 2009; Obstfeld, 2005; Reagans & McEvily, 2003). Furthermore, dense networks are likely to have effective norms, promote trust (Coleman, 1988), and facilitate the exchange of tacit and complex knowledge (Hansen, 1999; Hansen, Podolny, & Pfeffer, 2001; Uzzi, 1997). On the other hand, the opposite of a dense network, a sparse network, may also be effective for firm innovation (Burt, 2004). A sparse network, which features structural holes between clusters or sub-networks, enhances firm innovation through the likelihood that such a network structure exhibits diverse information and fosters creativity.

Although sparse networks have been shown to be associated with high levels of heterogeneity, which facilitate the creation of new knowledge, the absence of connections between the network members reduces the speed with which individuals can share knowledge and access information (Singh et al., 2010). In fact, even though knowledge heterogeneity is important for inventors to deal with unfamiliarity, existing ties are necessary to provide individuals the right channels to tap into each other's experience and knowledge. This is particularly true for intrafirm networks, given that relevant knowledge might exist within the firm boundaries and still remain unutilized if network configurations do not favor its detection and dissemination (Hansen, 1999).

Therefore, we claim that intrafirm network density is particularly relevant to firms' ability to quickly recombine and eventually integrate distant external knowledge. Intrafirm

inventor network density shortens the time it takes to recombine distant external knowledge for at least three reasons. First, dense networks ease the search for and detection of relevant knowledge available in the network of inventors. Through their ties, inventors may hear about and observe potentially relevant inventors with the knowledge and skills needed to recombine distant external knowledge. Thus, dense networks tend to speed up the search time for relevant information within the network (Zaheer & Bell, 2005). Second, dense inventor networks tend to encourage knowledge sharing and the willingness to devote time and effort to support peers (Reagans & McEvily, 2003). Such cooperative behavior is likely to create cooperative norms and fosters knowledge transfer between inventors in the firm. For this reason, one may expect that the prolonged recombination time inherent to distant knowledge tends to be shorter in dense networks as a result of a mutually supportive environment. Third, network density promotes the formation of norms, which, in turn, enhances mutual understanding between inventors and lowers the possibility of misinterpretation and loss of relevant information (Reagans & McEvily, 2003; Zaheer & Bell, 2005). Inventors in dense networks thus tend to save time due to the formation of successful communication routines. In line with our predictions, we claim that firms with a dense intrafirm co-invention network experience a shorter recombination time for distant external knowledge. Our second hypothesis thus states the following:

Hypothesis 2. Firms with an intrafirm inventor network that has a high level of network density recombine distant knowledge faster than firms with an intrafirm inventor network that has a low level of network density

Intrafirm average tie strength and recombination speed of distant external knowledge. Tie strength refers to the intensity of interaction between two members of the network and is “a

combination of the amount of time, the emotional intensity, the intimacy (mutual confounding) and the reciprocal services which characterize the tie” (Granovetter, 1973: 1361). Tie strength characteristics tend to increase with increasing frequency of collaboration between inventors. Tie strength promotes trust and facilitates knowledge transfer, especially knowledge that is complex and tacit (Hansen, 1999; Levin, Walter, & Murnighan, 2010; McFadyen et al., 2009). While weak ties help in the search of useful knowledge it also impedes individuals to exchange complex information, limiting the extent to which complex knowledge flows within the network (Hansen, 1999). In fact, Hansen (1999) points out that, particularly in the case of innovation, useful knowledge may fail to be appropriately shared among individuals even though information regarding the whereabouts of the knowledge is disseminated across the network. This argument emphasizes the need of strong ties in order to individuals’ knowledge and expertise to move from one point to another in the network. Strong ties among inventors within a firm are likely to mitigate disadvantages related to integrating distant external knowledge according to two main arguments. First, trust and knowledge-sharing among inventors increases with recurring interaction (Hansen, 1999; Reagans & McEvily, 2003). This, in turn, increases the willingness of inventors to spend more time and effort on supporting each other (Rost, 2010; Seibert, Kraimer, & Liden, 2001; Sosa, 2010), for example in problem-solving related to the integration of unfamiliar pieces of knowledge. Second, knowledge that is tacit and highly complex is better transferred through strong ties (Hansen, 1999; Phelps et al., 2012). Distant knowledge is likely to be a complex matter for inventors within the firm, and therefore, tie strength increases the likelihood that such complexity is shared throughout the firm, which accelerates the integration process (Hansen, 1999). Taken together, we expect that high average tie strength will shorten the recombination process of distant knowledge and we therefore posit the following hypothesis:

Hypothesis 3. Firms with an intrafirm inventor network that has high average tie strength recombine distant knowledge faster than firms with an intrafirm inventor network that has low average tie strength

Intrafirm network diversity and recombination speed of distant external knowledge. Network diversity refers to the diversity of resources available in the network. Or, in other words, the extent to which network connections span boundaries (Reagans & McEvily, 2003). In the context of this paper, network diversity refers to variety in technological experience among the collaborating inventors inside the firm (Harrison & Klein, 2007) or the extent to which inventor ties span technological boundaries. Network diversity or range increases knowledge sharing among members of the network (Reagans & McEvily, 2003) and promotes the problem-solving ability of members through access to diverse resources available in the network (Phelps, 2010). An intrafirm network composed of a diverse group of inventors will accelerate the time it takes to recombine distant external knowledge for at least three reasons. First, due to the inherent uncertainty of knowledge recombination, inventors benefit from having diverse partners in their intrafirm network. Diverse connections provide a single inventor with access to a diverse set of problem-solving heuristics (Page, 2007) and support the accomplishment of complex tasks related to recombining distant knowledge (Mors, 2010; Rodan & Galunic, 2004). Thus, the collective problem-solving ability of inventors increases with diversity and shortens the time it takes to recombine complex distant knowledge acquired from outside the boundaries of the firm. Second, when inventor with different technological backgrounds collaborate they expand their ability to convey knowledge across distinct bodies of meta-knowledge (Reagans & McEvily, 2003; Tortoriello, Reagans, & McEvily, 2012). Over time, building experience in interacting with dissimilar colleagues increases inventors' capability to efficiently and successfully frame

their communication with other inventors, which, in turn, may accelerate the recombination of distant knowledge based on future interactions among heterogeneous inventors. Third, diversity within the intrafirm network increases the likelihood of overlap between the acquired external knowledge component and available relevant knowledge already existent in the intrafirm co-inventor network (Cohen & Levinthal, 1990). Diversity among collaborating inventors thus eases the comprehensibility of distant external knowledge and leads to shorter recombination time. Our final hypothesis therefore states:

Hypothesis 4. Firms with an intrafirm inventor network that has a high level of network diversity recombine distant knowledge faster than firms with an intrafirm inventor network that has a low level of network diversity

In short, we posit that while technological distance prolongs the time it takes to recombine external knowledge into own invention, network density, average tie strength and diversity shorten the recombination process of distant knowledge pieces⁴.

DATA AND METHODS

We test the aforementioned hypotheses in the context of the global pharmaceutical industry. Firms in this industry develop and commercialize drugs, chemical components, and biological products. The focus on pharmaceutical firms provides a good research context for at least four reasons. First, the pharmaceutical industry is characterized as technology driven and R&D intensive, which makes technological knowledge a critical component to develop and sustain

⁴ We acknowledge the fact that prior work has identified costs related to excessive network density and diversity in particular (Phelps, 2010). We address this issue empirically in the section on robustness checks and theoretically in the discussion section.

competitive advantages (Roberts, 1999). Second, firms in this industry routinely and systematically protect and document their inventions (Hagedoorn & Cloodt, 2003). In particular, patenting is an important and common mechanism used in this industry (Levin et al., 1987). Since patents provide reliable documentation of a firm's innovative activities we rely on patent information to identify the technological profile of the firms in our sample (Roberts, 1999; Adegbesan and Higgins, 2010; Hoang and Rothaermel, 2010). Third, R&D collaboration with other firms and universities represents an important driver of technology development (Arora & Gambardella, 1990). Indeed, firms in this industry actively engage in external knowledge or technology acquisition to foster their own inventive activity. Finally, the pharmaceutical industry has proven to be a valuable context to identify and measure the effect of inventor networks on innovative output (Paruchuri, 2009).

The data used in this study derive from four data sources. First, we used detailed information on licensing agreements from the Deloitte Recap Database, which covers licensing deals in the global pharmaceutical industry for the period 1983 – 2008. This database is one of the most accurate sources of information regarding partnerships and technology exchange in the pharmaceutical industry (Audretsch & Feldman, 2003; Schilling, 2009). More specifically, this database allowed us to access the original licensing contracts, from which it was possible to extract precise information regarding the date of the licensing event, characteristics of the licensed technologies, contractual specifications, and information related to the identification of licensees and licensors (e.g. firm name, address and operating segment). Second, we drew on the NBER patent project to merge the specific patent numbers connected to the traded technologies from the Deloitte Recap Database with patents registered at the United States Patent and Trademark Office (USPTO). Furthermore, the information retrieved from the NBER project was used to identify the technological profile of the firms that acquire technologies through licensing

(i.e. licensees), and the firms that sell the technologies (i.e. licensors). Therefore, we were able to include in the analysis variables capturing the characteristics of firms on both sides of the licensing contract, allowing us to disentangle potentially confounding firm effects from the variables of interest. Third, we relied on the Harvard Patent Network Dataverse, which provided us with the disambiguated inventor names and inventor identification numbers. This allowed us to construct intrafirm inventor networks based on co-invention as well as to derive inventor-level information. Prior research has used qualitative evidence (i.e. interviews) to validate co-patenting ties as a measure of collaboration among inventors (Carnabuci & Operti, 2013; Fleming, King III, & Juda, 2007). Finally, we utilized the WRDS Compustat database mainly for control variables.

The final sample consists of 113 firms involved in the acquisition of 708 USPTO patents using licensing contracts. Given that the information regarding inventors' patenting activity is only available from 1981 and explanatory variables regarding intrafirm networks are calculated based on a five-year moving window, the first licensing contract in the sample is observed in 1986. Furthermore, we ended the sample in 2003⁵ to allow sufficient time to observe whether the patents produced by the licensee indicate that the licensed technology was successfully recombined. The number of observations used to run the econometric analysis corresponds to approximately 47% of the number of contracts registered at RECAP that was initially considered to test the hypotheses⁶.

⁵ The decision to end the licensing observations three years before the latest record of patent data was based on the fact that on average, firms in our sample take 26 months (2.2 years) to recombine the licensed technology. Alternatively, we also run the models using a five year gap, instead of three, and the results remained identical.

⁶ In order to investigate the presence of systematic differences in invention speed of the observations (firms) that were excluded from the analysis due to missing information and the ones included in the final sample, we conducted a t-test comparing the number of months that licensees take to produce the first patent after the licensing date. The results indicate no statistically significant differences between the two groups.

The Dependent Variable

Time to knowledge recombination. The time it takes firms to recombine licensed technologies is calculated on the basis of the number of months between the licensing date and the first time that the licensee incorporates the licensed technology in the backward citation of a new patent. Using the dates of the patent application, instead of the grant dates, we avoid noise introduced by differences in patent office procedures. To avoid potential issues regarding bias originating from the use of the same data source to calculate the initial and the final dates, the dependent variable was calculated on the basis of information from two different (independent) databases. The date of external knowledge acquisition is defined on the basis of the licensing date specified at the RECAP database, while the recombination date comes from the Patent Network Dataverse. This variable is intended to capture how fast firms are able to recombine a new externally acquired body of knowledge with existing ones. Leone & Reichstein (2012) apply this dependent variable in a similar context as a robustness check to capture how inward licensing can shorten the time firms take to invent a new technology. In a similar way, we consider the citation of the licensed technology in a new patent an indication that the licensee was able to assimilate and successfully apply the licensed knowledge⁷. The reliance on technology licensing to feed internal inventive efforts is particularly prominent in industries with well-functioning markets for technology, such as the pharmaceutical and biotechnology industries (Arora & Gambardella, 2010). For this reason we consider that the use of technology licensing in combination with the backward citations of patents constitutes a reliable set-up for the invention speed of pharmaceutical firms. In the section on alternative explanations and

⁷ One could argue that firms may cite a technology without having to license it. In our sample eight cases were observed in which the licensed technology was referred to in the backward citation of a patent applied to the licensee before the licensing date. These observations are excluded from the main analysis.

robustness checks we provide econometric evidence to alleviate endogeneity concerns regarding our dependent variable.

Explanatory variables

Technological distance. The distance between the licensed technology and the knowledge base of the licensee is calculated using the patenting behavior of the acquiring firm prior to the licensing agreement. We measure technological distance with the *focal index* proposed by Ziedonis (2007) as a way to capture the extent to which a firm is able to realize value from a licensed patent. The technological distance between a licensed technology and a firm's knowledge base is then measured on the basis of the patent class connected to the licensed technology and the technology classes the licensee has been active in prior to the licensing event. To illustrate this, the technological distance is high if the share of the firm's patent portfolio assigned to the same patent class as the licensed technology is low. On the other hand, the distance is low if a high share of patenting activity has been concentrated on the same primary class of the licensed technology. The measure is computed as follows:

$$Technological\ distance = 1 - \left[\frac{(\sum_{t-5}^t \sum_j \tilde{C}_i \cdot \rho_i)_c}{(\sum_{t-5}^t \sum_j \tilde{C}_i \cdot \rho_i)} \right]$$

in which $(\sum_{t-5}^t \sum_j \tilde{C}_i \cdot \rho_i)_c$ represents the citation-weighted sum of firm i 's patents that were applied for within five years of the time of the license agreement t and that belong to the same primary patent class c as the licensed patent; and $(\sum_{t-5}^t \sum_j \tilde{C}_i \cdot \rho_i)$ is the sum of all citation-weighted patents issued to firm j that were applied for by date t following the same time window

of five years. The use of weighted citations offers the possibility to capture the relative importance of each patent within the firm's portfolio (Griliches, 1990).

Network density. We measure network density by calculating the overall density of the intrafirm network (Ahuja, Soda, & Zaheer, 2011; Obstfeld, 2005). Density captures the extent to which potential linkages are realized within a network, and is a commonly used measure of network structure (Guler & Nerkar, 2012; Marsden, 1990). We calculated our density measure for five-year windows. Network density for firm i in year t is computed as follows:

$$\text{Network density} = \frac{\text{Observed } N \text{ inventor ties}_{it}}{\text{Possible } N \text{ inventor ties}_{it}}$$

The observed ties are defined as the number of unique ties existing between two inventors that appear together within the same patent, and the number of possible or potential ties follow the number of inventors (N) active in the firm ($\frac{N \times (N-1)}{2}$).

Average tie strength. Average tie strength captures the average intensity of collaboration between inventors within the firm. We measured tie strength between each observed pair of inventors on the basis of the number of patents they have co-invented with each other. We then averaged this across the number of inventors in the firm. We also use a five-year moving window.

Network diversity. The diversity measure aims to capture the level of technological diversity among the active inventors within the focal firm. To operationalize this measure we take into account the possibility that the inventors may also have accumulated knowledge from research activities developed prior to joining the focal firm. Therefore, rather than capturing firm-level diversity we focus on network level diversity formed by the active inventors at the

year of the licensing contract. Furthermore, we only look into diversity among the inventors that have at least one intrafirm active tie, which means that inventors that produced no patent or patented only in collaboration with other individuals outside the firm or were a single inventor in all patents are not included in the analysis. The diversity measure is calculated using a Herfindahl index of the IPC codes (two digits) of the patents produced by the firm's inventors with at least one patent, connected to the licensing firm, within the five years prior to the licensing contract. We define the network diversity present in firm i 's intra inventor network in year t as:

$$Network\ diversity = 1 - \sum_{j=1} \left(\frac{N_{ij}}{N_i} \right)^2$$

Following previous studies (Griliches, 1990; Hall, Jaffe, & Trajtenberg, 2001) we consider that the main IPC code attributed to a patent reflects a distinct technological field $j = 1, 2, 3...th$. Therefore, if the inventors within the i th firm have accumulated N_i patents within the five years prior to the licensing contract, each of the patents can be assigned to one technological field. The final measure is obtained by subtracting 1 from the value reflecting the concentration of patent classes across the different technological domains.

Control Variables

We include a variety of firm, technology and contract-level control variables that may affect the time it takes to recombine knowledge in order to isolate the effects of the explanatory variables. We applied moving windows of different time lengths to compute the control variables. The length of the windows ranged from four to seven and differed according to the control variable; the different lengths were determined on the basis of prior research. To check the robustness of

our results we tested alternative specifications (± 1 year) for the control variables and the results of the main independent variables remained the same. In the case of the control variables regarding the intrafirm network, all the measures were calculated for the same length of time as the explanatory variables (five years). Regarding intrafirm inventors network characteristics, we control for *clustering* and *average path length*. We expect that those two structural characteristics will affect the knowledge flow across inventors by speeding up the time it takes to transfer knowledge from one point to another within the network. Our measure of clustering is scaled by the degree of clustering expected in a random bipartite network of the same size and density. Additionally, we included a dummy variable that takes value 1 if the firm has *co-patented* at least once prior to the licensing date. This variable is intended to capture the availability of external ties through which inventors can acquire relevant knowledge.

We also control for several firm characteristics. First, we included the logarithm of the number of employees in the year of the licensing deal to control for *firm size*. Second, we control for cross-firm differences in terms of *R&D intensity* by adding the total R&D expenditures divided by total sales. We also control for the amount of unabsorbed resources using licensee *slack*, which is calculated on the basis of the ratio between sales and number of employees. Another characteristic that can also influence the speed with which the licensee is able to recombine the external knowledge faster regards the familiarity that it has with other licensor's technologies (other than the licensed technology). Therefore, we controlled for the total number of prior citations within four years prior to the licensing contract that the licensee has made to any of the licensor's patents. In order to capture fast-paced knowledge recombination driven by industry competitive pressures (Ferrier, Smith, & Grimm, 1999) we generated a dummy variable that takes value 1 when both firms operate in the same segment and 0 otherwise. We also control for the general licensee's invention speed by calculating the

average time between the patents produced before acquiring the licensed technology. We included a dummy variable taking value 1 if the firm has produced a patent within the 12 months that precede the licensing date. By adding this variable we expect to control for the fact that certain technologies may be licensed in different stages of the invention process. Finally, we add a dummy variable taking value 1 if the licensee has headquarters in the United States.

We also control for contractual specifications of the licensing deal using dummy variables. The inclusion of the technology-flow back provision clause (i.e. grant-back clause) indicates that the licensor has rights over any improvement that the licensee develops with regard to the licensed technology. Therefore, we expect that signing a contract with a *grant-back* clause reduces the incentives that licensees have to further develop the licensed technology (Choi, 2002). Contracts that include the *technology furnishing* clause indicate that the licensor commits to supply know-how on the licensed technology to support the licensee in understanding and applying it, mitigating part of the problems originating from distance. Finally, the inclusion of *milestone* payments in a licensing contract offers the possibility for the licensee to receive monetary compensations for further developing the licensed technology.

Looking into technology related characteristics, we control for *technology value* using the total number of forward citations received by the licensed technology (Yang, Phelps, & Steensma, 2010). We expect that more valuable technologies are also more likely to be recombined in a faster way. Additionally, we also control for the total number of *scientific references* listed in the backward citations of the licensed technology as a way to capture cross-technology differences in terms of the development stage. The final set of control variables is related to the licensor's characteristics. First, we control for the number of successfully applied patents that the licensor filed in the seven years prior to the licensing contract as the licensor's size and technological capabilities may also affect the licensee's willingness to quickly invent

using the licensed technology. Second, in order to control for differences between firms and universities as licensors we added a dummy variable to identify the contracts in which the licensor is a university. Finally, following the convention in this literature, we added sector dummies indicating the segment within the pharmaceutical firm in which the licensee operates and year dummies.

Model Specification and Estimation

Given that the hypotheses refer to the time it takes to recombine knowledge, we generated the dependent variable following an event history analysis structure. This type of model is conventionally used to examine the conditional probability that an event occurs in a particular time interval (t) (Blossfeld, Golsch, & Rohwer, 2007; Yu & Cannella, 2007). In this respect, we apply event history analysis to model the time taken, T , between the licensing date and the first time the licensing technology is cited by the licensee in a new patent. The use of event history analysis to investigate the effect of the explanatory variables on the time it takes to recombine knowledge offers at least two major advantages. First, it makes it possible to directly model time as the dependent variable without the need to transform it into a discrete outcome (Pennings & Wezel, 2009). Second, this technique also allows for modeling the observations that do not experience the transition during the time frame covered by the data by dealing with issues emerging from right-censoring as a non-random process (Blossfeld et al., 2007). Compared to alternative model specifications (e.g. logit or OLS), employing event history analysis allows us to include the observations for which we only have partial information, which covers the time they enter the sample (the licensing date) until the last date that patent data for backward citation are available.

In order to decide among the possible models within even history analysis we considered the underlying mechanisms driving the hazard to knowledge recombination. We expect that firms that license-in technologies with low distance will be able to recombine the new knowledge with existing components at a rapid pace, which increases the hazard to knowledge recombination as the time increases. However, as the time elapses, the technologies with lower distance exit the sample, leaving in the sample technologies that take more time to be recombined. This effect is expected to become dominant and lowers the hazard rate until a point at which the hazard function starts to decline. Accordingly, we decided to employ a log-logistic model as a way to accommodate the expected process of an initial increase followed by a decreasing rate (Mills, 2011). Alternatively, we also employed a log-normal specification as a robustness check and, as expected, both models produced comparable results.

Considering that the capacity to deal with distant knowledge is likely to be also determined by firm characteristics that are not captured by the explanatory variables used in the econometric model, we correct for potential endogeneity issues originating from the presence of unobserved heterogeneity across the firms. Prior studies using a similar setting to the one presented in this paper have dealt with unobserved firm-level differences affecting duration dependence by employing frailty estimators (e.g. Hoang & Rothaermel, 2010; Pennings & Wezel, 2009; Polidoro, Ahuja, & Mitchell, 2011). Following the recommendation by Blossfeld et al. (2007), we model the unobserved heterogeneity using a shared gamma mixture specification associated with the log-logistic model. The alternative to the use of a gamma mixture model would be the inverse Gaussian frailty model, but as demonstrated by Jenkins (2005), it is straightforward to assume a gamma or normal distribution for the frailty of log-logistic models. The inclusion of a gamma mixture refers to the incorporation of an “error term” in the model that relates multiplicatively to the hazard rate for each firm in the analysis

(Blossfeld et al., 2007; Hougaard, 1986). Additionally, the use of shared frailty also offers the possibility to model intragroup correlation, which in the case of our sample is created from repeated group observations (Gutierrez, 2002).

Descriptive Statistics and Correlations

Table 1 reports the means, standard deviations, and Pearson correlation coefficients of the variables used in the analysis. The results raised no concerns regarding collinear variables, except for the correlations between *Average path length* with *Network density* and *Clustering* with *Average Tie Strength*. The moderate correlations between those variables are in line with theoretical expectations, but in order to check for potential bias we entered the variables in a stepwise manner and the results for the main explanatory variables do not change as the variables enter the model. Additionally, the maximum variance inflation factor (VIF) associated with any of the independent variables was 4.34 (mean VIF = 2.15), which is well below the rule-of-thumb value of ten (Gujarati, 1995). In order to identify potential model estimation issues regarding the stability of the coefficients and standard error we also added the main explanatory variables one at a time. Finally, the likelihood ratio comparison test at the bottom of Table 2 indicates that models II – V provide significant improvement relative to the baseline model. Looking specifically into the likelihood ratio comparison for model V (likelihood ratio: 35, df: 4, $p < 0.001$) we observe a substantial improvement compared to the restricted model.

 Insert Table 1 around here

We were able to track the patenting behavior of the firms in our sample until December 2006; therefore, our analysis is censored at the latest dates available in the patent citation data. Looking into the knowledge recombination speed, the longest time to transition for the firms in our sample was 168 months. Out of 708 firm-technology observations, a total of 116 firms cited the licensed technology in a new patent (made the transition) during the time frame of our analysis. For the observations that experienced the transition, the average time for knowledge recombination was 25 months. In contrast, the average time of at-risk months for all firms in the sample (including censored observations) was 74 months. Considering the average time for knowledge recombination between the uncensored observations with high versus low technological distance (using mean values), small distance technologies are, on average, cited within 24 months, while large distance technologies are cited within 83 months. Among the 592 firm-technology observations that did not experience the transition during the time window of our analysis, 129 observations exit the sample earlier than December 2006. These observations were subject to a different type of right-censoring. In the empirical setting used in this paper these observations exit the sample earlier because their latest records on COMPUSTAT ended earlier than the latest information available in the patent data. We modeled those observations differently by setting the exit time at the date of the latest Compustat record, implying that although these observations exit the sample, they do not experience the transition. The fact that the financial records for a given firm are discontinued is likely to be due to bankruptcy or an M&A process, which eliminates the possibility of a firm being observed in the patent citation data⁸.

⁸ If we consider those firms exiting the sample earlier, approximately 20% of the observations experience the transition within the time frame of the event history analysis

To supplement, we plot the cumulative hazard function after the estimation of the log-logistic model to visualize the patterns of the hazard function regarding the non-monotonic shape. Indeed, the results (see figure 1) indicate an initial increase followed by a decrease in the hazard rate for the observations in our sample, suggesting the suitability of the log-logistic model specification. Additionally, in order to visualize the shape of the hazard rate for observations with high and low levels of technological distance we generated two groups on the basis of the mean values of distance. As expected, the visualization of the cumulative hazards indicates that the observations that present lower levels of distance exhibit a higher hazard rate compared to those with higher levels of distance, with the curves for the two groups exhibiting a similar non-monotonic pattern. This result offers initial support for our hypothesis regarding the effect of distance on the firm's capacity to recombine external knowledge. As suggested in the graph, the firms dealing with lower levels of distance have a higher probability of experiencing a transition earlier compared to those dealing with high distance levels.

Insert Figure 1 around here

RESULTS

Table 2 reports the results for the log-logistic model with the shared gamma mixture specification. The dependent variable across the six models reported in this table reflects the time gap between the licensing date and the first time the licensed technology was cited in a new patent (for the non-censored observations). Model I reports the estimators for controls and the main effects of the interaction terms. Additionally, we included year dummies to control for period effects, such as overall differences in patenting behavior in the pharmaceutical industry.

In models II – VI the interaction terms capturing the relationships described in the hypotheses were entered one-by-one along with all the controls. For the sake of simplicity we will focus the discussion of the results on the full model in column VI.

Insert Table 2 around here

Hypothesis 1 predicted that *the larger the distance between the externally acquired knowledge and the firm's knowledge base, the longer it takes the firm to recombine external knowledge*. The coefficient for the technological distance variable is positive and significant at the 1% level when all controls are included in the equation, providing strong evidences in favor of our first hypothesis. The result lends support to the fundamental idea developed in this paper that distance (unfamiliarity) is an important predictor of a firm's capacity to recombine external knowledge at a faster pace. This finding is similar to the results obtained by Leone & Reichstein (2012) regarding the joint effect of unfamiliarity and contractual specifications (the use of grant-back clause) on the time a licensee takes to produce its first invention after a licensing contract.

Hypothesis 2 stated that *firms with an intrafirm inventor network that has a high level of network density recombine distant knowledge faster than firms with an intrafirm inventor network that has a low level of network density*. Accordingly, the interaction term between technological distance and network density exhibits a negative and significant coefficient, indicating that the positive effect of distance on the time it takes to recombine knowledge becomes less positive (or more negative) when interacted with network density. This result supports the expected effect described in hypothesis 2. Thus, the negative and significant

interaction term indicate that firms with a densely connected intrafirm inventor network are better able to deal with technological distance in a faster way.

Hypothesis 3 did not find support in the results. We predicted that *firms with an intrafirm inventor network that has high average tie strength recombine distant knowledge faster than firms with an intrafirm inventor network that has low average tie strength*. The interaction between technological distance and tie strength did not produce significant coefficients at the conventional level. Hence, the insignificant coefficient for this interaction term indicates that distance is positively related to knowledge recombination regardless of the tie strength among the inventors within the firm. In other words, we do not find evidence of a significant moderating effect of tie strength on the relationship between distance and the dependent variable.

Finally, the results offered support for the moderation effect predicted in hypothesis 4 regarding the fact that *firms with an intrafirm inventor network that has a high level of network diversity recombine distant knowledge faster than firms with an intrafirm inventor network that has a low level of network diversity*. Accordingly, the interaction between technological distance and network diversity produced a significant and negative coefficient. This finding supports the idea that network diversity negatively moderates the relationship between distance and the time it takes to recombine knowledge and thus accelerates the recombination of distant knowledge.

ALTERNATIVE EXPLANATIONS AND ROBUSTNESS CHECKS

Despite the large number of prior studies indicating that technology licensing leads to knowledge transfer (Arora, 1996; Ceccagnoli & Jiang, 2012; Laursen et al., 2010), we acknowledge that the link between licensing-in and patent citations has not yet been established

in the literature. Therefore, we performed a robustness check to evaluate the number of citations received by a technology after and before the licensing date using a conditional difference-in-differences design (Singh & Agrawal, 2011). By doing so, we expect to strengthen the confidence in the main results by focusing on two important aspects. First, it could be argued that the licensing firm is more likely to cite a technology of relatively higher quality or relevance regardless of whether or not it licenses the technology. Accordingly, technologies with such characteristics may also be more likely to be commercialized in the markets for technology, which creates a selection problem in which backward citations do not reflect the true effect of licensing. Second, a licensee may be more likely to license a technology in a domain in which the firm is intending to expand its technological activities. Therefore, it is likely that the licensing efforts would also be associated with other measures aiming to improve a firm's access to a specific technological area.

To perform the difference-in-differences we followed the steps described in the study by Singh & Agrawal (2011). First, each licensed technology in our sample was matched on the basis of propensity scores using the application year, patent class, and subclass to the closest technology in the entire technological space (USPTO patents). Second, we certified that no observation in the control group was in fact licensed by the focal firm in the sample. Third, we computed the total number of citations that the focal firm made to both groups of technologies (the treatment and control) after and before the licensing date. There were only eight observations in which the licensed technology had been cited by the licensee before the licensing contract; those observations were removed from the event history analysis but were used to estimate the difference-in-differences model. On the basis of this matching sample between licensed and non-licensed technologies sharing similar characteristics, we evaluated the

change in the number of citations. The results indicate (see Table 3) a significant and substantial increase in the number of citations received by a licensed technology when the number of citations received by the technologies in the control group is taken into account. Considering the baseline period, it is observed that the patents in the control group received an average number of citations of *0.055*, while the licensed technologies had on average *0.031* citations. However, considering the years after the licensing date it is possible to observe that the average number of citations for the licensed technologies increases to *1.541* while the control group remains the same.

 Insert Table 3 around here

Further robustness checks are not reported here because of space limitation. First, the literature on network analysis has also pointed out to limitations in the extent that increasing levels of network density and diversity can benefit knowledge sharing and diffusion within networks. This claim naturally leads to the idea that density and diversity curvilinearly moderate the effect of distance on time to knowledge recombination. We empirically investigated if that is the case by including in the log-logistic model interaction terms between *Technological Distance* and the squared version of our measures for *Network Density* and *Network Diversity*, the results were statistically insignificant. Second, an alternative explanation for the effect of distance on time to knowledge recombination is related to the fact that the distant technologies may not be licensed with the intention of applying them in a new invention. Therefore, it could also be suggested that our results regarding the effect of technological distance on time to knowledge recombination comes from the censored observations, for which we have only partial information. To address this concern and check the plausibility of this argument we conducted a

t-test comparing the level of distance between those observations that experience the transition and those that do not during the time window of our analysis. We found no evidence of statistical significance between the two groups.

DISCUSSION AND CONCLUSION

The present study was motivated by the fact that the absorptive capacity literature has overlooked the actions and interactions of individuals within the organization in the process of external knowledge integration. In addition, research on absorptive capacity has not paid enough attention to how *quickly* firms can recombine knowledge from the external environment with internal knowledge. The ability to speed-up the process of external knowledge recombination is a competitive advantage, especially in fast-paced industries. In this paper we address these shortcomings and examine the influence of intrafirm inventor networks on firms' ability to recombine external knowledge with internal knowledge into own invention. We specifically investigated how network structure and network composition within the firm affect the absorption speed of distant external knowledge. We made the argument that firms often engage in distant knowledge acquisition, yet distant knowledge requires substantial time to be devoted to recombination due to inventors' lack of familiarity with it. By drawing on social network theory and literature on search within organizations we subsequently claimed that network density, average tie strength and network diversity shorten the time to recombine distant external knowledge with internal knowledge pieces.

The empirical results indeed showed that technologically distant external knowledge prolongs the time of external knowledge recombination compared to close knowledge. More importantly, the results showed that intrafirm network density and diversity shorten the time in which firms assimilate distant external knowledge. This is in line with our predictions. Yet, our

results did not support our prediction that tie strength moderates the relationship between technological distance and the speed of external knowledge recombination. We discuss our results in light of previous research on absorptive capacity and external knowledge sources.

Our finding that strong average intrafirm ties among inventors do not accelerate the recombination of distant knowledge is in contrast to what we expected on the basis of the literature on knowledge-sharing within firms (e.g. Hansen, 1999; McFadyen & Cannella, 2004). Two explanations can be put forward for why this is the case. First, in addition to its benefits, tie strength can also impair the inventors' ability to develop distant external knowledge. Recurring interaction between a pair of inventors may lead to a trustworthy relationship characterized by supportive behavior (Granovetter, 1973). Yet, inventors with a limited number of partners with whom they collaborate can become myopic and focus on a limited set of colleagues. As a result, the effect of tie strength does not have a clear direction. Another possible explanation for our finding is that co-invention in itself indicates strong ties between inventors. Co-invention requires frequent meetings between inventors and significant time investments from both sides.

Previous research on network density and diversity has pointed to the costs of certain network configurations (e.g. Ahuja, 2000; Phelps, 2010). To illustrate this, excessive diversity among inventors in the intrafirm network may lead to miscommunication, confusion, and a general lack of mutual understanding (Weitzman, 1998) and may negatively affect the ability to deal with distant knowledge. In a similar vein, network density may at some point negatively influence the ability to incorporate distant knowledge. Dense networks develop norms over time and this may result in group thinking, which, in turn, impairs the ability to find creative solutions and implement distant external knowledge. We tested for such decreasing or negative returns for each of the network variables, but did not find any such effects. Two reasons can be put forward why we do not find any curvilinear effects. A possible explanation may lie in the

fact that we focus on the speed with which firms recombine internal with external knowledge, rather than general innovation output or knowledge exchange among inventors. We suspect that the mechanisms that underlie our results rely on network access and the knowledge content available in the network. From this viewpoint, negative (marginal) effects from density and diversity may not necessarily affect the speed of knowledge recombination, as this recombination will not take place at all. Another reason why we do not find any curvilinear effect may relate to the specific investments made by R&D managers and firms in general to understand a certain technology, which we do not observe. In this case, negative marginal returns will not be experienced.

Another question that may arise as a result of our findings relates to fact that we do not find strong evidence of direct effects of intrafirm network characteristics on external knowledge integration. We attribute this finding to the specific role intrafirm networks play in the integration process of external knowledge. We claim that intrafirm network characteristics do not affect general acquisition of knowledge but become important when inventors face difficulties in providing solutions for the implementation of unfamiliar knowledge. In the latter case inventors are likely to activate their professional network and search for solutions among their fellow inventors (Singh et al., 2010).

This study contributes to several bodies of literature. Our main contribution lies in the literature on absorptive capacity (Cohen & Levinthal, 1990; Zahra & George, 2002). Social integration mechanisms and social networks within the firm are considered to be important antecedents of absorptive capacity (Volberda et al., 2010; Zahra & George, 2002). Despite these claims, we are not aware of any study that has focused on intrafirm networks as determinants of absorptive capacity. We provide evidence that intrafirm network cohesion and diversity indeed accelerate knowledge assimilation. In particular, our study supports the notion of inward-

looking absorptive capacity, which refers to the efficiency of internal communication (Cohen & Levinthal, 1990). External knowledge can only be effectively absorbed when a firm has the ability to internally share this knowledge among the members of the firm (Lenox & King, 2004; Rothaermel & Alexandre, 2008; Volberda et al., 2010).

Another important contribution of our study pertains to exploring the speed dimension of external knowledge integration. We are not only aware of few empirical studies in this area (e.g. Leone & Reichstein, 2012), but our findings also raise implications for research on recombinant search. Indeed, firms tend to update their knowledge base with unfamiliar knowledge (e.g. Rosenkopf & Almeida, 2003), but recombination of distant knowledge comes at a cost; it appears to be a relatively long process. Future research on this paradox is important as time becomes an increasingly scarce resource in innovation processes (Kessler & Chakrabathi, 1996).

This study also contributes to the literature on organizational learning and the knowledge-based view of the firm by following the idea that firms contain social communities (Argote, 1999; Argote et al., 2003; Kogut & Zander, 1992). Informal networks among employees affect knowledge sharing and the creation of new knowledge. We add to this literature the idea that social networks indirectly affect the ability of organizations to learn from knowledge previously external to the firm. The notion that social networks within the firm are fundamental to learning from external knowledge resonates well with recent studies that claim that inventors and their knowledge networks constitute the micro-foundations of a firm's R&D capabilities (Guler & Nerkar, 2012; Nerkar & Paruchuri, 2005; Paruchuri, Nerkar, & Hambrick, 2006).

The results of our study also have managerial implications. Our findings point to the indirect influence of network structure on the ability of firms to quickly integrate external knowledge. Thus, managers should direct their attention to the collaborative behavior of their

employees. We acknowledge the fact that a manager may not have full control over the social interactions that take place among employees. Yet, managers may assign inventors to participate in short-term projects to foster collaborative efforts between otherwise unconnected employees. Managers should evaluate how inventor network structure in the R&D department can be improved in such a way that an atmosphere of knowledge sharing and transfer among inventors and research units is guaranteed.

The results and contributions of this paper should be considered in the light of its limitations. Our findings may be specific to the pharmaceutical context, which is characterized by a mature market for technology, in which patent protection and licensing is the norm rather than the exception. Future research could therefore examine how quickly firms learn from other external sourcing mechanisms such as hiring in variety of industries (see Tzabbar et al., 2012, for a recent example). Second, we utilize co-patenting to capture collaboration and knowledge networks, following recent literature (Fleming et al., 2007; Paruchuri, 2009; Singh, 2005). Although our focus on co-invention is particularly relevant in the context of knowledge recombination, we acknowledge the fact that patent collaborations only capture a subset of the present interpersonal ties within a firm. Future research could advance our understanding of intrafirm networks and recombination speed by focusing on different types of interpersonal networks, including friendship networks. Third, we focus specifically on the role of intrafirm co-invention ties as antecedents of absorption speed. Inventors that maintain ties that span firm boundaries may also have an impact on a firm's absorptive capacity (Perry-Smith, 2006; Tortoriello & Krackhardt, 2010; Tushman & Scanlan, 1981). Yet, individual external ties are beyond the scope of this paper. We encourage future research to investigate how the interaction of individuals' internal and external ties affects firm absorptive capacity. Finally, we believe our empirical strategy reduced concerns with endogeneity issues as a result of unobserved

heterogeneity and omitted variable bias. First, we employed a frailty estimator in our hazard models, which captures unobserved heterogeneity through the inclusion of a shared gamma mixture specification. In addition to this, our difference-in-differences approach towards the relationship between licensing-in and citation patterns strengthens our view that licensing represents a mechanism through which firms acquire external knowledge, which, in turn, fuels firms' inventive performance.

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APPENDIX

Figure 1. Estimated Hazard Functions of Small versus Large Distance Licensed Technologies

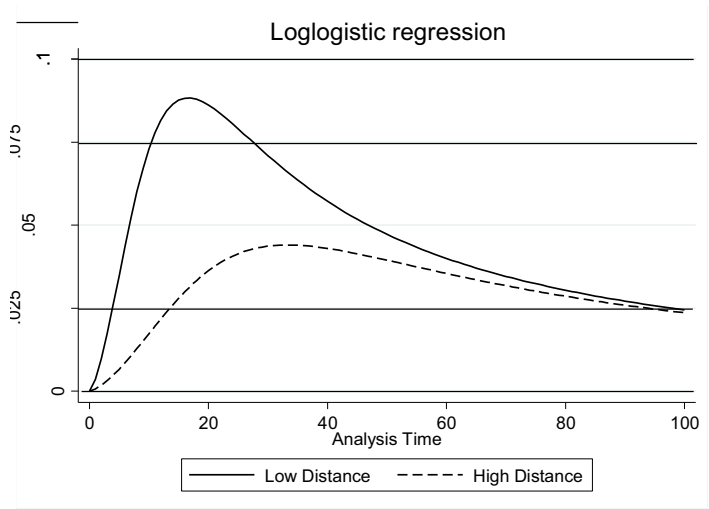


Table 1. Descriptive Statistics and Correlations Coefficients (N = 708)

Variable	Mean	S.D.	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
[1] Technological Distance	0.824	0.280	1.00										
[2] Network Density	0.259	0.285	-0.19	1.00									
[3] Average Tie Strength	1.581	1.007	-0.01	-0.21	1.00								
[4] Network Diversity	0.622	0.228	0.15	-0.57	0.13	1.00							
[5] Clustering	2.246	0.854	-0.07	-0.05	0.77	0.09	1.00						
[6] Average Path Length	2.557	1.632	0.20	-0.64	0.25	0.43	0.10	1.00					
[7] Same Sector	0.357	0.479	0.01	0.07	0.10	0.06	-0.07	-0.18	1.00				
[8] Co Patent	0.892	0.310	-0.18	-0.08	0.05	0.07	0.07	0.04	-0.04	1.00			
[9] Prior Citations	1.261	7.847	-0.04	0.12	-0.06	0.01	0.03	-0.12	-0.05	0.04	1.00		
[10] Scientific References	30.381	52.714	-0.01	-0.06	0.11	0.02	0.10	0.07	0.05	0.07	-0.01	1.00	
[11] Technology Value	60.671	155.548	-0.11	0.14	-0.03	0.00	0.02	-0.08	-0.01	0.07	0.07	0.00	1.00
[12] Technological Furnishing	0.559	0.497	0.08	-0.29	-0.01	0.15	-0.06	0.26	0.15	0.05	-0.10	-0.05	-0.11
[13] Grant-back Clause	0.242	0.429	0.02	-0.03	-0.05	0.04	-0.13	0.08	0.17	-0.08	-0.07	-0.07	0.00
[14] Milestone	0.613	0.487	-0.00	-0.05	0.12	-0.15	0.13	0.07	-0.01	-0.03	0.08	-0.04	-0.08
[15] R&D Intensity	124.633	132.409	-0.21	0.26	-0.02	-0.20	0.05	-0.32	0.13	0.00	-0.01	0.01	-0.10
[16] Licensor University	0.177	0.381	-0.12	0.21	-0.11	-0.34	-0.04	-0.27	-0.35	-0.18	0.03	-0.07	-0.06
[17] Licensor Number of Patents	334.927	1,451,046	-0.05	0.16	-0.07	-0.11	0.00	-0.17	-0.11	0.00	0.77	-0.04	0.03
[18] US Firm	0.898	0.303	0.01	0.12	-0.00	-0.06	-0.05	-0.09	0.08	-0.09	0.05	-0.06	-0.04
[19] Log(Number Employees)	7.129	2.844	0.24	-0.52	0.16	0.32	0.08	0.68	-0.25	0.25	-0.08	0.10	0.06
[20] Average Patenting Time	4.091	5.165	-0.05	0.39	-0.24	-0.38	-0.31	-0.51	0.11	-0.39	-0.07	-0.13	-0.04
[21] Previous Year Patent	0.766	0.423	0.09	-0.27	0.13	0.34	0.13	0.33	-0.01	0.63	0.03	0.09	0.06
[22] Slack	165.471	149,181	0.09	-0.37	0.35	0.28	0.21	0.42	-0.01	0.24	-0.11	0.14	-0.09

Variable	Mean	S.D.	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]	[21]	[22]
[12] Technological Furnishing	0.559	0.497	1.00										
[13] Grant-back Clause	0.242	0.429	0.18	1.00									
[14] Milestone	0.613	0.487	0.17	0.04	1.00								
[15] R&D Intensity	124.633	132.409	-0.06	-0.07	0.15	1.00							
[16] Licensor University	0.177	0.381	-0.32	-0.23	0.08	0.28	1.00						
[17] Licensor Number of Patents	334.927	1,451.046	-0.13	-0.02	0.12	0.21	0.06	1.00					
[18] US Firm	0.898	0.303	-0.14	-0.05	-0.10	0.08	0.09	0.07	1.00				
[19] Log(Number Employees)	7.129	2.844	0.07	0.08	-0.01	-0.60	-0.37	-0.22	-0.20	1.00			
[20] Average Patenting Time	4.091	5.165	-0.07	-0.02	-0.02	0.13	0.22	0.03	0.11	-0.49	1.00		
[21] Previous Year Patent	0.766	0.423	0.08	0.03	-0.02	-0.08	-0.36	0.01	-0.09	0.40	-0.55	1.00	
[22] Slack	165.471	149.181	0.14	-0.03	0.12	-0.25	-0.32	-0.16	-0.08	0.54	-0.26	0.25	1.00

Table 2. Results of Log-Logistic Hazard Models with Gamma Frailty Predicting the Time to Knowledge Recombination

Variable	Model I	Model II	Model III	Model IV	Model V	Model VI
Technological Distance		2.439*** (0.614)	2.339*** (0.555)	2.446*** (0.605)	2.019*** (0.530)	1.915*** (0.460)
Technological Distance x Network Density			-6.418** (2.191)			-12.107*** (3.433)
Technological Distance x Avg. Tie Strength				1.368 (1.629)		0.959 (0.972)
Technological Distance x Network Diversity					-9.815** (3.234)	-10.860** (4.008)
Network Density	-2.561+ (1.484)	-1.309 (2.132)	-1.160 (1.325)	-1.014 (2.075)	-1.238 (1.779)	-1.097 (1.219)
Average Tie Strength	0.184 (0.312)	0.374 (0.395)	0.504+ (0.295)	0.424 (0.419)	0.535+ (0.296)	0.617+ (0.349)
Network Diversity	-1.083 (1.255)	0.332 (1.684)	-0.282 (1.070)	0.123 (1.838)	1.828 (1.404)	0.227 (1.330)
Clustering	-0.428 (0.371)	-0.677 (0.526)	-0.933** (0.326)	-0.649 (0.569)	-0.930** (0.326)	-0.867* (0.380)
Average Path Length	-0.499* (0.197)	-0.633*** (0.177)	-0.688*** (0.168)	-0.584** (0.178)	-0.745*** (0.163)	-0.713*** (0.156)
Same Sector	0.235 (0.457)	-0.190 (0.546)	-0.103 (0.449)	-0.238 (0.581)	-0.020 (0.398)	-0.198 (0.394)
Co Patent	7.060** (2.401)	6.449* (3.045)	3.483 (2.291)	8.458+ (4.779)	13.465*** (3.323)	6.821 (5.064)
Prior Citations	0.060* (0.029)	0.038 (0.037)	0.024 (0.037)	0.032 (0.040)	0.040+ (0.023)	0.020 (0.023)
Scientific References	0.003 (0.004)	0.005 (0.005)	0.006 (0.005)	0.006 (0.005)	0.004 (0.005)	0.006 (0.004)
Technology Value	-0.011***	-0.010**	-0.011***	-0.010**	-0.008*	-0.010***

Technological Furnishing	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
	-0.078	-0.360	-0.154	-0.331	-0.323	-0.374
(0.454)	(0.412)	(0.383)	(0.419)	(0.453)	(0.397)	
Grant-back Clause	-1.186**	-1.116**	-1.225***	-1.152**	-0.823*	-1.020**
(0.429)	(0.385)	(0.353)	(0.394)	(0.362)	(0.341)	
Milestone	1.405***	1.129**	1.353***	1.073*	1.151***	1.288***
(0.374)	(0.430)	(0.345)	(0.432)	(0.329)	(0.297)	
R&D Intensity	0.004*	0.007**	0.006***	0.007**	0.008***	0.007***
(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	
Licensor University	-1.309*	-1.413*	-1.119*	-1.426*	-1.048+	-1.034*
(0.613)	(0.703)	(0.521)	(0.710)	(0.557)	(0.515)	
Licensor Number of Patents	0.000	0.000	0.000+	0.000	0.000	0.000
(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
US Firm	-0.880	-1.490*	-1.323*	-1.440*	-1.978***	-1.356*
(0.697)	(0.709)	(0.583)	(0.733)	(0.584)	(0.646)	
Log (Number Employees)	0.574**	0.461*	0.474**	0.448*	0.500***	0.544***
(0.213)	(0.183)	(0.149)	(0.186)	(0.144)	(0.141)	
Average Patenting Time	0.084	0.002	-0.012	-0.003	0.018	-0.020
(0.107)	(0.088)	(0.081)	(0.097)	(0.061)	(0.077)	
Previous Year Patent	-4.202**	-5.654**	-2.385+	-7.873*	-11.820***	-5.386
(1.462)	(1.877)	(1.331)	(3.892)	(2.457)	(4.381)	
Slack	-0.001	0.001	0.001	0.000	0.002	0.000
(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	
Sector Dummies	YES	YES	YES	YES	YES	YES
Year Dummies	YES	YES	YES	YES	YES	YES
Constant	-1.818	3.108	3.013	3.405	2.093	1.964
(4.452)	(4.422)	(3.139)	(4.840)	(2.838)	(3.054)	
log(G) constant	-0.532***	-0.746***	-0.835***	-0.760***	-0.938***	-1.006***
(0.154)	(0.168)	(0.148)	(0.165)	(0.220)	(0.175)	
log ((-)) constant	1.648***	1.818***	1.869***	1.826***	1.902***	1.960***

Number of observations	(0.245) 708	(0.219) 708	(0.207) 708	(0.218) 708	(0.232) 708	(0.203) 708
Log-likelihood	-383.459	-375.553	-372.579	-374.985	-371.680	-365.758
Chi2	86.523***	102.335***	108.284***	103.472***	110.081***	121.926***
Likelihood ratio comparison		15.812***	21.761***	16.949***	23.559***	35.403***

+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 3. Difference-in-Differences Estimators with robust standard errors (N=708)

Outcome Variable	Base Line			Follow Up		
	Control	Treated	Difference	Control	Treated	Difference-in-Differences
Number of Citations	0.055	0.031	-0.024	0.055	1.541	1.486
Standard Deviation	0.034	0.017	0.038	0.034	0.181	0.188
t	1.61	-1.39	-0.63	0.06	8.38	8.18
P> t	0.107	0.061	0.527	0.107	0.000	0.000***

*<0.10, **p<0.05, ***<0.001

CHAPTER 5

BOUND TO THE IVORY TOWER? MOBILITY OF UNIVERSITY SCIENTISTS AS A DRIVER OF UNIVERSITY-INDUSTRY COLLABORATION

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ABSTRACT: This study examines the influence of scientist mobility from academe into for-profit firms based on a firm's propensity to engage in R&D collaboration with universities. Drawing on human and social capital theory, I study how scientists' academic experience (i.e. *novice vs. seasoned scientists*) and firms' science base (i.e. *in-house scientist ratio*) affect the relationship between academic scientist recruitment and firms' likelihood of engaging in subsequent R&D collaboration with universities. Analyses of longitudinal Danish data – including employer-employee data, survey and patent data – supported the hypothesis that the likelihood of engaging in university collaboration increases with prior recruitment from academia. The findings do not suggest that the impact of recruitment accentuates with scientists' academic experience, but that both types of scientist recruitment are positively associated with university collaboration. Finally, for firms with high levels of scientific orientation, the influence of joining university scientists on collaboration with a university decreases. This study advances our understanding of the micro-level antecedents of university-industry interaction, and highlights the facilitative role of movement of both recent graduates and formerly employed scientific personnel for the formation of formal collaboration between organizations.

KEYWORDS: collaboration, scientist mobility, social capital, human capital, university-industry

“Scientific knowledge is not freely available to all, but only to those who have the right educational background and to members of the scientific and technological networks” (Salter & Martin, 2001: 512)

INTRODUCTION

Universities play an important role in industrial technological advances (Cohen, Nelson, & Walsh, 2002; Gibbons & Johnston, 1974; Mansfield, 1991; Stephan, 1996; Toole, 2012). Interaction with universities provides firms with scientific discoveries and state-of-the-art research and development (R&D) capabilities, which in turn may be translated into commercialized inventions (Cockburn & Henderson, 1996; Stuart, Ozdemir, & Ding, 2007). In fact, studies have noted academia’s growing involvement with established for-profit firms (Narin, Hamilton, & Olivastro, 1997; Perkmann & Walsh, 2007). University-industry linkages can take multiple forms, including informal collaboration among scientists (Liebeskind, Oliver, Zucker, & Brewer, 1996), recruitment of academic scientists (Zucker, Darby, & Torero, 2002) and organizational-level formal collaboration (Bercovitz & Feldman, 2007). In particular, the latter type of university-industry interaction – formal collaboration between academe and industry – has been a much studied phenomenon and continues to receive attention in the university-industry literature (see Cohen et al., 2002; Kleinknecht, 1992; Laursen & Salter, 2004; Link & Rees, 1990; Tether, 2002).

Prior work on formal university-industry collaboration from the firm’s perspective has identified a plethora of factors that shape the propensity of firms to draw on universities. Managerial factors, such as openness strategy, or firm attributes, including firm age, size and R&D intensity, increase a firm’s likelihood to draw on university research (Cohen et al., 2002; Fontana, Geuna, & Matt, 2006; Fritsch & Lukas, 2001; Laursen & Salter, 2004; Tether, 2002).

Thus, current research has made a significant impact on our understanding of a firm's propensity to collaborate with universities. However, current scholarship on university-industry collaboration lacks a theory on the underlying micro-level mechanisms that drive firms' inclination and ability to tap into universities through formal collaboration. After all, studying the antecedents of firms' formal engagement with academia is important because firms that do so exhibit superior (innovative) performance (Toole, 2012). At the same time, prior research has also shown that few firms possess the actual ability to set up formal collaboration arrangements with universities⁹ (Belderbos, Carree, & Lokshin, 2004; Bruneel, D'Este, & Salter, 2010; Laursen, Reichstein, & Salter, 2011; Laursen & Salter, 2004).

This paper aims to address this shortcoming in the literature on university-industry interaction by advancing the claim that the movement of scientists and engineers¹⁰ from academe into industry shapes university-industry collaboration. This claim relies on two observations made in prior literature. First, collaborating with universities proves to be a difficult endeavor for firms, as it requires a high level of absorptive capacity, particularly with regard to understanding the principles of basic science (Cockburn & Henderson, 1998; Fabrizio, 2009; Subramanian, Lim, & Soh, 2013). Second, firms simply lack the information on potential partners in academe (and vice versa for universities), which inhibits the market to efficiently match firms with universities (Mindruta, 2013). I argue that recruitment of university scientists defines the possibilities for a firm to acquire scientific expertise and information on potential partnering opportunities with academia. Thus, this paper proposes that movement of former academic scientists into industry may drive formal collaboration between industry and academe.

⁹ Indeed, my sample confirms the prior finding that very few firms (around 7 percent of the firms in my sample) possess the ability to tap into universities through formal collaboration.

¹⁰ Hereafter, I use the term "scientist", even though this study includes data on scientists and engineers. In addition to this, with "scientist movement" I refer to full-time job changes. Thus, my definition of a moving scientist – i.e. a scientist that changes their full-time job from university to industry – could also be characterized as an "affiliated scientist" (Zucker et al., 2002) .

Drawing on organizational learning, and human and social capital theory, I extend the current understanding of the drivers of university-industry collaboration from the firm's perspective. In particular, this study examines the conditions under which recipient firms of university scientists engage in future R&D collaboration with academia. First, I consider the academic experience of scientists (i.e. *seasoned* vs. *novice scientists*) – built-up prior to joining the recipient firm – as an important element of the heterogeneity of scientific expertise and social relations across scientists. In other words, scientists' prior academic experience affects *what* and *who* they know. Such heterogeneity among scientists may have implications for the recipient firm's ability and inclination to collaborate with academia. Second, I develop the idea that the availability of in-house scientific resources (i.e. *in-house scientist ratio*) attenuates the impact of scientist recruitment on the firm's likelihood to collaborate with a university. Indeed, science-based firms already possess an intellectual understanding of basic science and have alternative mechanisms at their disposal to identify potential universities to partner-up with (e.g. informal collaboration).

The empirical context of this paper is a representative cross-industry sample of Danish firms. Prior studies have dealt with a dearth of large-scale, detailed and reliable identification of scientist movement. The empirical analysis in this paper relies on a unique data set for the period 2000–2005, which combines Danish matched panel employer-employee data from Statistics Denmark, R&D and innovation survey data from the Danish Centre for Studies in Research and Research Policy (DCSRRP) and patent data from the European Patent Office (EPO). This data set allows for the identification and measurement of all movements of scientists and engineers (i.e. master's and PhD degree holders) from academe into established for-profit firms, while controlling for other types of scientific labor flows (e.g. scientists returning back to academia and the hiring of industrial scientist). I utilize logistic regression

techniques to estimate the influence of inbound scientist mobility on a firm's propensity to collaborate on R&D with universities. The findings are partially in line with the hypothesized effects. A firm's propensity to collaborate on R&D with a university increases with prior recruitment from academia, yet this attenuates for science-based firms. In addition, by comparing novices (i.e. recent master's and PhD graduates) and seasoned academic scientists (i.e. scientists with prior employment at the university), I show that both types of researcher recruitment positively affect firm-university collaboration, and do not find support for the hypothesis that the effect accentuates with seniority. This suggests that novice scientists or skilled graduates may also play a role in the transfer of academic values and information on partnering opportunities when they move into industry.

This article thus contributes a micro-level perspective on an important phenomenon. By suggesting that the hiring of scientists facilitates collaboration between firms and universities, this study advances research on the drivers of university-industry interaction (Cohen et al., 2002). My study also contributes to emerging literature on the relationship between employee mobility and firms' social and human capital (Somaya, Williamson, & Lorinkova, 2008). Furthermore, I add to the literature which examines the direct effects of university scientist mobility on industrial innovation (Ejsing, Kaiser, Kongsted, & Laursen, 2012). I propose that public researcher mobility into industry affects formal collaboration between firms and academia, which indirectly affects industrial innovation.

THEORETICAL BACKGROUND AND HYPOTHESES

The goal of this paper is to increase our understanding of how scientist mobility from academia into for-profit firms affects a firm's propensity to engage in a formal collaborative agreement with universities. The premise underlying this research is that scientist recruitment represents a

facilitative role when it comes to maintaining and initiating cooperation with academia. This expectation is grounded in three complementary theoretical perspectives: organizational learning; human theory; and social capital theory. I propose in this paper that a firm's likelihood to form a cooperative agreement with a university depends on: 1) scientists' academic experience; and 2) a firm's in-house science base. In the next sections I introduce the definitions of the concepts used in this study and develop the hypotheses.

Scientist Mobility as Transfer Mechanism

The connection between mobility of individuals and transfer of resources across organizations has been a long-studied phenomenon (Argote, 1999; Argote, Mcevily, & Reagans, 2003; Arrow, 1962). In this study, I follow this reasoning to study how scientists who move from a university into for-profit firms influence the ability to collaborate with external organizations. Note that prior research on movement of scientific personnel has identified different types of job changes among scientists. In particular, Zucker, Darby, and Torero (2002) distinguished between so-called "linked scientists" and "affiliated" scientists. The former type of scientists move partially to an incumbent firm (i.e. part-time employment) or initiated a start-up (Zucker, Darby, & Torero, 2002). Instead, scientist mobility in this study refers to affiliated scientists or full-time job changes of scientists among incumbent organizations.

When scientists move into industry, firms acquire different types of resources embodied in the individual. In this respect, recent literature on employee mobility has pointed to both human and social capital consequences for organizations (Aime, Johnson, Ridge, & Hill, 2010; Carnahan & Somaya, 2013; Dokko & Rosenkopf, 2009). Human capital refers to knowledge and skills possessed by individuals, and human capital is related to an individuals' education, training and experience (Becker, 1962; Coff & Kryscynski, 2011; Hitt, Bierman, Shimizu, &

Kochhar, 2001; Sturman, Walsh, & Cheramie, 2007). Prior work on the role of scientists in biotechnology has emphasized the intellectual human capital of academics (Hess & Rothaermel, 2012; Zucker et al., 1998). Social capital refers to “the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit” (Nahapiet & Ghoshal, 1998: 243). With regard to the relationship between scientist mobility and firms’ partnering opportunities, the concept of external social capital is particularly relevant (Adler & Kwon, 2002; Somaya et al., 2008). External social capital refers to external ties maintained by members between organizations.

Based on the foregoing, I expect that inbound mobility of scientists serves as a mechanism to acquire scientific expertise, and also provides a recipient firm with information on potential university partners based on a scientists’ social network accumulated at university. Based on this logic, I develop the hypotheses in the next sections.

The Effects of Scientist Mobility on University-Industry Collaboration

Prior literature has established that firms cross boundaries and acquire external knowledge in order to foster firm invention. A key mechanism to acquire external knowledge is R&D collaboration (Ahuja, 2000; Grant & Baden-Fuller, 2004; Uzzi, 1996). R&D collaboration concerns active participation in joint R&D projects. Prior literature has identified several reasons why firms collaborate on R&D with academia, including lack of resources (i.e. getting access to instrumentation and scientific apparatus/equipment) and to lower the risk associated with innovating (Kleinknecht, 1992; Tether, 2002). University collaboration may also be important, as a university acts as “an information science facility with a strong element of judgement” (Faulkner & Senker, 1994: 682), which points towards the interpretative and legitimizing role of academia.

Despite these motivations, collaborating with universities is a difficult endeavor for firms. First, firms have to identify the academic organization that is suitable to their specific needs. Prior research has shown that firms encounter difficulties in finding the right university partner for their R&D projects (Mindruta, 2013). Second, firms also have to signal their worth to academic institutions, which may be a daunting task. Third, firms may simply lack the in-house scientific expertise needed to maintain collaboration with universities. Formal cooperation with a university requires an understanding of basic knowledge and the ability to assimilate external scientific knowledge (Cohen & Levinthal, 1990).

Scientist movement from academe into for-profit firms occurs at the individual level, yet has consequences for the firm level. I claim that recruitment of academic scientists enhances a firm's capacity to cooperate with universities through two different but complementary effects. First, freshly recruited scientists provide the recipient firm with up-to-date *scientific knowledge and skills*. Scientists possess superior basic knowledge and skills relevant for performing R&D due to long-term education and engagement in academic research (Zellner, 2003; Zellner & Fornahl, 2002). Long-term education provides individuals with a general ability to utilize basic knowledge necessary for some types of problem-solving. Individuals obtain a so-called second-order form of knowledge during education (Gibbons & Johnston, 1974). Some have even argued that individuals with a scientific background may draw on cognitive maps (Fleming & Sorenson, 2004) – which are relevant for problem-solving – obtained during studies. Individuals who engage in academic research have in-depth knowledge of a specific scientific area, including skills related to scientific apparatus, instrumentation and equipment (Rosenberg, 1992; Salter & Martin, 2001). As a consequence, recruitment of university scientists provides a recipient firm with scientific expertise that is crucial to the integration of basic knowledge (Liebeskind et al., 1996).

Second, university researchers facilitate the diffusion of *information on potential partnering opportunities*. Prior research has established that academics maintain social and professional relationships throughout their academic career (Baba, Shichijo, & Sedita, 2009; Bozeman & Corley, 2004; Liebeskind et al., 1996; Schiller & Diez, 2012; Subramanian et al., 2013; Zellner & Fornahl, 2002). Such relationships may be leveraged by recipient companies, as they serve as channels through which information is shared (related to “open science”). In this respect, Murray (2004) has argued that academic scientists’ social relationships can be traced back to two important sources: (1) a laboratory network, which connects current and former academics at different levels through a shared affiliation; and (2) a cosmopolitan academic network that scientists obtain through, for instance, collaboration and collegiality, which lie at the heart of modern academe. Thus, scientists may serve firms with a network of contacts (Ding, 2010) and a greater community of practice (Gittelman, 2007). At the same time, when firms hire university scientists they communicate their suitability towards universities for engaging in R&D. Ongoing social relationships between recruited scientists in industry with their former colleagues in academia may serve as a channel through which firms signal expertise and become visible for academia as potential R&D partner. In sum, these effects support the argument that scientist recruitment enables recipient firms to initiate and/or maintain R&D collaboration with university. Accordingly, the first hypothesis is as follows:

Hypothesis 1. Hiring scientists from university is positively associated with the subsequent recipient firm’s propensity to collaborate on R&D with universities.

Academic Experience of Scientists

Substantial heterogeneity exists among scientists in their capacity to produce superior research and maintain a wide-spanning social network (Bozeman & Corley, 2004; Hall & Mansfield, 1975; Hess & Rothaermel, 2012; Zucker & Darby, 1996; Zucker, Darby, & Armstrong, 2002). One crucial determinant of the resources scientists carry when mobile is *academic experience*, as it determines the degree of what and who scientists know. Scientists develop their stock of scientific expertise and social relationships over the course of their career; as such, longer experience will be more useful to the collaborative capabilities of the recipient firm. The literature provides several reasons why this is the case. First, experienced or seasoned scientists develop a deeper understanding of basic knowledge and instrumentation. A seasoned scientist has a better reading of the scientific literature in his or her area (Faulkner & Senker, 1994). In addition to codified knowledge, being active in the academic environment over time enables a scientist to develop and communicate tacit knowledge obtained through “bench-level” experience and interaction with other academics (Zucker et al., 1998). Or, as Toole & Czarnitzki (2008) suggest: “the particular skills that make up their human capital are developed during their research careers in the academic research environment” (Toole & Czarnitzki, 2008: 113). As a result, seasoned scientists are better at communicating with potential academic collaboration partners due to a shared language. In addition, scientists with extensive academic experience are also assumed to be able to understand the needs and goals of universities and their scientific staff. Hence, they are likely to convince their counterparts in academia to engage in R&D collaboration.

Second, keeping all else constant, experienced scientists also possess a larger stock of social contacts than novice scientists. In this respect, Faulkner & Senker (1994) argue that “relative reliance on literature and contacts is a function both of personality and of seniority and

work experience, with more senior researchers generally having a larger array of contacts to call on” (Faulkner & Senker, 1994: 681). Scientists in later stages of their career have obtained contacts (both planned and unplanned) within academia through joint projects, informal meetings and conferences (Faulkner & Senker, 1994; Lam, 2007). Consequently, experienced academic researchers, such as tenured faculty, possess a larger network of potential collaborators within academia. Also, the composition of contacts of seasoned scientists may exhibit greater variety, in terms of geographical location and type of organization, compared to novice scientists (Bozeman & Corley, 2004; Lam, 2007; Murray, 2004). What is more, experienced scientists are more likely to have built up industry relations (Dietz & Bozeman, 2005; Faulkner & Senker, 1994; Ponomariov & Boardman, 2010). In terms of signaling, seasoned scientists are also likely to communicate authority towards university scientists. As a result, the larger array of social contacts held by seasoned scientists combined with a deep scientific understanding make recipient firms well-equipped to collaborate with universities. In line with this reasoning, the second hypothesis states:

Hypothesis 2. The positive association between academic scientist recruitment and the subsequent recipient firm’s propensity to collaborate on R&D with universities is positively moderated by scientists’ academic experience.

Science Base and Links to Academia

For-profit firms which are recipients of newly attracted scientists vary in terms of in-house scientific resources. Even though firms’ reliance on science may vary by industry, the inclination to engage with academia also varies within industries (Klevorick, Levin, Nelson, & Winter, 1995; Pavitt, 1991). Science-based firms have a natural orientation towards academia.

Connecting with science is part of their general strategy, including connecting to public research institutes (Rosenberg, 1990). Often, science-based firms are part of a broader scientific community and have adopted “open science” practices, including publication policies and general dissemination of research results that resemble those found in academia (Cockburn & Henderson, 1996; Ding, 2010; Furukawa & Goto, 2006; Gittelman, 2007; Sauermann & Stephan, 2012). Although prior research has argued that this may attract high-quality recruits (Agarwal & Ohyama, 2013; Roach & Sauermann, 2010; Stern, 2004), I argue that the degree to which firms rely on science deteriorates the effect of scientist recruitment on recipient firms’ likelihood to formally collaborate with a university. Heterogeneity, in terms of the scientific knowledge base across firms, affects the relationship between scientist recruitment and the firm’s propensity to collaborate due to two reasons. First, science-based firms already possess the in-house resources required for initiating and maintaining R&D collaboration with universities (Cohen & Levinthal, 1989; Gambardella, 1992). The availability of in-house scientists attenuates the importance of basic knowledge, problem-solving skills and the handling of instrumentation that newly hired scientists may carry with them. For science-based firms, recruitment of academic scientists thus becomes a redundant channel of collaboration-specific human capital.

Second, similar arguments can be made with regard to the value of the social relationships that scientist recruits carry to the recipient firm. Prior research has shown that scientists within science-based firms maintain informal relationships with their counterparts in academia (Allen & Cohen, 1969; Almeida, Hohberger, & Parada, 2011; Fabrizio, 2009; Faulkner & Senker, 1994; Furukawa & Goto, 2006; Gambardella, 1992; Kreiner & Schultz, 1993; Liebeskind et al., 1996; Zucker, Darby, & Armstrong, 2002). In a similar vein, contacts from the former academic workplace, as well as contacts from the broader scientific community

that hired scientists may bring with them, are therefore more likely to become redundant for science-based recipient firms. The third and final hypothesis thus states:

Hypothesis 3. The positive association between academic scientist recruitment and the subsequent recipient firm's propensity to collaborate on R&D with universities is negatively moderated by a firm's science base.

In summary, the theoretical framework considers scientist movement as a facilitator of university-industry collaboration due to the scientific expertise and the stock of social contacts that scientists carry to their industrial employer. Subsequently, I argue that the level of human and social capital embodied in university scientists may vary with their academic experience and that the role of scientific expertise and contacts may vary relative to the science base of the recipient firm. Figure 1 visualizes the hypothesized relationships of this study in a conceptual model.

Insert Figure 1 around here

METHODS

Data

I tested the hypotheses using data from three sources for the period 2000–2005. The Danish matched panel employer-employee register database, better known as Denmark's Integrated Database for Labor Market Research (IDA being its Danish acronym), served as the main data source for this study. The IDA contains information on all firms, plants and individuals in the

Danish economy. Statistics Denmark, the central authority on Danish statistics, relies on the personal identification numbers of Danes to maintain the social security system. IDA includes detailed information on individuals' education, labor market status, wages and demographics. On the firm-level, IDA provides information such as sector, geographical location and financial statistics. One of the main strengths of this data set is that it allows for tracking all individuals' yearly movement in the Danish labor market, including the career of all scientists and engineers. IDA has been widely used in recent years in economics and management (Dahl, 2010; Dahl, Dezso, & Ross, 2012; Parrotta & Pozzoli, 2012). Based on firms' national identification number I matched the IDA with Danish R&D and innovation surveys, which are in accordance with the Organisation for Economic Co-operation and Development (OECD) guidelines for research statistics described in the Frascati Manual (i.e. similar to the European Community Innovation Survey, CIS). The surveys were annually conducted by the Danish Centre for Studies in Research and Research Policy (referred to by its Danish acronym CFA) and have been commissioned by the Danish Ministry of Science, Technology and Innovation. Each survey was sent to a stratified representative sample of (relatively large) firms according to industry, and responses were obtained by mail and phone. Throughout the study period, a response rate of around 70 percent was achieved, which equals roughly 3000 firms each year. The surveys include questions on the use of external partners such as other firms, universities and customers. More specifically, the R&D and innovation surveys provided information on whether firms collaborate on R&D with universities. As a final step, patent application data from the European Patent Office (EPO) was matched to the IDA and survey data on the firm-level to obtain information on the technological abilities of firms in the sample. In the next sections I will provide a detailed description how I identified the scientists and their movement in this study.

Scientists. To identify scientists who are employed in Danish universities and firms, I relied on the detailed information about individuals which is available in the IDA (for a similar approach, see Ejsing et al., 2012; Kaiser, Kongsted, & Rønde, 2013). Scientists are defined as individuals with a master's or PhD degree in engineering, natural, veterinary, agricultural or health sciences. When scientists move into for-profit firms, they should be employed in a job function that requires the individual to possess high levels of skills. A job position that matches this requirement is the so-called high-level knowledge worker¹¹, which follows the International Standard Classification of Occupations (ISCO). In addition, I made sure to remove retired individuals. In line with the theoretical framework, I classified individuals who recently graduated university with a master's or PhD degree as novice scientists. Seasoned scientists are scientists who have been employed at university for at least one year.

Hiring. Scientists' yearly movement was recorded when an individual moved from one organization to another in the Danish economy. The data allows me to observe all possible hires among universities and firms. Great care was taken to remove instances in which recruitment coincided with firm splits, mergers and spin-offs. The final sample includes a total of 3505 hired academic scientists in the period 2000–2005 (see Table 1 for an overview of the number of moves for each type of labor).

R&D collaboration. The R&D and innovation surveys provided self-reported measures on whether firms collaborate with a variety of external partners, including customers, industry and universities. Around 7 percent of unique Danish firms collaborated with universities in the period 2000–2005 (i.e. 677 out of 10418 unique firms in the sample).

¹¹ This refers to a job position that consists "of increasing the existing stock of knowledge, applying scientific and artistic concepts and theories to the solution of problems, and teaching about the foregoing in a systematic manner" (ILO, 2004)

Firms. After matching the three independent data sources and excluding governmental organizations, the final data set contains 18013 firm-year observations for 10418 firms for the period 2000–2005. Firms are from 14 different industries (see Table 2) and have on average 142 employees. The yearly surveys do not necessarily target the same firms over time, so long as it represents a representative sample of Danish firms according to industry. Thus, as the firms are randomly sampled, the analysis relies on a pooled cross-sectional data set. With the sample for this study I aim to explain the impact of scientist recruitment on university-industry collaboration for firms from across different industries.

Insert Table 1 around here

Insert Table 2 around here

Construct Measurement

Dependent variable: University collaboration. The aim of this paper is to explain a firm’s probability to collaborate on R&D with universities. The dummy variable took the value 1 when a firm’s respondent answered the following question positively: “Has your company collaborated with university in year ‘X’ in connection with the company’s R&D?”, and zero when respondents answered negatively or when no answer was given (i.e. missing value). The total number of observations amounts to 18013 firm-year observations, of which 1302 observations (approximately 7 percent) indicate university collaboration.

Focal independent variables: Inbound mobility of university scientists. I measured the recruitment of scientists as the log number of hired scientists for firm *i* in year *j* (*inbound*

university scientists). I added a constant of 1 to account for firm-year observations without any recruitment. To consider the moderating role of academic experience, I modified the previous variable by splitting *inbound university scientists* into two orthogonal types of scientists: *inbound seasoned university scientists* and *inbound novice university scientists*. These two logged variables refer to experienced academics and recently graduated academics. The main difference between the two types of scientists is that seasoned scientists have been employed at the university after graduation, whereas novice scientists provide firms with human and social capital obtained during studies.

Control variables. The following relevant control variables are included. First, I control for the availability of in-house scientists by dividing the number of in-house scientists by the total number of employees (*in-house scientist ratio*). This control variable serves to control for a firm's ability to recognize and integrate basic external knowledge (Cohen & Levinthal, 1990). Furthermore, in-house scientists are also likely to maintain informal and formal collaboration with academia (Liebeskind et al., 1996), since science-based firms prove to be reliable partners for universities (Mindruta, 2013). More importantly, the *in-house scientist ratio* also serves as a moderating variable. I control for several other different external mechanisms which may influence the ability of firms to engage in collaboration with universities. First, the outbound mobility of scientists back into academia also impacts a firm's informal and formal collaboration structures (Corredoira & Rosenkopf, 2010; Dokko & Rosenkopf, 2009; Somaya et al., 2008). The log number of scientists that leave the focal firm and return to academia act as a proxy for such outbound social capital effects (*outbound university scientists*). Second, recruitment from other firms could also serve as a capability-enhancing mechanism (Lacetera, Cockburn, & Henderson, 2004). Thus, I control for the log number of scientists hired from industry (*inbound industry scientists*). Third, following prior work (Boeker, 1997; Kraatz &

Moore, 2002; Tushman & Rosenkopf, 1996), this study controls for the hiring of new top management team members (TMT) from other organizations by controlling for the number of incoming TMT members (*inbound TMT members*). The inflow of new TMT members may bring institutional change, for instance, pertaining to the use of scientific knowledge. Fourth, to control for a firm's high-tech collaborative inclination, I add a dummy variable which indicates whether a firm has recently engaged in co-patenting (*co-patenting*).

Firm-specific characteristics may also influence a firm's likelihood to engage in joint cooperation with academia. First, prior literature has argued that start-ups may serve as a vehicle for translating university research into commercial products (Cohen et al., 2002), indicating that young firms are likely to tap into academia, even though other studies have not found this effect (e.g. Laursen & Salter, 2004). Nevertheless, I add the log number of years since a company is founded (*firm age*). Second, I include firm size – measured as the log number of *general* employees (*firm size*) – as large firms are able to leverage a larger pool of resources for collaborations with academia (Laursen & Salter, 2004; Link & Rees, 1990). Fourth, to control for the technological capabilities of a firm, I include a dummy variable coded 1 if a firm has engaged in prior patenting, and 0 otherwise (*prior patenting*). Finally, I include 14 industry dummies, four regional dummies, and five year dummies to control for industry-, regional- and year-specific effects.

Estimation

The aim of this study is to examine how prior hiring of university scientists impact a firm's propensity to engage in R&D collaboration with universities. I thus conduct a firm-level study where each observation relates to one firm-year observation. My sample has an unbalanced panel data structure with a binary variable indicating whether a firm collaborated with a

university. My preferred estimation method for all three hypotheses is thus a logit model (Hoetker, 2007) with robust standard errors by clustering at the firm-level (alternatively, I estimated probit models, which provided identical results). The logit model compares those firms which collaborate with universities with those that do not, and estimates which independent variables have an influence on the probability that a firm collaborates on R&D with universities. The explanatory variables are lagged one year. I use the following main regression specification to test my hypotheses:

(1) *Logit (University Collaboration)*_{*i,t*}

$$\begin{aligned}
&= \alpha + \beta_1 * \text{Inbound university scientists}_{i,t-1} + \beta_2 \\
&* \text{In-house scientist ratio}_{i,t-1} + \beta_3 \\
&* \text{Outbound university scientists}_{i,t-1} + \beta_4 \\
&* \text{Inbound industry scientists}_{i,t-1} + \beta_5 * \text{Inbound TMT members}_{i,t-1} \\
&+ \beta_6 * \text{Co-patenting}_{i,t-1} + \beta_7 * \text{Firm size}_{i,t-1} + \beta_8 * \text{Firm age}_{i,t-1} + \beta_9 \\
&* \text{Prior patenting}_{i,t-1} + \beta_{10} * \text{Industry dummies}_{i,t-1} + \beta_{11} \\
&* \text{Regional dummies}_{i,t-1} + \beta_{12} * \text{Year dummies}_{i,t-1} + \varepsilon_{i,t-1}
\end{aligned}$$

In the subsequent specification, I replace the variable *inbound university scientists* for *inbound seasoned university scientists* and *inbound novice university scientists*. For the final main specification, I add the interaction effect between *inbound university scientists* and *in-house scientist ratio*. Finally, as an extension to this main analysis, I studied the effect of scientist recruitment on university collaboration for specific samples (e.g. firms with at least one in-house scientist) and I also analyze the effect of academic experience of hired scientists on a firm's

propensity to collaborate with universities within (i.e. national) and outside Denmark (i.e. international).

RESULTS

Descriptive statistics and correlations on the variables included in the analysis (except the industry, geographical and year dummies) are presented in Table 1. An examination of the correlations in Table 1 reveals that multicollinearity was not an issue. I computed the variance inflation factor (VIF) values and they are well below the maximum value of 10 (Belsley, Kuh, & Welsch, 1980); in fact, none of the individual VIF values exceed the value of 2.8. Nevertheless, the inbound industry scientists variable correlates relatively high with the university scientist recruitment variables. The results are identical when I remove this variable. I follow a stepwise estimation procedure.

Insert Table 3 around here

I now turn to the testing of the hypotheses. Results of the logit estimations with clustered robust standard errors explaining a firm’s propensity to collaborate on R&D with universities are reported in Table 4. Model I represents the empirical model estimated with all controls. In model II, the main effect of scientist recruitment from university was entered. Model II provides support for the first hypothesis (*Hiring scientists from university is positively associated with the subsequent recipient firm’s propensity to collaborate on R&D with universities*). The coefficient for inbound university scientists is positive and significant ($p > 0.001$, two-sided). In line with my

prediction, this result suggests that prior recruitment of academic scientists is associated with a firm's propensity to engage in university collaboration.

In model III, I distinguished between seasoned and novice scientists, and entered them both into the regression. The coefficients for inbound seasoned university scientists and inbound novice university scientists are both positive and significant (both $p > 0.05$, two-sided). Although the coefficient for inbound seasoned university scientists is larger than the coefficient for its novice counterpart, the coefficients are not significantly different from each other based on the Wald test ($\text{Chi}^2 = 0.4$, $p = 0.5293$). This suggests I find no support for hypothesis 2 (*The positive association between academic scientist recruitment and the subsequent recipient firm's propensity to collaborate on R&D with universities is positively moderated by scientists' academic experience*). Even though the post-estimation does not support the hypothesis, I also present the variables' marginal effects in Table 5, as one cannot interpret the size of coefficients in logit models (Hoetker, 2007). The logit estimation, marginal effects and Wald test indicate that both novice and seasoned scientists are positively associated with a firm's likelihood to cooperate with universities, yet the coefficients are not significantly different from each other. This indicates that both types of public researcher mobility play an important role in university-industry collaboration.

In the final model in Table 4 – model IV – I included the interaction effect between inbound university scientists and the in-house scientist ratio to test the final hypothesis (*The positive association between academic scientist recruitment and the subsequent recipient firm's propensity to collaborate on R&D with universities is negatively moderated by a firm's science base*). The coefficient for this interaction is positive but insignificant. However, the logistic regression model is of a nonlinear nature, and the marginal effect of the interaction effect is therefore not simply the coefficient of the interaction (Ai & Norton, 2003; Hoetker, 2007;

Norton, Wang, & Ai, 2004). Also, the interaction effect may have different signs for different values of the covariates. I therefore apply a procedure developed by Ai & Norton (2003) that computes the correct size and standard errors for the interaction effect (i.e. *inteff* command in Stata). The procedure provides graphical representations of the magnitude of the interaction effect (Figure 2), and shows the significance of the effect for each observation (Figure 3). The horizontal axes in both graphs show the model's predicted probability that the recipient firm collaborates on R&D with universities (taking the effects of all other covariates into account). Figure 2 illustrates that the strongest (negative) interaction effects occurs between 0.6 and 0.8. Figure 3 shows that the majority of observations are insignificant at the two-sided 5% level, yet the interaction effect is significant and negative when the probability of engaging with universities is very high. In conclusion, I find some support for the idea that the science-base of a firm attenuates the effect of recruitment of academic scientists on R&D collaboration with a university, but only in cases where the explanatory variables suggest that the likelihood of R&D collaboration with a university is high

The significant control variables in the estimations reported in Table 4 have the expected direction for the formation of university collaboration based on prior literature. The availability of in-house scientists increases a firm's propensity to collaborate with universities due to its scientific capabilities. With regard to the other types of labor flows, Table 4 shows that recruitment of scientists from other firms, and scientists who leave the focal firm and return to academia, both positively affect future university collaboration. In particular, the effect of the outbound mobility of scientists has a strong marginal effect (Table 5), which is in line with recent prior work on outbound employee mobility and social capital (Somaya et al., 2008). As expected, firm size and prior patenting both have positive signs. Firm age is only weakly

significant in model I, which indicates that these analyses provide weak support for the idea that start-ups and universities tend to partner with each other (e.g. Cohen et al., 2002).

Insert Table 4 around here

Insert Table 5 around here

ROBUSTNESS CHECKS

I performed several robustness checks to ensure the stability of the results and to avoid alternative explanations. First, one concern that may arise is related to the fact that I use the full sample of firms that have responded to the Danish R&D and innovation surveys. One may argue that some of the companies will never tap into academia, which raises concerns about comparing apples with oranges. Therefore I re-estimated logistic regression models with a restricted sample in Table 6. Those estimates refer to firms with at least one in-house scientist. The results are remarkably stable and are identical in magnitude, direction and significance. This strengthens the confidence in the results. Second, another concern may point to the fact that I observe very few firms that actually collaborate with universities (7.2 percent). Even though this should not bias the results of the logit models, I also repeated the analyses using rare event logit models (Table 7) and received similar results. I did not find a significant difference between novice and seasoned scientists in the logistic regressions on the restricted sample and the rare event logit models. In additional analyses, I exploited the information available in the R&D and innovation surveys concerning the geographical location of firms' university partners. Consistently over the period 2000–2005, the respondents answered the question whether R&D

collaboration was maintained with universities within Denmark (i.e. national) or outside Denmark (i.e. international). This allowed me to test the idea that experienced academic scientists bring the social capital of globalized nature with them to the recipient firm. The results are shown in Table 8. The first two models refer to national university collaboration, while the subsequent two models refer to international collaboration. The significance of the coefficients of seasoned and novice scientists in models II and IV indicate that only the recruitment of novice scientists increases the likelihood of national university collaboration ($p<0.01$), while international university collaboration is only weakly explained by both seasoned and novice scientist hiring (both $p<0.10$). I interpret these results as evidence of graduate student mobility being associated with collaboration with universities located within Denmark. In the case of collaboration with universities abroad, both novice and seasoned scientist recruitment seem to weakly explain international collaboration, yet the coefficients are not significantly different from each other; this does not support the idea that seasoned scientists carry resources that are important for international collaboration compared to novices.

Insert Table 6 around here

Insert Table 7 around here

Insert Table 8 around here

DISCUSSION AND CONCLUSION

Fueled by the current lack of our understanding of micro-level mechanisms that drive university-industry collaboration, this paper set out to empirically test the extent to which movement of scientific personnel influences a firm's propensity to collaborate on R&D with universities. Combining insights from organizational learning, and human and social capital theory, I claim that heterogeneity in terms of scientists' academic experience and firms' science base affects the *level* and *value* of scientists' human and social capital for a firm's ability to cooperate with universities. By exploiting detailed employer-employee data covering 14 industries, this study shows evidence of the facilitative role of scientists for subsequent university-industry collaboration when they move from academia to for-profit firms. More specifically, the empirical results reveal that firms increase their propensity to collaborate with universities when they engaged in prior recruitment from university. However, in contrast to what was predicted, the analysis shows that novices and seasoned scientists both have a similarly positive impact on university collaboration. Finally, firms with a strong scientific orientation already possess the necessary resources to partner up with academia. Thus, I find partial support for the idea that the degree to which a recipient firm is dominated by in-house scientists attenuates the impact of additional entering university scientists.

This study makes four important contributions to different bodies of literature. First, this paper highlights the interaction between distinct channels of university-industry interaction. Indeed, prior research has identified multiple forms that university-industry linkages may take, such as R&D cooperation, licensing and short- and long-term employment of scientists, e.g. by means of surveys (Cohen et al., 2002). Despite this important insight, few studies have examined the interaction between different mechanisms (cf. De Fuentes & Dutrénit, 2012). I

made an attempt to fill this void by showing how the mobility of scientific personnel affects university-industry collaboration.

Second, I complement literature in strategic management which points to the role of mobility in organizations' learning ability (Argote, 1999). The findings of this paper suggest that individual mobility positively impacts a firm's likelihood to collaborate with universities. Theoretically, I identified two types of resources that university scientists carry from academia into for-profit firms that potentially affect a firm's collaborative ability. First, public researchers are likely to embody scientific expertise, which is in line with prior research on the human capital effects of mobility from an university-industry perspective (Zucker, Darby, & Torero, 2002). Second, another resource that academics are likely to carry into industry is information on potential partnering opportunities through their social network in academia. The relationship between individual mobility, social capital and inter-organizational relationships has recently received increasing attention (Carnahan & Somaya, 2013).

Third, and in contrast to what I predicted, I highlight the role recruiting novice scientists or recent graduates play in a firm's likelihood to collaborate with academia. Despite being championed for its human capital implications in prior literature (Cohen et al., 2002; Gibbons & Johnston, 1974; Salter & Martin, 2001), we still know relatively little of other roles that recent graduates may play in university-industry interaction. This paper calls for more research into the role of recent graduates in shaping firms' relationships with academia. A possible explanation for the finding that seasoned and novice scientists do not significantly differ in their impact on firms' likelihood to collaborate with universities is related to the abundance of novice scientists relative to seasoned scientists (as underlined in the descriptive statistics). Academics with a taste for a career in industry (Perkmann et al., 2013; Roach & Sauermann, 2010) are likely to move into for-profit firms after graduation. As a result, those graduates that self-select into academia

are therefore less likely to move into industry at later stages of their career. This paper thus complements prior literature in favor of graduate student mobility, and how such mobility may indirectly lead to substantial economic benefits (Salter & Martin, 2001).

A final contribution of this paper concerns firms' propensity to form partnerships of a collaborative nature. Research on R&D alliances and other types of research cooperation has mapped the consequences of collaboration (Bercovitz & Feldman, 2007; Owen-Smith & Powell, 2004), but has emphasized the antecedents of collaboration less so (cf. Zhang & Baden-Fuller, 2010). This paper suggests that the movement of scientific personnel acts as a catalyst for future formation of collaboration between different types of organizations.

This study has also its limitations, which may fuel opportunities for future research on mobility and collaboration patterns between academe and industry. First, prior work on the role of scientists in university-industry interaction has paid extensive attention to the quality of scientists (Hess & Rothaermel, 2011; Higgins, Stephan, & Thursby, 2011; Subramanian et al., 2013). Indeed, movement of star scientists, or scientists who are producing high-quality research in large quantities, may have a profound effect on a firm's ability to collaborate with universities; for example, through attracting the attention of universities. Unfortunately, the data does not allow for capturing the research excellence of scientists. Future research could disentangle scientist quality among recruited novice and seasoned scientists, as well as its role for university-industry collaboration.

Second, the analysis raises questions concerning endogeneity and the overall hiring strategy of firms. Despite my attempt to control for the science base of the firm and different types of labor flows, such as the recruitment of new TMT members, I cannot rule out that firms develop a strategy that involves recruitment of university scientists as well as the inclination to collaborate with universities. Related to this issue, the current empirical set-up cannot exclude

the possibility that ongoing university-industry collaboration may also affect hiring from academia, even though I theoretically discuss why I expect scientist movements to precede R&D collaboration. Also, informal collaboration between scientists from the industrial and academic realm (Faulkner & Senker, 1994; Kreiner & Schultz, 1993; Liebeskind et al., 1996) is not captured in this study. Informal contacts between industry and university scientists may indeed affect a firm's hiring decisions. Being aware of these issues, this paper emphasizes associations rather than causal links between university scientist recruitment and a firm's likelihood to collaborate with universities.

Third, the survey which this study relies on provides limited information on firms' collaboration with university. For instance, the survey lacks information on the intensity of collaboration, and the specific universities that firms have collaborated with. In addition, the analysis does not capture whether firms change their collaborative arrangements with academia. Such information could provide a nuanced view on the effect of mobility on dyadic collaboration between different types of organizations and the effect of hiring on strategic change.

Fourth, the empirical setting of this study – a sample of firms from 14 industries in Denmark – has potential drawbacks. The focus on a cross-industry sample design does increase the generalization of the results, yet may not do justice to industry specificity with regard to the role and use of science (Klevorick et al., 1995). On another note, even though the Danish economy is characterized by high mobility rates, similar to the US, the collaboration patterns among firms and universities may be specific to Denmark (Owen-Smith, Riccaboni, Pammolli, & Powell, 2002; Spencer, 2001).

A final potential research area that this paper alludes to is based on the finding that scientists who return to academia from industry may also play a role in inter-organizational

collaboration. In fact, I find that around 10 percent of scientists with a master's and PhD degree that initially moved from academia to industry return back to university. Future research on the economic and collaborative implications of such returning scientists would increase our understanding of this phenomenon.

Overall, this research addresses an important phenomenon – the fact that few firms possess the ability to initiate and maintain R&D collaboration with universities – and proposed a micro-level explanation for such heterogeneity among firms. This paper emphasizes the role of individuals and their movement across organizational boundaries for shaping university-industry interaction.

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APPENDIX

Figure 1. Conceptual Model

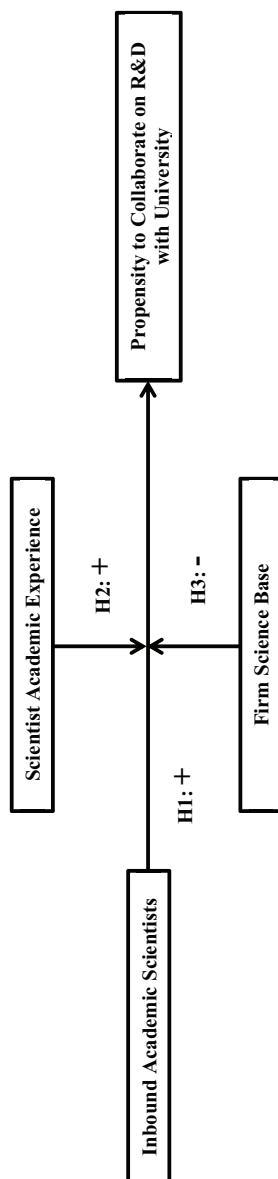


Figure 2. The Size Effect of the Interaction between Inbound University Scientists and In-House Scientist Intensity

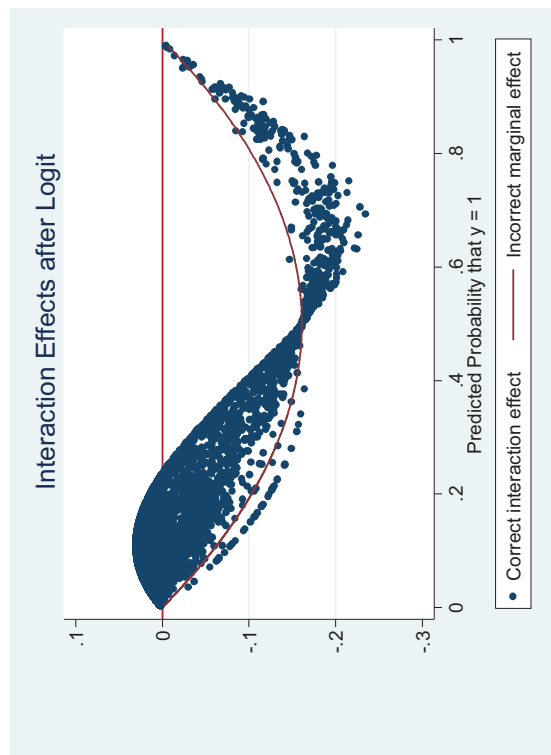


Figure 3. The Significance of the Interaction between Inbound University Scientists and In-House Scientist Intensity

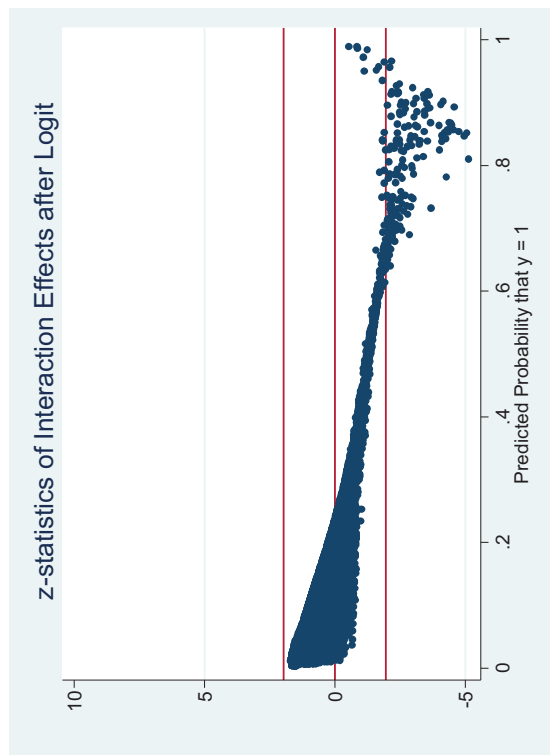


Table 1. Descriptive Statistics on Different Types of Labor Movement

Labor flows	Total no. of moves	Average per firm	Total no. of unique firms
Inbound university scientists	3505	0.20	3508
Inbound seasoned university scientists	767	0.04	826
Inbound novice university scientists	2738	0.15	3172
Outbound university scientists	338	0.02	562
Inbound industry scientists	15251	0.85	11821
Inbound TMT members	680	0.04	677

Table 2. Descriptive Statistics on Industries

Industry	Observations	Collaboration with university	% university collaboration
Gross and retail trade	4516	114	2.5
Farming and food	947	109	11.5
Textile and paper	1536	39	2.5
Plastics and glass	781	77	9.9
Chemicals	313	74	23.6
Metals	1405	61	4.3
Machinery	1322	127	9.6
Electrics	579	88	15.2
Medical	325	88	27.1
Vehicles	269	14	5.2
Furniture	609	29	4.8
IT and telecom	1727	82	4.7

Technical services	1933	335	17.3
Business and other services	1751	65	3.7
Total	18013	1302	7.2

Table 3. Descriptive Statistics and Correlations

Variable	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
<i>Dependent variable</i>																
(1) University collaboration	0.072	0.259	0.000	1.000	1.00											
<i>Independent variable</i>																
(2) Inbound university scientists	0.075	0.314	0.000	4.369	0.31	1.00										
<i>Independent variables experience</i>																
(3) Inbound seasoned university scientists	0.022	0.151	0.000	3.258	0.26	0.74	1.00									
(4) Inbound novice university scientists	0.063	0.281	0.000	3.989	0.29	0.97	0.58	1.00								
<i>Control variables</i>																
(5) In-house scientist ratio	0.056	0.131	0.000	1.000	0.18	0.29	0.18	0.28	1.00							
(6) Outbound university scientists	0.011	0.101	0.000	2.303	0.19	0.46	0.45	0.43	0.18	1.00						
(7) Inbound industry scientists	0.240	0.585	0.000	6.304	0.33	0.66	0.52	0.63	0.34	0.34	1.00					
(8) Inbound TMT members	0.038	0.191	0.000	1.000	0.01	0.01	0.00	0.01	-0.02	0.00	0.04	1.00				
(9) Co-patenting	0.002	0.040	0.000	1.000	0.09	0.13	0.18	0.11	0.03	0.05	0.10	-0.01	1.00			
(10) Firm size	3.743	1.436	0.693	10.150	0.23	0.29	0.22	0.28	-0.08	0.15	0.43	0.07	0.06	1.00		
(11) Firm age	2.578	0.917	0.000	4.883	0.06	0.05	0.05	0.05	-0.08	0.03	0.07	0.01	0.02	0.32	1.00	
(12) Prior patenting	0.120	0.325	0.000	1.000	0.32	0.25	0.22	0.22	0.12	0.13	0.34	0.02	0.09	0.31	0.17	1.00

Correlations above 0.02 are significant on the 1% level

Table 4. Logit Estimates for the Probability of R&D Collaboration with Universities

VARIABLES	Model I	Model III	Model III	Model IV
H1: Inbound university scientists		0.398*** (0.108)		0.548** (0.168)
H2: Inbound seasoned university scientists			0.398* (0.182)	
H2: Inbound novice university scientists			0.254* (0.114)	
H3: Inbound university scientists \times in-house scie ratio				-0.644 (0.477)
In-house scientist ratio	2.160*** (0.346)	2.102*** (0.346)	2.123*** (0.345)	2.230*** (0.337)
Outbound university scientists	0.700** (0.214)	0.465* (0.232)	0.465* (0.233)	0.511* (0.231)
Inbound industry scientists	0.315*** (0.063)	0.189** (0.071)	0.199** (0.071)	0.188** (0.071)
Inbound TMT members	0.077 (0.167)	0.092 (0.169)	0.090 (0.169)	0.096 (0.168)
Co-patenting	0.843* (0.392)	0.730+ (0.428)	0.679 (0.437)	0.738+ (0.429)
Firm size	0.381*** (0.039)	0.374*** (0.039)	0.378*** (0.039)	0.372*** (0.039)
Firm age	-0.091+ (0.055)	-0.088 (0.055)	-0.088 (0.055)	-0.083 (0.055)
Prior patenting	1.377*** (0.116)	1.377*** (0.116)	1.376*** (0.116)	1.361*** (0.115)
Industry dummies	yes	yes	yes	yes
Regional dummies	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Constant	-4.770*** (0.269)	-4.742*** (0.269)	-4.754*** (0.269)	-4.765*** (0.270)
Observations	18,013	18,013	18,013	18,013
Wald Chi ²	1304.675***	1242.309***	1234.872***	1252.784***
Log pseudolikelihood	-3469.425	-3459.956	-3461.254	-3458.583
Pseudo R ²	0.258	0.260	0.260	0.260

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 5. Marginal Effects for the Probability of R&D Collaboration with Universities

VARIABLES	Model III
H2: Inbound seasoned university scientists	0.014* (0.006)
H2: Inbound novice university scientists	0.009* (0.004)
In-house scientist ratio	0.075*** (0.013)
Outbound university scientists	0.017* (0.008)
Inbound industry scientists	0.007** (0.003)
Inbound TMT members	0.003 (0.006)
Co-patenting	0.024 (0.016)
Firm size	0.013*** (0.001)
Firm age	-.003 (0.002)
Prior patenting	0.049*** (0.004)

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 6. Logit Estimates for the Probability of R&D Collaboration with Universities for Firms with In-House Scientists

VARIABLES	Model I	Model III	Model III	Model IV
H1: Inbound university scientists		0.445*** (0.104)		0.449** (0.163)
H2: Inbound seasoned university scientists			0.412* (0.171)	
H2: Inbound novice university scientists			0.315** (0.109)	
H3: Inbound university scientists × in-house scie ratio				-0.018 (0.468)
In-house scientist ratio	1.658*** (0.386)	1.536*** (0.386)	1.554*** (0.385)	1.540*** (0.389)
Outbound university scientists	0.789*** (0.204)	0.536* (0.220)	0.525* (0.222)	0.537* (0.222)
Inbound industry scientists	0.263*** (0.064)	0.126+ (0.071)	0.131+ (0.071)	0.126+ (0.071)
Inbound TMT members	0.026 (0.186)	0.043 (0.189)	0.041 (0.189)	0.043 (0.189)
Co-patenting	0.841* (0.351)	0.716+ (0.382)	0.667+ (0.392)	0.716+ (0.382)
Firm size	0.324*** (0.048)	0.305*** (0.049)	0.310*** (0.048)	0.305*** (0.049)
Firm age	-0.094 (0.063)	-0.090 (0.063)	-0.090 (0.063)	-0.090 (0.064)
Prior patenting	1.289*** (0.121)	1.285*** (0.122)	1.285*** (0.121)	1.284*** (0.121)
Industry dummies	yes	yes	yes	yes
Regional dummies	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Constant	-4.226*** (0.387)	-4.135*** (0.385)	-4.145*** (0.385)	-4.136*** (0.390)
Observations	7,213	7,213	7,213	7,213
Wald Chi ²	618.153***	594.100***	583.636***	606.250***
Log pseudolikelihood	-2458.970	-2447.123	-2448.088	-2447.122
Pseudo R ²	0.199	0.203	0.203	0.203

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 7. Rare Event Logit Estimates for the Probability of R&D Collaboration with Universities

VARIABLES	Model I	Model III	Model III	Model IV
H1: Inbound university scientists		0.394*** (0.108)		0.543** (0.167)
H2: Inbound seasoned university scientists			0.391* (0.182)	
H2: Inbound novice university scientists			0.251* (0.114)	
H3: Inbound university scientists × in-house scie ratio				-0.640 (0.476)
In-house scientist ratio	2.159*** (0.345)	2.100*** (0.345)	2.122*** (0.344)	2.229*** (0.337)
Outbound university scientists	0.692** (0.214)	0.460* (0.231)	0.460* (0.232)	0.505* (0.231)
Inbound industry scientists	0.312*** (0.063)	0.188** (0.071)	0.198** (0.071)	0.186** (0.071)
Inbound TMT members	0.084 (0.167)	0.099 (0.168)	0.097 (0.168)	0.103 (0.168)
Co-patenting	0.816* (0.391)	0.704+ (0.427)	0.654 (0.436)	0.713+ (0.428)
Firm size	0.381*** (0.038)	0.373*** (0.039)	0.377*** (0.038)	0.372*** (0.039)
Firm age	-0.091+ (0.055)	-0.088 (0.055)	-0.088 (0.055)	-0.083 (0.055)
Prior patenting	1.372*** (0.115)	1.371*** (0.116)	1.370*** (0.116)	1.356*** (0.115)
Industry dummies	yes	yes	yes	yes
Regional dummies	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Constant	-4.751*** (0.269)	-4.724*** (0.268)	-4.735*** (0.268)	-4.745*** (0.270)
Observations	18,013	18,013	18,013	18,013

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 8. Logit Estimates for the Probability of R&D Collaboration with National and International Universities

VARIABLES	Model I	Model II	Model III	Model IV
	Nat. Coll.	Nat. Coll.	Int. Coll.	Int. Coll.
H1: Inbound university scientists	0.434*** (0.108)		0.368** (0.141)	
H2: Inbound seasoned university scientists		0.296 (0.186)		0.334+ (0.190)
H2: Inbound novice university scientists		0.326** (0.113)		0.256+ (0.142)
In-house scientist ratio	2.195*** (0.340)	2.205*** (0.339)	1.727*** (0.523)	1.740*** (0.521)
Outbound university scientists	0.520* (0.223)	0.530* (0.225)	0.477* (0.237)	0.460+ (0.238)
Inbound industry scientists	0.172* (0.072)	0.187** (0.072)	0.167 (0.109)	0.171 (0.107)
Inbound TMT members	0.088 (0.180)	0.084 (0.180)	0.078 (0.226)	0.075 (0.227)
Co-patenting	0.474 (0.437)	0.457 (0.448)	0.718 (0.521)	0.669 (0.535)
Firm size	0.364*** (0.040)	0.367*** (0.040)	0.407*** (0.055)	0.412*** (0.055)
Firm age	-0.099+ (0.057)	-0.099+ (0.057)	-0.132+ (0.077)	-0.133+ (0.077)
Prior patenting	1.385*** (0.121)	1.388*** (0.120)	1.490*** (0.150)	1.493*** (0.150)
Industry dummies	yes	yes	yes	yes
Regional dummies	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Constant	-4.726*** (0.280)	-4.730*** (0.280)	-5.908*** (0.405)	-5.919*** (0.405)
Observations	18,013	18,013	18,013	18,013
Wald Chi ²	1203.137***	1195.677***	901.216***	900.890***
Log pseudolikelihood	-3205.959	-3207.975	-1906.661	-1906.765
Pseudo R ²	0.258	0.257	0.296	0.296

Robust standard errors in parentheses *** p<0.001, ** p<0.01, * p<0.05, + p<0.10

CHAPTER 6

CONCLUSION

This PhD dissertation aimed to improve our understanding of the role of individuals in the process of how firms search for, and subsequently develop, external knowledge, to innovate. The thesis was premised in the idea that scientists and engineers play an important role in firm innovation, especially when they move from one organization to the other, and thereby enrich the recipient firm's innovation potential. This PhD research drew on three complementary theoretical perspectives: organizational learning, KBV, and search for innovation. Furthermore, it examined the impact of micro- or individual-level behavior on meso- or firm-level innovation outcomes. The leading research question of this PhD thesis as formulated in Chapter 1 stated the following:

How does external knowledge sourcing affect firm-level innovative activity?

This research question was further split into two sub-questions; these questions guided the process of finding an answer on the main question. The first sub-question concerned three specific external knowledge sourcing mechanisms that are central in this dissertation: labor mobility, R&D collaboration, and licensing, wherein labor mobility was the primary focus. This sub-question also clarifies that this dissertation research is concerned with different dimensions of innovative output. The second sub-question highlighted the individual- and firm-level

conditions under which external knowledge sourcing leads to innovation. The sub-questions were stated as follows:

- *How does recruitment of scientists and engineers, as well as collaboration and licensing, influence different dimensions of the recipient firm's innovative output?*
- *How do firm- and individual-level factors affect the relationship between these specific external knowledge sourcing mechanisms and firm innovative activity?*

In four empirical chapters I assessed the research questions. The next sections will discuss how both sub-questions have been addressed in each chapter.

MAIN FINDINGS BY CHAPTER

Chapter 2, which is co-authored with Hans Christian Kongsted, addressed the first sub-question by examining the role of recruitment of scientists and engineers, or so-called R&D workers, for firms' ability to explore novel knowledge areas. Following the second sub-question of this dissertation we examined both individual- and firm-level factors that might potentially affect the relationship between R&D worker recruitment and firm exploration. A matched panel dataset was utilized that included employer-employee register data from Statistics Denmark and patent application data from the EPO for the years 1999 to 2005. The results showed that recruited R&D workers with an educational background that is not present among the incumbent engineers and scientists of the hiring firm was positively associated to the recipient firm's degree of exploration. Yet, we also revealed that the effect of recruiting cognitively distant R&D workers on firms' non-local search attenuates as firms mature. This essay thus extended the organizational learning and search literature by showing how educational background and firm age moderated the relationship between recruitment and firm's ability to explore new knowledge areas.

In Chapter 3, an essay co-authored with Lori Rosenkopf, the main unit of analysis was firm-level patenting output. In this chapter we studied the combined effect of inbound mobility and R&D collaboration when firms use these mechanisms simultaneously to source knowledge from other firms and/or universities. This study thus examined the role of the firm-external context for the relationship between boundary-spanning and innovative performance. Three datasets were combined for this essay, including employer-employee register data, R&D and innovation survey data, and patent data. The results of the econometric analysis showed that in some cases firms actually experience negative marginal returns to innovation, rather than innovation synergies. This substitution effect appeared in with-domain boundary-spanning as well as across-domain knowledge sourcing. This chapter contributed to the scholarly debate in both the search and organizational learning literature surrounding the limits and costs related to the use of external knowledge.

The third essay, or Chapter 4, which is co-authored with Solon Moreira, concerns the relationship between licensing-in and the speed with which firms integrate external knowledge. A potential determinant of firms' absorptive capacity, the configuration of the intra-firm inventor network, was explored as a potential moderator in the process of external knowledge recombination. The quantitative analysis was based on a dataset that combines information on licensing contracts, inventor-level patent data and firm-level characteristics. The results showed that unfamiliarity delays the integration of external knowledge. However, firms that exhibited rather dense and diverse intrafirm inventor networks in fact shortened the time to recombine distant external knowledge. This chapter thus added to the KBV and organizational learning

literatures by showing how knowledge networks within firms may shape the learning capacity of firms.

Chapter 5 is a single-authored essay and focused on university scientist mobility as an external knowledge sourcing mechanism. This study aimed to explain heterogeneity among firms in terms of their ability to collaborate with universities, which is notably correlated with innovative performance. Two potential moderators were explored in this essay: the academic experience of scientists and the science-base of firms. A unique dataset was constructed to examine the effect of scientist recruitment on the likelihood of firms to collaborate with universities. The dataset consisted of R&D and innovation survey data, employer-employee register data, and patent data. The results revealed some support for the idea that the positive association between recruitment of academics and future university-industry collaboration was negatively moderated by a firm's science-base, yet only in cases where the explanatory variables suggest a high likelihood of university collaboration. In addition, we find that both novice and seasoned scientists positively benefit a firm's ability to collaborate with academia. This study complements the KBV literature and organizational learning literature from a university-industry perspective.

CONTRIBUTIONS

The four empirical studies in this dissertation have revealed that, in general, the effect of external knowledge sourcing mechanisms favor firm innovative performance. This result varies, however, according to individual- and firm-level characteristics. Taken together, the empirical results described above contribute in three main ways to the current literature on the KBV of the firm, organizational learning and firms' search for innovation.

The first main contribution pertains to the importance of spanning organizational boundaries for firm innovation. Sourcing external knowledge has been generally known to foster internal R&D and therefore firm innovative performance (Rosenkopf & Nerkar, 2001), yet this PhD dissertation shows a rather differentiated view. Each essay in this dissertation has shown how a distinct type of knowledge sourcing mechanism affects a different dimension of innovation. To illustrate this, the first and second essay both complement prior research on the relationship between labor mobility and innovation (Rao & Drazin, 2002) by showing that heterogeneity among recruited highly-skilled individuals differentially impact the degree to which firms explore new knowledge areas and quality-weighted patents. These studies also extend prior examination of inventor movement as rich mode of knowledge transfer (Rosenkopf & Almeida, 2003; Song, Almeida, & Wu, 2003).

Second, this PhD dissertation not only shows a differentiated view on external knowledge sourcing and innovation, but it also provides a nuanced approach towards this association. In particular, the individual-level and firm-level context in which firms operate when they source external knowledge moderates the effectiveness of boundary-spanning through recruitment, collaboration and licensing. This is in line with a recent stream of articles that show that firm-internal and firm-external conditions influence the relationship between external knowledge sourcing and innovation (Hess & Rothaermel, 2011; Tzabbar, 2009). In line with this approach, this dissertation shows that rather than emphasizing the positive influence of licensing on the speed with which firms integrate external knowledge into own invention, collaborative relationships among individuals within the firm may actually attenuate problems related to licensing distant knowledge components (Chapter 4). In Chapter 3, it is the external condition under which firms operate that is of interest, as for example recruitment of university employees in the presence of university collaboration leads to negative marginal returns to

innovation, thus suggesting that firms experience limits to integrating different mechanisms simultaneously.

The final contribution of this research is the crucial role of the individual in firm strategy and firm innovation outcome. As such, this dissertation emphasizes the microfoundations view on organizational heterogeneity (cf. Felin, Foss, Heimeriks, & Madsen, 2012). Illustrative in this regard is Chapter 5, which shows that firms that are dominated by scientific personnel have less to gain from scientist recruitment for increasing the recipient firm's likelihood to collaborate with universities. At the same time, however, we need to be cautious and not overemphasize individuals. The first essay showed that the cognition of recruited individuals may impact firm exploration, yet this association is not affected by the heterogeneity in educational background among incumbent R&D workers.

LIMITATIONS

The limitations of this PhD research also merits discussion. First, in this thesis I have focused on the influence of scientists and engineers on firm-level outcomes, but without being able to connect this firm-level output to specific individuals and their capabilities. To illustrate this, the first essay discusses the role of education in individuals' problem-solving ability and therefore individuals' potential impact on firm-level exploration. Similarly, in Chapter 4 we study the role of employee networks for firms' absorptive capacity, yet the data does not allow us to identify whether specific inventors are involved in making sense of external knowledge. Future research could improve our understanding in this respect by matching individual-level data, such as patent or survey data, to employer-employee register data (such as that available in Denmark). Second, related to the previous limitation, this PhD dissertation assumes transfer of knowledge and skills when highly-skilled individuals move from one organization to another. Even though

prior research has shown knowledge transfer (e.g. Tzabbar, Aharonson, & Amburgey, 2013) indeed takes place, I do not pinpoint the quantity, quality and types of skills, knowledge and capabilities that labor potentially carries and utilizes in the new workplace. The final essay in this dissertation illustrates well how future research could benefit our understanding of academic scientist movement by disentangling and measuring which specific types and quantity of human and social capital they carry into industry. Third, with the exception of Chapter 4, the essays rely on rather short longitudinal datasets. Gathering data that spans a longer time period would allow us to perform more robust estimations methods (e.g. fixed-effects estimations) and study sequential effects in greater detail. For example, future research could address the implications deriving from the idea that some firms may collaborate with a competitor in one year, and recruit from this company in the following year. Or, in other cases, one could disentangle short-term from long-term implications of utilizing external knowledge. Fourth, a final limitation of the research presented in this dissertation is the hesitation to claim causality. Even though our results are in line with theoretical predictions, future research should focus on whether relationships are endogenous, or, in other words, whether unobserved factors (such as a new strategy implementation) may drive both external knowledge sourcing and innovation outcomes at the firm-level. In this respect, recent work in the area of labor mobility and innovation has made solid initial headway (Lacetera, Cockburn, & Henderson, 2004; Tzabbar, 2009), although much work remains. Moreover, addressing the fact that firms may be heterogeneous in ways we cannot observe raises concerns. Nevertheless, by focusing on the conditions under which boundary-spanning is associated to firm innovation, we improve our understanding of how to foster open forms of innovating and the effect on firm performance.

FUTURE RESEARCH DIRECTIONS

In addressing the research question this study has opened up avenues for further research. These future research directions are by no means exhaustive but show some exciting abstract-level and also concrete questions future research may take up.

Regarding the relationship between labor mobility and firm innovation, future research may also study the role of outflows of knowledge and skills due to employees that leave the focal firm. On the one hand, when employees leave, a firm could lose knowledge or the exclusivity of knowledge which could diminish the competitive advantage of firms (Phillips, 2002; Wezel, Cattani, & Pennings, 2006). On the other hand, recent research has shown firms may also benefit from employees that depart to competitors or other organizations due to for instance external social capital and reverse knowledge transfer (Carnahan & Somaya, 2013; Corredoira & Rosenkopf, 2010; Somaya, Williamson, & Lorinkova, 2008). Whereas this PhD dissertation made an attempt to increase our understanding of the innovative implications of recruitment or inbound mobility, future research may examine under which conditions departing employees may be beneficial or harmful for the focal firm's innovation output.

Another issue that future research may address is how external knowledge sourcing or boundary-spanning may affect firm performance beyond innovation. With regard to employee turnover future research may for instance study how internal routines change after a hiring or dismissal event. In more concrete terms, when one combines insights from this thesis, an interesting future research objective would be to examine how mobility of skilled individuals may affect the relationships among employees within the firm. In this respect, mobility events may be seen as disruptive events and may alter the knowledge networks within and between firms (See Paruchuri & Eisenman, 2012 for an examination of how mergers affect intrafirm networks).

A broader recommendation for future research concerns the effect of mobility on individual outcomes. In this dissertation I studied firm-level innovation outcomes, future research may increase our understanding of how individuals change employers over the course of their career (Bidwell & Briscoe, 2010) and how this may affect individuals' innovative performance (Hoisl, 2007, 2009). One of the questions that future research may raise in this respect is whether individual performance is portable from one organization to the other (Groysberg, Lee, & Nanda, 2008).

Beyond the role of scientists and engineers, future research may also examine the impact of mobile TMT members, support workers and board members. Different types of labor flows may differentially affect innovation and general performance of firms. On a related note, Chapter 3 of this dissertation pointed to the different types of inter-organizational relationships that firms simultaneously maintain (cf. Ranganathan & Rosenkopf, 2013; Shipilov & Li, 2012). Future research could examine how these different types of relationships and labor flows interact with regard to firm innovation.

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